Block C: Routine Trade Activities and Electrical Concepts

TRU Open Press

Plumbing Apprenticeship Program Level 1 Series

Block C: Routine Trade Activities and Electrical Concepts

BC Plumbing Apprenticeship, Level 1

SKILLEDTRADESBC

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Block C: Routine Trade Activities and Electrical Concepts of the Plumbing Apprenticeship Program Level 1 Series features Skilled Trades BC industry-authority content on the routine trade activities and foundational electrical concepts that support accurate, efficient, and code-compliant plumbing work. This block emphasizes the knowledge apprentices rely on to interpret information, apply standards, and make informed decisions on the job site.

In Block C, apprentices develop core skills in mathematics and science as they apply to the trades, build an understanding of basic electrical concepts and principles of electricity, and learn how to read and interpret drawings and specifications. The block also introduces codes, regulations, and standards, along with the effective use of manufacturer and supplier documentation. Together, these competencies help apprentices work safely, communicate clearly with other trades, and ensure installations meet required technical and regulatory expectations.

Plumbing Apprenticeship Program Level 1 Series

The *Plumbing Apprenticeship Program Level 1 Series* offers comprehensive training materials designed to build on foundational skills and knowledge. The series is divided into four main blocks, each focusing on critical areas of plumbing systems and installations.

Block A: Safety Related Functions

A-1: Workplace Hazards
A-2: WorkSafeBC Regulations
A-3: Safe Handling of Hazardous Materials
A-4: Personal Safety Practices
A-5: Fire Safety

Block B: Tools and Equipment

B-1: Use Hand Tools and Measuring Tools
B-2: Use Portable Power Tools and Use
B-3: Use Access Equipment
B-4: Use Rigging, Hoisting, Lifting and Positioning Equipment, and Rigging
B-5: Use Soldering and Brazing Equipment and Oxy-Fuel Cutting Equipment
B-6: Use Welding Equipment

Block C: Routine Trade Activities and Electrical Concepts

C-1: Mathematics and Science
C-2: Electrical Concepts and Principles of Electricity
C-3: Drawings and Specifications

C-4: Codes, Regulations and Standards
C-5: Manufacturer and Supplier Documentation

Block D: Piping and Components

D-1: Install Pipe and Tubing
D-2: Install Valves
D-3: Install Fittings
D-4: Penetrate Structures

Plumbing Apprenticeship Program Overview and Upcoming Resources

- **Plumbing Apprenticeship Program Level 1 Series** can be found in the TRU Open Press Collection.
- **Plumbing Apprenticeship Program Level 2 Series** can be found in the TRU Open Press Collection.
- **Plumbing Apprenticeship Program Level 3 Series** can be found in the BCCampus Open Collection.
- **Plumbing Apprenticeship Program Level 4 Series** can be found in the BCCampus Open Collection. (Block F: Commission and Service will be available soon.)

Disclaimer

The materials in these Learning Guides are intended for use by students and instructional staff. They have been compiled from sources believed to be reliable and to represent the best current opinions on these subjects. These manuals are designed to serve as a starting point for good practices and may not cover all minimum legal standards. No warranty, guarantee, or representation is made by the BC Piping Trades Articulation Committee, the Skilled Trades BC authority, or the King's Printer of British Columbia regarding the accuracy or sufficiency of the information contained in these publications. These manuals aim to provide basic guidelines for piping trades practices. Therefore, do not assume that all necessary warnings and safety precautions are included, and additional measures may be required.

Safety Advisory

The current Standards and Regulation in BC can be obtained at the WorkSafeBC website: http://www.worksafebc.com

Please note that it is always the responsibility of any person using these materials to inform themselves about the Occupational Health and Safety Regulation pertaining to their areas of work.

[From previous 2021 book – confirm this message with Skilled Trades]

Symbol Legend

Important Information

Potentially Toxic/ Poisonous Situation

Required or Optional Resources

Potentially Flammable Situation

Complete a Self-Test

Possibly Explosive Situation

Use Protective Equipment

Potential Electric Shock

Acknowledgements

The development of the *Plumbing Apprenticeship Level 1* learning resources was a collaborative effort driven by a commitment to excellence in trades education. These resources were created to support apprentices and journeypersons in mastering the skills and knowledge essential to the piping trades. This achievement would not have been possible without the dedication and expertise of *Skilled Trades BC* and the *Piping Trades Articulation Committee*, whose contributions, leadership, and guidance have been instrumental in shaping high-quality, industry-aligned training resources. We extend our sincere gratitude for their contributions and ongoing stewardship in advancing the piping trades.

The content for *Block C: Routine Trade Activities and Electrical Concepts* is adapted from the Piping Trades Apprenticeship Program from SkilledTradesBC (2019 Harmonized) and the Trades Access Common Core (TACC) resources developed by Camosun College, created in 2015 and revised in 2019, and made available through BCcampus:

- Line D: Organizational Skills: Competency D-1: Solve Trades Mathematical Problems
- Line D: Organizational Skills: Competency D-2: Apply Science Concepts to Trades Applications
- Line D: Organizational Skills: Competency D-3: Read Drawings and Specifications
- Line D: Organizational Skills: Competency D-4: Use Codes, Regulations and Standards
- Line D: Organizational Skills: Competency D-5: Use Manufacturer and Supplier Documentation
- Line D: Organizational Skills: Competency D-6: Plan Projects

The original materials were produced in collaboration with industry partners and aligned with the Industry Training Authority (ITA)/SkilledTradesBC harmonized program outlines for Plumbing, Steamfitting/Pipefitting, and Sprinkler Fitting. These works were released under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence, except where otherwise noted.

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The Open Press

The Open Press combines TRU's open platforms and expertise in learning design and open resource development to support the creation and reuse of open educational resources, while encouraging open scholarship and research.

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- Open School BC
- Camosun College
- Trades Training BC

For the latest BC Plumbing Trades Program Outline (2025), see the SkilledTradesBC website: www.skilledtrades.bc.ca

To order printed copies of Program Outlines or learning resources (where available) for BC Trades, contact:

Crown Publications, King's Printer
Web: www.crownpub.bc.ca
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- Piping Trades Apprenticeship Program – Perform Safety Related Functions – Level 1 Harmonized (2019) (Binder) (ISBN: 978-0-7726-7362-6; product no. 7960000260) Crown Publications Online Catalogue – Piping Trades Apprenticeship Program – Perform Safety Related Functions – Level 1 Harmonized (2019) (Binder)
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If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Introducing SkilledTradesBC

Starting December 1, 2022, Industry Training Authority was officially renamed to SkilledTradesBC. Hear more in this video from SkilledTradesBC CEO, Shelley Gray, on what this means for the trades industry and British Columbians. Closed captioning and transcripts are available with this video, Introducing Skilled Trades BC (2022) on YouTube.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2618

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Camosun College. (n.d.). *Line D: Organizational Skills*. BCcampus. https://collection.bccampus.ca/textbook/qFKGAJ78/

SkilledTradesBC. (2025). Plumber program outline (Implementation date: August 18, 2025; Last revised: December 16, 2025) [PDF]. Province of British Columbia. https://skilledtradesbc.ca/media/2776/download

SkilledTradesBC. (2022, December 1). Introducing Skilled Trades BC. YouTube. https://www.youtube.com/watch?v=OQgwdP0rNog

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The web version of *Block C: Routine Trade Activities and Electrical Concepts* has been designed to meet Web Content Accessibility Guidelines 2.0, level AA. In addition, it follows all guidelines in Appendix A: Checklist for Accessibility of the Accessibility Toolkit – 2nd Edition.

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Other Formats Available

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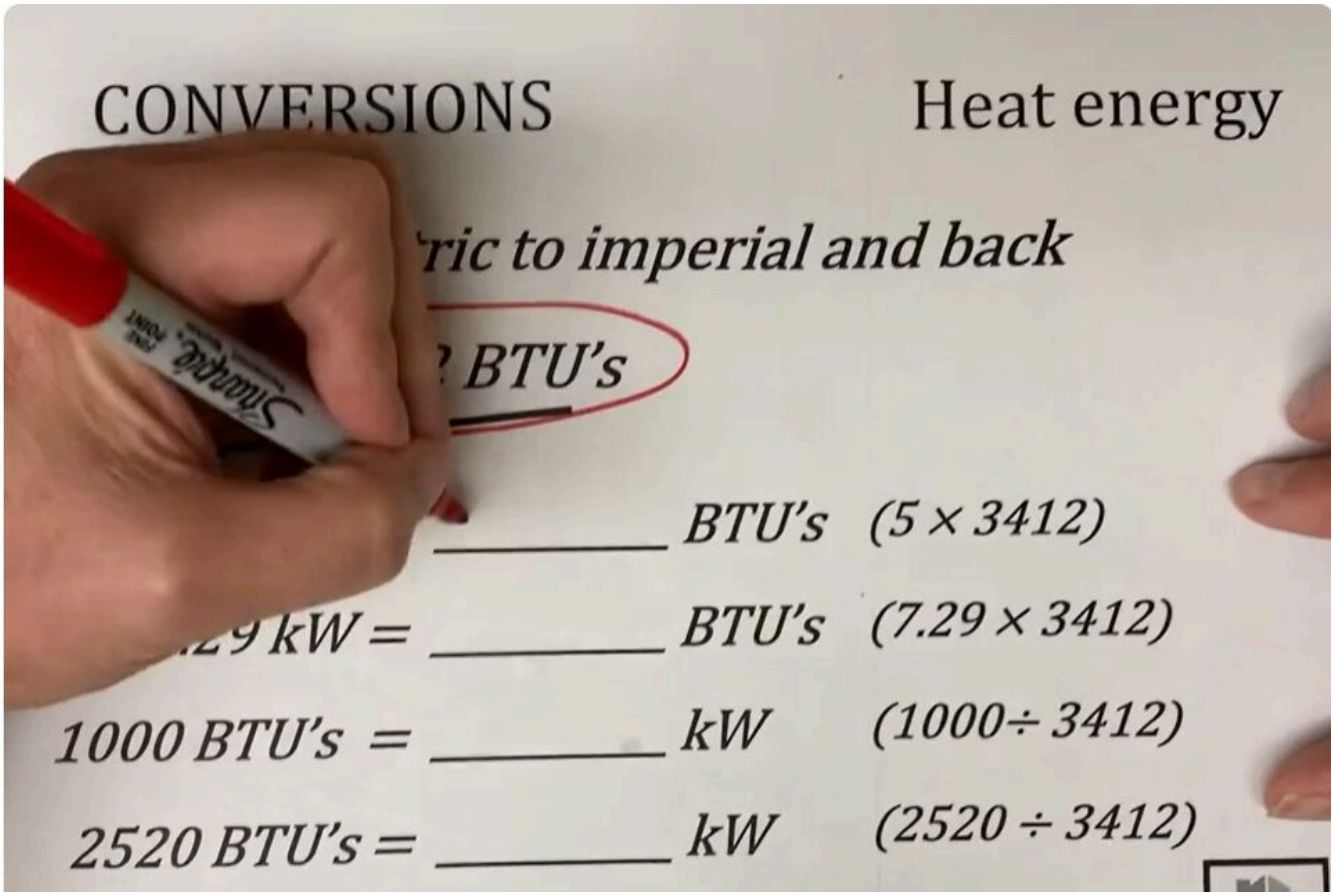
C-1 MATHEMATICS AND SCIENCE

Plumber Apprenticeship Program – Level 1



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C-1 Mathematics and Science Introduction

In this section, you will build the math and science skills that are essential for success in the plumbing trade. Plumbers use these skills every day to measure, calculate, and solve problems on the job. You will learn how to work with whole numbers, fractions, decimals, and percentages, and how to apply formulas to calculate area, volume, and capacity. You will also explore important scientific principles that relate to plumbing systems, including pressure, fluid flow, heat transfer, and the behaviour of gases and materials. By the end of this section, you will be able to perform accurate calculations, understand how piping systems work, and apply these concepts safely and effectively in real-world situations.

Learning Objectives

After completing this section, you should be able to:

- Add, subtract, multiply and divide whole numbers, fractions, decimals and percentages.
- Transpose formulas.
- Use formulas to calculate area, volumes, and capacity.
- Perform conversions.
- Calculate piping measurements.
- Use the Pythagorean theorem of right angles.
- Calculate offsets using the applicable trigonometric function.
- Calculate required measurements for piping offsets.
- Define the properties of matter.
- Use Pascal's theory of pressure and force.
- Use Archimedes' principles of displacement and flotation.
- Define mechanical advantage as it relates to fluid power.
- Describe factors that affect fluid flow in a piping system.
- Describe factors that affect gas volumes and pressures.
- Calculate the expansion and contraction of various piping materials due to heating and cooling.
- Define methods of heat transfer.
- Perform heat load calculations.
- Describe characteristics of hydrocarbon gases.

Topic areas covered in this publication are in alignment with SkilledTradesBC Harmonized 2018 Program Outlines.

You will be required to reference publications and videos available online at WorkSafeBC.

Supplementary Resources

The best way to improve on your math skills in the Trades is to practice. The following resources, available from Mark Overgaard from Camosun College, and Chad Flinn at BCcampus, may help you further:

- *Math for Trades: Volume 1*, by Chad Flinn and Mark Overgaard, available from BCcampus
- *Math for Trades: Volume 2*. by Chad Flinn and Mark Overgaard, available from BCcampus
- Math for Trades: Volume 3, by Chad Flinn and Mark Overgaard, available from BCcampus
- **Videos:** OER for Trades: Math for Trades
    - Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus by Camosun College.

ITA Calculator Policy Note

SkilledTradesBC has implemented a policy regarding the type of calculators that may be used on all ITA-administered exams, including the Inter-Provincial Standards exam (IPSE). The calculator specified for piping trades is the Sharp EL-520X. You should start using this calculator early in your training so that you are familiar with it and will avoid having difficulties during important exams.

Be sure to take the time to thoroughly read the operation manual. You will be using many of the functions available with this model during this course.

Scientific calculator

Modern scientific calculators generally have many more features than a standard four- or five-function calculator, and the feature set differs between manufacturers and models. However, the defining features of a scientific calculator include:

- Scientific notation
- Floating point arithmetic
- Trigonometric functions

    ▸ It is very important that your calculator be in the right mode. For the majority of your work the mode should be in “deg” or degree mode. This notation will appear in the screen of your calculator.

- Exponential functions and roots beyond the square root
- Quick access to constants such as π (pi)

***Sharp* EL-520X**

Terminology

The following terms may be used throughout this section. Note that some glossary terms may be in italics throughout the section content but are not included in this list. A complete list of terms for Section C-1 can be found in the **Glossary.**

- **addition**: Finding the total when two or more numbers are put together. (Section C-1.1)
- **absolute pressure:** The total pressure measured from a perfect vacuum (zero pressure). (Section C-1.6)
- **Archimedes' Principle:** States that an object placed in a fluid (liquid or gas) is pushed upward by a force equal to the weight of the fluid it displaces. (Section C-1.13)
- **atmospheric pressure:** The pressure created by the weight of air around the Earth. (Section C-1.6)
- **common denominator**: A number that is the same on the bottom of two or more fractions so they can be added or subtracted. (Section C-1.1)
- **conductivity:** The ability of a material to let heat or electricity pass through it. (Section C-1.11)
- **conservation of energy:** Energy cannot be created or destroyed—it can only change from one form to another (like from heat to movement), meaning the total amount of energy always stays the same, even when it changes form. (Section C-1.15)
- **conversion factor:** A number used to change one unit of measurement into another. (Section C-1.6)
- **cubic unit:** A unit used to measure volume, based on length × width × height (for example, m^3 or ft^3). (Section C-1.6)
- **decimal**: A number that shows parts of a whole using a decimal point (for example, 0.5). (Section C-1.1)
- **decimal point**: A dot used to separate whole numbers from parts of a number. (Section C-1.1)
- **denominator**: The bottom number in a fraction that shows how many equal parts there are in total. (Section C-1.1)
- **difference**: The answer you get when you subtract one number from another. (Section C-1.1)
- **differential pressure:** The difference between two pressure measurements. (Section C-1.6)
- **dividend**: The number that is being divided. (Section C-1.1)

- **divisor**: The number you divide by. (Section C-1.1)
- **division**: Finding how many times one number fits into another number. (Section C-1.1)
- **fitting allowance (FA):** The distance from the end of the pipe inside a fitting to the centre of the fitting; this value changes depending on the type and size of the fitting. (Section C-1.7)
- **flashback:** A dangerous condition where a flame travels backward into the burner or piping because the flame speed is faster than the gas–air mixture leaving the burner. (Section C-1.20)
- **fraction**: A number that shows equal parts of a whole. (Section C-1.1)
- **gauge pressure:** (sometimes referred to as *overpressure*); the pressure measured above atmospheric pressure. (Section C-1.6)
- **hydrocarbon gas:** A gas made up of hydrogen and carbon atoms, commonly used as a fuel. (Section C-1.20)
- **hypotenuse (travel):** The longest side of a right triangle, opposite the right angle. (Section C-1.9; Section C-1.10)
- **improper fraction**: A fraction where the top number is equal to or larger than the bottom number. (Section C-1.1)
- **inverse operation:** An opposite operation that undoes another operation (for example, addition and subtraction) (Section C-1.2)
- **joule:** The standard metric unit used to measure energy. (Section C-1.6)
- **least common denominator (lcd)**: The smallest number that two or more denominators can divide into evenly. (Section C-1.1)
- **lowest terms**: A fraction written in its simplest form, where the top and bottom numbers cannot be divided further by the same number. (Section C-1.1)
- **mixed number**: A number made up of a whole number and a fraction (for example, 2 ½). (Section C-1.1)
- **multiplication**: A short way of adding the same number more than once. (Section C-1.1)
- **numerator**: The top number in a fraction that shows how many parts you have. (Section C-1.1)
- **offset (piping):** A small change in direction in a pipe that helps absorb movement caused by expansion or contraction. (Section C-1.17)
- **order of operations (BEDMAS):** A rule that tells you the correct order to solve a math problem. It stands for Brackets, Exponents, Division and Multiplication, and Addition and Subtraction; it helps you know which steps to do first so you get the right answer. (Section C-1.2)
- **pascal (Pa):** The metric unit used to measure pressure. (Section C-1.6)
- **percentage**: A way of showing a number out of 100 using the symbol %. (Section C-1.1)
- **place value**: The value of a digit based on its position in a number. (Section C-1.1)
- **psid (pounds per square inch differential):** An imperial unit of pressure that measures the difference between two pressure readings in a system (i.e., differential pressure). (Section C-1.6)
- **product**: The answer you get when you multiply numbers. (Section C-1.1)
- **proper fraction**: A fraction where the top number is smaller than the bottom number. (Section C-1.1)
- **Pythagorean theorem:** A formula used to find the longest side of a triangle using the other two sides. (Section C-1.10)
- **quotient**: The answer you get when you divide one number by another. (Section C-1.1)
- **reciprocal**: A fraction turned upside down (for example, 1/2 becomes 2/1). (Section C-1.1)
- **remainder**: The amount left over after division when a number does not divide evenly. (Section C-1.1)
- **specific gravity (SG):** (*relative density*); a number that compares how dense a substance is to water. (Section C-1.13)
- **streamline flow:** (laminar flow); smooth fluid flow where the liquid moves in layers without mixing.

(Section C-1.15)

- **subtraction**: Taking one number away from another. (Section C-1.1)
- **sum**: The answer you get when you add numbers. (Section C-1.1)
- **thread engagement (TE):** The distance from the face of a fitting to how far the pipe screws into it; this distance changes depending on the size of the pipe. (Section C-1.7)
- **throw (centre to face [C-to-F]):** The distance from the centre of a fitting to its face (end). (Section C-1.7)
- **units (ones place)**: The place value of the digit farthest to the right in a whole number. (Section C-1.1)
- **venturi (narrowing):** A section of pipe that narrows, causing fluid to speed up and pressure to decrease. (Section C-1.15)

C-1.1 Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Calculating Whole Numbers

Whole numbers, ***fractions*** and ***decimals*** are fundamental parts of trade mathematics. To be successful in any trade, you must be proficient when working with whole numbers, fractions and decimals.

Careful work is the key to solving these and more difficult problems without making discouraging and frustrating mistakes. You should consciously follow these steps:

- Read the question twice. Make sure you understand what is being asked and what information has been provided.
- Plan how you are going to solve the problem. Do you need to add, subtract, multiply, or divide? Write the solution down carefully, making sure the calculation is written clearly and correctly. Take time to organize your work in a logical progression for future reference. Don't sacrifice accuracy for speed; it's much more important to be accurate.

You will use a calculator to find the answers to most of the problems in this competency. While on your work site, however, you will often need to perform manual calculations. To help you become proficient at this, **DO NOT USE YOUR CALCULATOR WHILE COMPLETING THE FIRST SELF-TEST.**

Place Value

The idea of ***place value*** is at the heart of our number system. If you look at the number 333, it only involves one numeral, 3. The numeral 3 has a different meaning based on its position in the overall number. The first 3 stands for 300, the second 3 stands for 30, and the last 3 only stands for 3. The fact that this one numeral can stand for multiple numbers is called place value. This means that the numeral's value is determined by what place it is within the number (Table 1).

Beginning with the ones place at the right, each place value is multiplied by increasing powers of 10. For example, the value of the first place on the right is one, the value of the place to the left of it is ten, which is 10 times 1. The place to the left of the tens place is hundreds, which is 10 times 10, and so forth. The "ones" place is also called the "units" place. In the trades, you may hear "***units***" used more often, but both terms mean the same thing.

The decimal system of numbers lets us write numbers as large or as small as we want using the ***decimal point***. In our number system, digits can be placed to the left and right of a decimal point, to indicate numbers greater than one or less than one. The decimal point helps us to keep track of where the units place is; it's placed just to the right of the units place. As we move right from the decimal point, each number place is divided by 10.

Table 1: Place Value Positions

THE PLACE VALUE									
Millions	Hundred Thousands	Thousands	Hundreds	Tens	Units (or Ones)	. (Decimal Point)	Tenths	Hundredths	Thousandths

Addition

Addition is the process of finding the total of two or more numbers. The result of addition is called the ***sum***. The sign for addition is "+" and the word indicating addition is *plus*. The digits must be properly lined up in a column: all units, tens and hundreds, etc., must be in a dedicated column, as in Table 2.

Table 2: Alignment of Digits in Place Value Columns

Thousands	Hundreds	Tens	Units (or "Ones")
	8	4	6
7	4	2	3
		7	8
			6
8	3	5	3

To solve the addition problem in Table 2, first add the numbers in the units column. The sum of the column is 23. Place the 3 in the units column under the total line (the last row) and carry the 2 into the tens column. The total of the tens column is thus 15. Place the 5 under the total line and carry the 1 into the hundreds column. The total of the hundreds column is 13, so we place the 3 under the total line and carry the 1 into the thousands column, giving 8 as a total for this column. The total is 8,353.

If decimal fractions are used, line up the decimals to the right of the units column and proceed as normal, adding up the columns from right to left.

Example:

Some plumbing fixtures are to be shipped to a *construction* site on a truck that can carry 1,750 kg. The load includes 378.45 kg of water closets, 622.48 kg of bathtubs and 208.6 kg of sinks. Will this overload the truck?

Solution:

Add all the masses together and see if the sum exceeds 1,750 kg.

Table 3: *Addition of Numbers Containing Decimals*

Thousands	Hundreds	Tens	Units	.	Tenths	Hundredths
	3	7	8	.	4	5
	6	2	2	.	4	8
	2	0	8	.	6	0
1	2	0	9	.	5	3

Note: Zeros have been added where necessary in the hundredths column to make all numbers contain the same number of decimal places. For example, 208.6 kg → 208.6**0** kg.

Answer:

The total weight of the shipment is 1,209.53 kg, so the 1,750 kg-capacity truck can safely carry the shipment of fixtures to the site.

Subtraction

As with addition, you must line up the columns when subtracting numbers. You may find that a number on the bottom is too large to subtract from the number on the top. When you encounter this, simply borrow ten from the next number on the left. (Remember to reduce the number on the left by one, as shown in the example below.) To check your work, add your answer to the number you subtracted. The sum should equal the number you subtracted from. The result of ***subtraction*** is called the ***difference***. The sign for subtraction is "–" and the word indicating subtraction is *minus*.

Example:

If the sinks were left off the truck in the previous problem, could the rest of the material be safely carried by a smaller 1,000 kg-capacity truck?

Solution:

Using the previous example, subtract the mass of the sinks from the 1,209.53 kg total. See if the difference is less than 1,000 kg.

Table 4: Line Up the Numbers for Subtraction

Thousands	Hundreds	Tens	Units	.	Tenths	Hundredths
1	2	0	9	.	5	3
	2	0	8	.	6	0
1	0	0	0	.	9	3

Note: 10 was borrowed from the 9 in the units column and added to the 5 in the tenths column to make it 15. The 9 was reduced to 8.

Answer:

The truck will be just over the safe rated load capacity and should not be used for this shipment.

Multiplication

Multiplication is really a short method of adding two or more numbers. Instead of saying $6 + 6 + 6 = 18$, we say $3 \times 6 = 18$. The result of multiplication is called the ***product***. The sign for multiplication is "×," and the word indicating multiplication is *times*.

When solving a multiplication problem in which the numbers have two or more digits, make sure that you write your answer for each step of the problem in proper alignment with the answers for the other steps. When each step of the multiplication is complete, add up all the answers to get the final product. If there are decimal numbers involved, ignore them until you have found the product. Then count the total number of places occupied by numbers on the right of the decimals and place the decimal in the answer so the same total number of places will be found to the right of it.

Example 1:

Multiply 4,328 by 129.

The calculation will look like this:

$$
\begin{array}{rrrrrr}
 & & 4 & 3 & 2 & 8 \\
 & & \times & 1 & 2 & 9 \\
 & 3 & 8 & 9 & 5 & 2 \\
 & 8 & 6 & 5 & 6 & 0 \\
4 & 3 & 2 & 8 & 0 & 0 \\
5 & 5 & 8 & 3 & 1 & 2
\end{array}
$$

We read the product as five hundred fifty-eight thousand, three hundred twelve.

Sometimes we will multiply by a number containing one or more zeroes, such as 206.

Example 2:

Multiply 511 by 206.

$$
\begin{array}{cccccc}
 & & & 5 & 1 & 1 \\
 & & \times & 2 & 0 & 6 \\
 & & 3 & 0 & 6 & 6 \\
 & & 0 & 0 & 0 & 0 \\
1 & 0 & 2 & 2 & 0 & 0 \\
1 & 0 & 5 & 2 & 6 & 6
\end{array}
$$

First multiply 511 by 6. Next is the zero, but since any number multiplied by zero is zero, simply add a row of zeroes, as shown, and continue with the next digit, which in this case is 2.

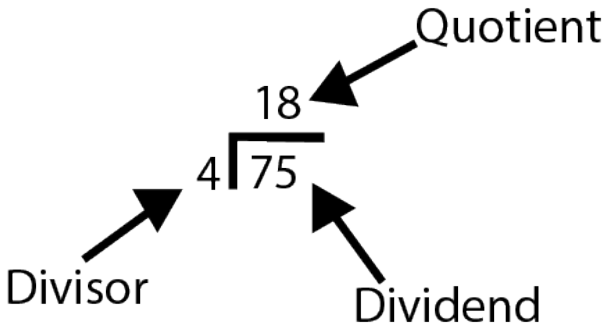
To check a multiplication problem, reverse the two numbers and carry out the multiplication:

$$
\begin{array}{cccccc}
 & & & 2 & 0 & 6 \\
 & & \times & 5 & 1 & 1 \\
 & & & 2 & 0 & 6 \\
 & & 2 & 0 & 6 & 0 \\
1 & 0 & 3 & 0 & 0 & 0 \\
1 & 0 & 5 & 2 & 6 & 6
\end{array}
$$

The two results match, so your calculation is correct.

Division

Division is the process of finding how many times one number is found in a larger number. For instance, 9 is found in 18 twice, and in 27, three times. The terms for division are ***divisor*** (the number you divide by), the ***dividend*** (the number being divided), and ***quotient***, which is the result of the division, or the answer to the problem.



To solve a division problem, write the answer for each step above the last number that was divided into. If the divisor has a decimal in it, the decimal must be removed at the start. To do this, move the decimal to the right end of the divisor and do the same with the dividend. To keep the question correct, the decimal in the divisor and dividend must be moved to the right the same number of places. Add zeroes if necessary to make this possible; write the decimal point in the answer directly above the decimal point in the dividend.

Example:

A construction heater will run for 7.35 hours on one cylinder of propane before the fuel supply is exhausted. How many cylinders would be required if the general contractor wanted the heater to run for 128.65 hours?

Solution:

Divide 128.65 hours by 7.35 hours per cylinder.

$$
\begin{array}{r}
17.5 \\
735\overline{)12865.0} \\
-7350 \\
\hline
5515 \\
-5145 \\
\hline
370
\end{array}
$$

Note: Move the decimal two spaces to the right to eliminate the decimal in the question.

Answer:

17.5 cylinders would be required, so the contractor would order 18 cylinders from the supplier.

(The decimal in the remainder can be located by noting the original position of the decimal in the question.)

Self-Test C-1.1.1: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.1 and check your answers.

If you are using a printed copy, please find Self-Test C-1.1.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2397#h5p-1

Fractions

Common fractions are numbers that express parts of a whole. Common fractions are written as two numbers, separated by a forward slash or a horizontal line. For example, suppose a pie is cut into five equal pieces and we eat two of them. Then we can say that we ate two-fifths, or 2/5, of
the pie.

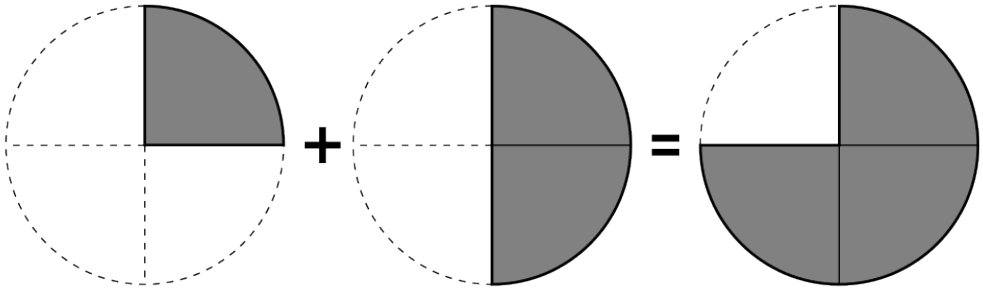


Figure 1 *Adding fractions are like adding pieces of a pie (Averater/Wikimedia Commons) CC BY-SA 3.0*

Measurements you are required to make on the job seldom turn out to be convenient whole numbers. Instead, they are often fractional amounts. Fractions are used extensively in all trades. In the construction trades many of the materials are still most commonly referred to by their imperial fractional widths. Mechanics encounter fractions in connection with the revolutions of rear axles, crankshafts, ring gears and wheels, in the measurement of parts, and in the adjustment of components of all kinds.

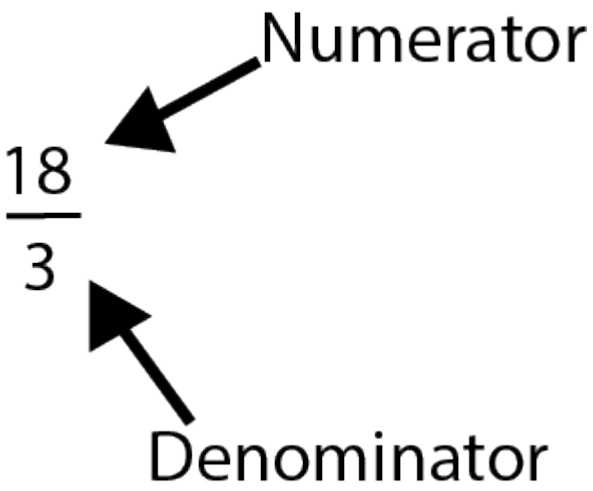
Calculating with Fractions

Fractions are simply one or more equal parts of a whole, divided by the total number of equal parts of that whole.

To be able to work with fractions as readily as with whole numbers, we must be familiar with the terms associated with fractions as well as with the addition, subtraction, multiplication and division of fractions.

Numerators and Denominators

Every fraction consists of two numbers. The number on the bottom is called the ***denominator***. The denominator indicates into how many equal parts the object is divided. The top number is called the ***numerator*** and states the number of equal parts the fraction represents.



If we have a group of fractions in which the numerators are all the same, the fractions that have larger denominators will represent smaller values than those with smaller denominators. For example, when you read a tape measure, $\frac{1}{8}$ inch is less than $\frac{1}{4}$ inch; and $\frac{1}{16}$ is less than $\frac{1}{8}$, $\frac{1}{4}$ or $\frac{1}{2}$.

Conversely, when the denominators are the same, the fraction with the largest numerator is the largest: $\frac{13}{16}$ is greater than $\frac{7}{16}$; $\frac{5}{8}$ is greater than $\frac{3}{8}$.

Proper Fractions

A fraction that is equal to less than one (e.g., $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$) is called a ***proper fraction***. The numerator is smaller than the denominator.

Improper Fractions

A fraction that is equal to one or more than one (e.g., $\frac{5}{4}$, $\frac{18}{16}$) is called an ***improper fraction***. The numerator is equal to or larger than the denominator.

Mixed Numbers

When a number is made up of a whole number and a fraction (e.g., $2\frac{1}{4}$ and $4\frac{7}{8}$), it is called a *mixed number*. It represents a whole quantity of an object plus a part (fraction) of another.

Lowest Terms

A fraction is properly expressed in its ***lowest terms***. It is in its lowest terms when the numerator and the denominator are such that no other number can be divided into both of them evenly, and without some amount left over, called a ***remainder***. For example, the fraction $\frac{12}{16}$ is not in its lowest terms, since 4 can be divided into both top and bottom:

$$\frac{12}{16} \div \frac{4}{4} = \frac{3}{4}$$

Therefore, $\frac{12}{16}$ reduced to its lowest terms is $\frac{3}{4}$.

Fractions may be reduced to their lowest terms by dividing the numerators and denominators by the same number. For example, to reduce $\frac{2}{8}$ to its lowest terms, divide the numerator and denominator by 2:

$$\frac{2}{8} \div \frac{2}{2} = \frac{1}{4}$$

Fractions are often written in their lowest terms for clarity; however, only reduce them if the question asks you to do so (confirm with your instructor if necessary), or if your mathematical problem on the job requires it.

Changing Mixed Numbers to Improper Fractions

Multiplication and division require the changing of ***mixed numbers*** to improper fractions. The tape measure in Figure 4 shows the following:

- A mixed number, $1\frac{3}{8}$ in., and the equivalent improper fraction, $\frac{11}{8}$ in.
- A mixed number, $1\frac{11}{16}$ in., and the equivalent improper fraction, $\frac{27}{16}$ in.
- A mixed number, $2\frac{1}{4}$ in., and the equivalent improper fraction, $\frac{9}{4}$ in.

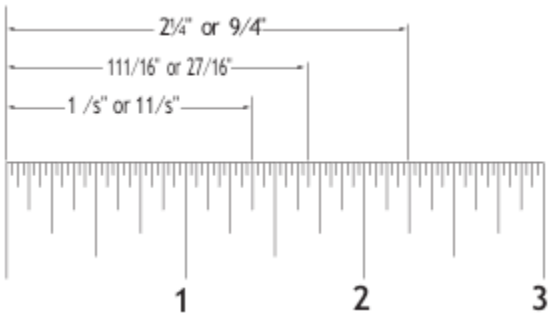


Figure 4 *Mixed numbers and improper fractions (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

To change a mixed number to an improper fraction, follow the steps in the examples below.

Example 1:

Change $3\frac{5}{8}$ to an improper fraction.

Solution:

Multiply the denominator of the fraction by the whole number:

$$8 \times 3 = 24$$

Add the numerator to the result:

$$5 + 24 = 29$$

Place this result over the denominator:

$$\frac{29}{8}$$

Example 2:

Change $3\frac{11}{16}$ to an improper fraction.

Solution:

$$16 \times 3 = 48 \quad 11 + 48 = 59$$

Place this result over the denominator:

$$\frac{59}{16}$$

Changing Improper Fractions to Mixed Numbers

Improper fractions usually result from the addition, subtraction, multiplication or division of proper fractions. For example, $6\frac{7}{8}$" plus $4\frac{3}{8}$" equals $10\frac{10}{8}$" . The improper fractions must be changed to mixed numbers. This change is made by dividing the numerator by the denominator.

$$\begin{array}{r} 1 \\ 8\overline{)10} \\ \underline{-8} \\ 2 \end{array}$$

The answer to the division example above is 1 with 2 eighths remaining. Add the whole number to your previous whole number $(10 + 1 = 11)$ and change the 2 eighths to a proper fraction, or $\frac{1}{4}$. In summary, $10\frac{10}{8}" = 11\frac{1}{4}"$.

Self-Test C-1.1.2: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.2 and check your answers.

If you are using a printed copy, please find Self-Test C-1.1.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2397#h5p-2

Common Denominators

When each fraction in a group has the same or ***common denominator***, they are called ***like fractions***. For example, in the series of like fractions $\frac{1}{16}$, $\frac{3}{16}$, $\frac{5}{16}$ and $\frac{15}{16}$, the number 16 is the common denominator.

Before a group of fractions can be added or subtracted, all the fractions must be like fractions and have the same denominator.

Addition and Subtraction of Like Fractions

It's easy to add and subtract like fractions, or fractions with the same denominator. You just add or subtract the numerators, keep the same denominator, and then reduce to the lowest terms.

Examples with like fractions:

Addition:

$$\frac{1}{8}+\frac{5}{8}=\frac{6}{8}=\frac{3}{4}$$

$$\frac{5}{16}+\frac{9}{16}=\frac{14}{16}=\frac{7}{8}$$

$$\frac{5}{32}+\frac{21}{32}=\frac{26}{32}=\frac{13}{16}$$

Subtraction:

$$\frac{11}{16}-\frac{3}{16}=\frac{8}{16}=\frac{1}{2}$$

$$\frac{7}{8}-\frac{5}{8}=\frac{2}{8}=\frac{1}{4}$$

$$\frac{4}{5}-\frac{2}{5}=\frac{2}{5}$$

Addition and Subtraction with Uncommon Denominators

You will often need to add or subtract fractions that have different denominators. To do this, you need to know how to find the *lowest* or ***least common denominator (LCD)***. Since only like fractions can be added or subtracted, we first have to convert unlike fractions to equivalent like fractions. We want to find the smallest, or least, common denominator, because working with smaller numbers makes our calculations easier. The LCD, of two fractions is the smallest number that can be divided by both denominators. To find the LCD, start by writing all the multiples of both denominators, beginning with the numbers themselves.

Here's an example of this method:

Add:

$$\frac{1}{6}+\frac{3}{4}$$

Multiples of 4 are 4, 8, 12, 16 and so forth (because 1 × 4 = 4, 2 × 4 = 8, 3 × 4 = 12, 4 × 4 = 16, etc.). The multiples of 6

are 6, 12, … The number we're looking for is 12, because it's the first one that appears in both lists of multiples. It's the smallest or least common multiple, so we'll use it as our least common denominator:

$$\frac{1}{6} + \frac{3}{4}$$

$$\frac{2}{12} + \frac{9}{12} = \frac{11}{12}$$

When subtracting fractions, follow the same rules as for addition by making sure the denominators are common. Next, subtract the numerators of the fractions, place the answer over the common denominator, and reduce to the lowest terms:

$$\frac{11}{12} - \frac{1}{8}$$

Multiples of 12 are 12, 24, 36 and so on. The multiples of 8 are 16, 24.

The number 24 is the first one that appears in both lists of multiples, so it's the least common denominator:

$$\frac{11}{12} - \frac{1}{8}$$

$$\frac{22}{24} - \frac{3}{24} = \frac{19}{24}$$

Addition and Subtraction of Mixed Numbers

A mixed number consists of a whole number and a fraction. Any mixed number can also be written as an improper fraction, in which the numerator is larger than the denominator. To add mixed numbers where the fractions have a common denominator, we add the whole numbers together and then the fractions. If the sum of the fractions is an improper fraction, then we change it to a mixed number.

Example 1:

$$2\frac{5}{8} + 3\frac{1}{8} = 5\frac{6}{8} = 5\frac{3}{4}$$

In this example, the whole numbers, 2 and 3, add up to 5. The fractions, $\frac{5}{8}$ and $\frac{1}{8}$, add up to $\frac{6}{8}$, which when reduced to the lowest terms is $\frac{3}{4}$.

If the denominators of the fractions are different, then first find a common denominator before adding. Then proceed as before.

Example 2:

$$3\frac{13}{32} + 9\frac{1}{4} =$$

$$3\frac{13}{32} + 9\frac{8}{32} =$$

$$12\frac{21}{32}$$

Subtracting mixed numbers is similar to adding them. A problem arises when the fractional part of the number you are subtracting is larger than the fractional part of the number you are subtracting from.

Example:

Since you're trying to subtract a larger fraction from a smaller one, you need to "borrow" a 1 from the whole number 9, change it to $\frac{16}{16}$, and add it to the fraction $\frac{2}{16}$, making it $\frac{18}{16}$.

$$9\frac{1}{8} - 4\frac{13}{16} =$$

$$9\frac{2}{16} - 4\frac{13}{16} =$$

$$8\frac{18}{16} - 4\frac{13}{16} =$$

$$4\frac{5}{16}$$

Multiplication of Fractions and Mixed Numbers

Multiplying fractions is simpler than adding or subtracting them. It is not necessary to have a common denominator.

To multiply two fractions, simply multiply the numerators of the fractions to get the new numerator, and multiply the denominators of the fractions to get the new denominator. Simplify the resulting fraction, if possible.

Example:

Multiply $\frac{1}{4} \times \frac{2}{3}$.

$$\frac{1}{4} \times \frac{2}{3} = \frac{2}{12} = \frac{1}{6}$$

Multiplying mixed numbers is just like multiplying fractions. In fact, it is multiplying fractions, since you first change the mixed numbers into improper fractions:

$$2\frac{3}{4} \times 4\frac{1}{2} = \frac{11}{4} \times \frac{9}{2} = \frac{99}{8} = 12\frac{3}{8}$$

To multiply a fraction and a whole number, treat the whole number as if it were over 1, and then proceed as follows:

$$4 \times \frac{5}{8} = \frac{4 \times 5}{1 \times 8} = \frac{20}{8} = 2\frac{4}{8} = 2\frac{1}{2}$$

When multiplying more than two fractions or mixed numbers, just add them to the string and proceed as normal:

$$\frac{1}{4} \times \frac{2}{5} \times \frac{1}{3} = \frac{1 \times 2 \times 1}{4 \times 5 \times 3} = \frac{2}{60} = \frac{1}{30}$$

Cancellation

Cancellation is a technique used to simplify our work. This is done by using smaller numbers rather than larger ones. By cancelling, we reduce to lowest terms, as far as possible, before multiplying, rather than afterwards.

Example:

$$\frac{3}{8} \times \frac{5}{11} \times \frac{4}{9} = \frac{60}{792} \quad \frac{\cancel{3}^{1}}{\cancel{8}^{2}} \times \frac{5}{11} \times \frac{\cancel{4}^{1}}{\cancel{9}^{3}} =$$

Note that the numerator 3 divides into the denominator 9, and the numerator 4 divides into the denominator 8. The numerator 5 and the denominator 11 are prime numbers and are only divisible by 1 and themselves, so they do not assist in cancellation.

Resulting in:

$$\frac{1}{2} \times \frac{5}{11} \times \frac{1}{3} = \frac{5}{66}$$

Also note that cancellation does not apply in addition or subtraction.

Division of Fractions and Mixed Numbers

Dividing fractions is just like multiplying fractions, except for one additional step.

Find the ***reciprocal*** of **one** of the fractions and multiply the original by the reciprocal of the fraction you just found. Reduce the fraction to the lowest terms.

To find the reciprocal of a fraction simply turn it upside down. For example, the reciprocal of $\frac{1}{4}$ is $\frac{4}{1}$.

Example 1:

Divide $\frac{3}{8}$ by $\frac{1}{4}$:

$$\frac{3}{8} \div \frac{1}{4} = \frac{3}{8} \times \frac{4}{1} = \frac{12}{8} = 1\frac{1}{2}$$

Dividing mixed numbers is very similar to multiplying mixed numbers. You just add one step. After changing the mixed numbers into improper fractions, you then find the reciprocal of one of the fractions. Always use cancellation if the opportunity presents itself, and multiply the numerators together and the denominators together.

Example 2:

Divide $4\frac{1}{4}$ by $3\frac{3}{8}$:

$$4\frac{1}{4} \div 3\frac{3}{8} \quad = \frac{17}{4} \div \frac{27}{8} \quad = \frac{17}{\cancel{4}^{1}} \times \frac{\cancel{8}^{2}}{27} \quad = \frac{17}{1} \times \frac{2}{27} = \frac{34}{27} = 1\frac{7}{27}$$

Self-Test C-1.1.3: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.3 and check your answers.

If you are using a printed copy, please find Self-Test C-1.1.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2397#h5p-3

Calculating with Decimals

Adding and Subtracting Decimals

If you know how to add and subtract whole numbers, then you can add and subtract decimals. The only requirement is to be sure to line up the terms so that all the decimal points are in a vertical line.

Add Decimal Numbers

Put the numbers in a vertical column, aligning the decimal points. Add each column of digits, starting on the right and working left. If the sum of a column is more than 10, carry digits to the next column on the left. Place the decimal point in the answer directly below the decimal points in the terms.

Example:

$$\begin{array}{rr} & {\scriptstyle 1}\,{\scriptstyle 1}\quad\quad\;\;{\scriptstyle 1}\,{\scriptstyle 1} \\ & 45{\scriptstyle 1}62.{\scriptstyle 1}23{\scriptstyle 1}0 \\ & \quad\;\;125.287 \\ & \quad\;\;\;\;24.128 \\ + & \quad\;\;\;\;\;\;1.210 \\ \hline & 4712.855 \end{array}$$

Subtract Decimal Numbers

Put the numbers in a vertical column, aligning the decimal points. Subtract each column, starting on the right and working left. If the digit being subtracted in a column is larger than the digit above it, borrow a digit from the next column to the left.

Place the decimal point in the answer directly below the decimal points in the terms.

$$\begin{array}{rcccccc} & 2 & \cancel{4}^{\,3} & 2 & . & 8 & 7 & 5 \\ - & & 1 & 7 & . & 4 & 3 & 3 \\ \hline & 2 & 2 & 5 & . & 4 & 4 & 2 \end{array}$$

Multiply Decimal Numbers

Multiply the numbers just as if they were whole numbers. Line up the numbers on the right, and this time don't worry if the decimal points are not aligned. Starting on the right, multiply each digit in the top number by each digit in the bottom number, just as with whole numbers. Add the products and place the decimal point in the answer by starting at the right and moving the point the number of places equal to the sum of the decimal places in both of the numbers that you multiplied.

Example:

Multiply 47.32×56.1 :

$$\begin{array}{rcccccc} & & 4 & 7 & . & 3 & 2 \\ & \times & & 5 & 6 & . & 1 \\ \hline & & & 4 & 7 & 3 & 2 \\ & & 2 & 8 & 3 & 9 & 2 & 0 \\ & 2 & 3 & 6 & 6 & 0 & 0 & 0 \\ \hline 2 & 6 & 5 & 4 & . & 6 & 5 & 2 \end{array}$$

Divide Decimal Numbers

Dividing decimals is like dividing whole numbers, but there is one extra step.

If the number you are dividing by (the divisor) has a decimal, move the decimal point to the right until it becomes a whole number. Then move the decimal point in the other number (the dividend) the same number of places.

Now divide as you normally would. If the numbers do not divide evenly, you can add zeros to the end (to the right of the last digit in the dividend) and keep dividing until it comes out evenly or a repeating pattern shows up.

Place the decimal point in your answer directly above the decimal point in the dividend.

Example:

Divide $55.318 \div 3.4$:

$3.4\overline{)55.318}$

$3.\widehat{4})\overline{55.\widehat{3}18}$ (move decimal one place to right)

$34\overline{)553.18}$

$$\begin{array}{r} 16.27 \\ 34\overline{)553.18} \\ -340 \\ \hline 213.18 \\ -204 \\ \hline 9.18 \\ -6.8 \\ \hline 2.38 \\ -2.38 \\ \hline 0 \end{array}$$

Quotient = 16.27

Self-Test C-1.1.4: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.4 and check your answers. **This self-test is meant to be done without a calculator.*

If you are using a printed copy, please find Self-Test C-1.1.4 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2397#h5p-4

Calculating Percentages

We use the percent symbol (%) to express percent. ***percentages*** are used extensively in the trades, so you'll need to understand them well. Here are three ways to write the same thing:

$$15\% = \frac{15}{100} = 0.15$$

Fifteen percent is the same as the fraction $\frac{15}{100}$ and the decimal 0.15. They all simply mean "fifteen out of a hundred."

A percentage can always be written as a decimal, and a decimal can be written as a percentage, like this:

$$0.85 = 85\%$$

To find a percentage of a number, convert the percentage to a decimal and multiply. One hundred percent of a number is just the number itself. Two hundred percent of a number is twice that number:

$$100\% \text{ of } 50 = 50$$

$$200\% \text{ of } 50 = 2 \times 50 = 100$$

Example:

Find 30% of 400.

Solution:

First change 30% to a decimal by moving the decimal point 2 places to the left:

$$30\% = 0.30$$

Then multiply:

$$0.30 \times 400 = 120$$

30% of 400 is 120.

The simplest way to calculate what percentage one number is of another is to divide the given amount by the total amount and then multiply the answer by 100. This gives the percentage that the given amount forms with respect to the total amount. The equation can be set up as follows:

$$\frac{\text{Given Amount}}{\text{Total Amount}} \times 100$$

For example, if you score 60 out of 75 in mathematics, we can find your mark as a percentage by dividing 60 by 75. This comes to be 0.8. Multiplying by 100 gives us the percentage, which is 80%:

$$(\frac{60}{75}) \times 100 = 80\%$$

Converting Percentages to Common Fractions or Decimal Numbers

To convert a percentage to a common fraction, divide by 100. Use the percentage as the numerator and 100 as the denominator, and reduce, if possible.

To convert a percentage to a decimal number, divide by 100; or simply move the decimal place in the percentage two places to the left.

Example:

Convert 35% to a common fraction and a decimal number:

$$35\% = 35 \div 100 = \frac{35}{100} = \frac{7}{20} \text{ or } 35 \div 100 = 0.35$$

Converting Common Fractions or Decimal Numbers to Percentage

To convert either a common or decimal number to a percentage, simply multiply it by 100. Write the percent symbol (%) after the answer.

Example:

Convert $\frac{5}{6}$ to a percentage:

$$(5 \times 100) \div 6 = 83.3\%$$

Convert 0.28 to a percentage:

$$0.28 \times 100 = 28\%$$

Multiplying the decimal number by 100 gives the same result as moving the decimal point two places to the right.

Self-Test C-1.1.5: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.5 and check your answers.

If you are using a printed copy, please find Self-Test C-1.1.5 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2397#h5p-5

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Note: these videos align with the open textbooks *Math for Trades: Volume 1* and *Math for Trades: Volume 2*. All videos are by Chad Flinn and available under a Creative Commons Attribution 4.0 Licence.:

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C-1.2 Equations and Formulas

Equations

Many pipefitting problems involve ***equations*** or ***formulas***, making them important tools for solving trade-related tasks. It is essential to understand how they work.

An equation is a mathematical sentence that uses an equal sign (=) to show that two expressions are equal, for example $2x = 12$. A formula is a type of equation that shows a relationship between quantities. ***Ohm's Law***, for example, describes the relationship between *voltage*, *amperage*, and *resistance* in a circuit:

$$\text{Voltage} = \text{Amperage} \times \text{Resistance}$$

Equations can include ***variables*** (unknown values) and ***constants*** (known values). Solving an equation means finding the value of the variable that makes the equation true.

You can think of an equation like a balance scale—whatever you do to one side, you must do to the other to keep it balanced. The process of isolating the variable on one side of the equal sign is called transposing.

Key idea: Whatever you do to one side of the equation, you must do to the other side.

We will first use this "***balance method***" to solve equations, and later learn a shortcut called ***transposing***.

Order of Operations (BEDMAS)

Before solving equations or working with formulas, it is important to understand the correct order for completing calculations. This is called the ***order of operations***, and it ensures that everyone solves problems in the same way and gets the same answer.

Many tradespeople use the acronym **BEDMAS** to help them remember the correct order:

STEP 1 → Brackets ( )
STEP 2 → Exponents 2^3
STEP 3 → Division ÷
STEP 4 → Multiplication ×
STEP 5 → Addition +
STEP 6 → Subtraction −

How BEDMAS Works

When solving a problem, follow these steps:

1. **Brackets first** – solve anything inside brackets ( ), [ ], or { }.

2. ***Exponents* next** – solve ***power*s** (such as ***squared numbers***).
3. **Division and multiplication** – work from left to right.
4. **Addition and subtraction** – work from left to right.

Important: Division and multiplication are done in order from left to right. The same rule applies to addition and subtraction.

Example 1:

$$6 + 2 \times 3$$

Step 1: Multiply first (because of BEDMAS)

$$2 \times 3 = 6$$

Step 2: Add

$$6 + 6 = 12$$

Answer: 12

Example 2 (using the same numbers as above):

$$(6 + 2) \times 3$$

Step 1: Solve inside the brackets

$$6 + 2 = 8$$

Step 2: Multiply

$$8 \times 3 = 24$$

Answer: 24

The brackets change the answer!

Example 3:

$$20 \div 5 + 3$$

Step 1: Divide (left to right)

$$20 \div 5 = 4$$

Step 2: Add

$$4 + 3 = 7$$

Answer: 7

Why BEDMAS Matters

In the trades, calculations are often part of formulas and measurements. If the order of operations is not followed correctly, the final answer may be wrong, which can lead to errors in measurements, materials, or system performance.

By following BEDMAS, you can ensure your calculations are accurate and consistent.

Grouping Numbers

Parentheses ( ) and brackets [ ] mean that two or more numbers are to be treated as one. For practical purposes, they indicate that the work in parentheses is to be done first. $2(a+b)$ reads "two times the sum of a plus b," and $2a+b$ reads "two times a plus b."

If $a=5$ and $b=6$, then $2(a+b)=22$ and $2a+b=10+6=16$.

A long division bar groups numbers: $\frac{a+b}{5}$ means that the sum of a and b are divided by 5.

However, $\frac{a}{5}+b$ means that only a is divided by 5.

Again, if a = 5 and b = 6, then $\frac{5+6}{5}=\frac{11}{5}=2\frac{1}{5}$.

But, $\frac{5}{5}+6=1+6=7$.

A long radical bar such as $\sqrt{a^2+b^2}$ indicates the square root of the sum of the two squares.

Working with Positive and Negative Numbers

When working with equations, you will often see positive (+) and negative (−) numbers.

Addition Rules

- **Same signs → add → keep the sign**
- **Different signs → subtract → keep the sign of the larger number**

Examples:

+5 + +3 = +8
−4 + -2 = −6

+7 + −3 = +4
−8 + +5 = −3

Subtraction Rule

Change subtraction into addition:

Example:

4 − 6 = 4 + (−6)

Multiplication Rules

The sign of the product:

- **Same signs → positive**
- **Different signs → negative**

Examples:

$$\begin{array}{rrrr} & + & 3 \times & + & 3 \\ hline & + & 9 & & \end{array}$$

$$\begin{array}{rrrr} & + & 4 \times & - & 3 \\ hline & - & 12 & & \end{array}$$

$$\begin{array}{rrrr} & - & 4 \times & - & 4 \\ hline & + & 16 & & \end{array}$$

Division Rules

- **Same signs → positive**
- **Different signs → negative**

$$(+4) \div (+2) = +2 \qquad (+12) \div (-3) = -4$$

$$(-6) \div (-3) = +2 \qquad (-16) \div (+4) = -4$$

Solving Simple Equations (Balance Method)

Example of an Addition Equation

$$x + 15 = 30$$

To solve the equation, we must try to get the variable x alone on one side. Use the inverse of adding 15—or subtracting 15—to get x alone on the left side. Now x is alone on the left side, since 15 − 15 = 0, but the scale is not in balance. To balance the scale, subtract 15 from the right side of the equation.

$$x + 15 - 15 = 30 - 15$$

$$x = 15$$

Example of a Subtraction Equation

$$y - 9 = 3$$

To solve this equation, we must try to get the variable y alone on one side. We can use the inverse of subtracting 9, or adding 9, to get y alone on the left side.

$$y - 9 + 9 = 3 + 9$$

$$y - 0 = 12$$

$$y = 12$$

Example of a Multiplication Equation

The mechanical contract to construct the regional hospital was estimated at $4,775,000.00, which was 4 times the cost of the administration building in the same complex. What was the cost of the administration building contract?

We can write a multiplication equation to find the answer to problems like this. Our unknown number is the cost of the administration building contract. Let x represent this cost. We know that $4x$ is the cost of the regional hospital. We can write our equation like this:

$$4x = \$4,775,000$$

To solve this equation, we can use the inverse of multiplying by 4, which is dividing by 4.

If we divide the left side of the equation by 4, we will get x alone on the left. Remember, any operation done to one side must also be done to the other side, so we must also divide the right side by 4:

$$\frac{4x}{4} = \frac{4,775,000}{4}$$

$$x = 1,193,750$$

Example of a Division Equation

Canada's shoreline is the longest in the world. If you were to try to walk around Canada, following the shoreline at a good pace of 20 km per day, it would take you over 33 years (12,150 days) to complete the journey. How long is Canada's shoreline?

We can write a division equation to find the answer to problems like this. Our unknown number is the length of Canada's shoreline. Let x represent this number. We know that x divided by 12,150 days is the rate of travel in one day. We can write the equation like this:

$$\frac{x}{12,150} = 20$$

To solve this equation, we can use the inverse of dividing by 12,150, or multiplying by 12,150. If we multiply the left side of the equation by 12,150, we will get x alone on the left. Remember, any operation done to one side must also be done to the other side, so we must also multiply the right side by 12,150:

$$\frac{x}{\cancel{12,150}} \times \cancel{12,150} = 20 \times 12,150$$

$$x = 243,000 \text{ km}$$

The length of Canada's coastline is 243,000 km.

Checking Equations

Always check your answer by substituting it back into the original equation.

The process of checking is essential at all times to prove the accuracy of dimensions and quantities. It is comparatively simple to substitute computed values into the original equation to determine the accuracy of computation.

Substitute the computed value of any letter or symbol into the original equation. Perform each operation as indicated.

Note: The equation is balanced when the values on both sides of the equation are equal.

Example 1:

Check the answer $b = 9$ in the equation $6b = 54$.

First substitute the value of b in the original equation, $6b = 54$.

$$6 \times 9 = 54$$

Since both sides are equal, the answer is correct.

Example 2:

Solve the equation $4x + 3 = -2x + 33$.

First, transpose the known quantity 3 from left to right in the original equation and change the sign:

$$4x = -2x + 33 - 3$$

Next, transpose the unknown quantity from right to left and change the sign:

$$4x + 2x = 33 - 3$$

Next, collect all terms:

$$6x = 30$$

Finally, divide both sides by 6:

$$x = \frac{30}{6}$$

Answer:

$$x = 5$$

Check: Substitute the computed value 5 for the unknown x in the original equation:

$$4x + 3 = -2x + 33 \qquad \text{(Original equation)}$$

$$4(5) + 3 = -2(5) + 33$$

Next, collect terms on both sides of the equation by performing the operations as indicated. Finally, check final values on both sides of the equation to see that they are equal:

$$23 = 23$$

Transposing Equations (Shortcut Method)

Transposing is a quicker way to solve equations by moving terms from one side of the equal sign to the other. When you move a term across the equal sign, you must change its operation. This means:

- addition (+) becomes subtraction (−)

- subtraction (−) becomes addition (+)
- multiplication (×) becomes division (÷)
- division (÷) becomes multiplication (×)

Rule: When you move a number across the equals sign, do the opposite operation.

Using this method, all the unknown values are moved to one side of the equation, and all the known values are moved to the other side.

Transposing is often faster and simpler than adding or subtracting the same value on both sides of the equation.

Transposing with Addition

$$x + 15 = 92$$

$$x = 92 - 15$$

$$x = 77$$

Transposingwith Subtraction

$$y - 45 = 81$$

If we move the −45 across the equal sign, it becomes +45 on the other side.
As before, we must eliminate the −45, which would isolate y by itself on one side of the equal sign:

$$y - 45 = 81$$

$$y = 81 + 45$$

$$y = 126$$

Transposingwith Multiplication

The area of a square or rectangle is expressed in square units and is the product of the length times the width. The equation is expressed as follows:

$$\text{Area} = \text{Length} \times \text{Width}$$

If you are asked to solve for the width of a rectangle, the equation can be transposed as follows: Isolate the width by moving the length across the equal sign. Because it was multiplication on the right, it becomes division on the left.

$$\frac{\text{Area}}{\text{Length}} = \text{Width}$$

If you are asked to solve for the length of a rectangle, isolate the length by moving the length across the equal sign and divide.

$$\frac{\text{Area}}{\text{Width}} = \text{Length}$$

Transposingwith Division

The pressure found in piping systems is expressed as the force (pounds) pushing on a unit of area (usually a square inch). We shortcut this relationship by saying ***psi***. The actual equation is expressed as follows:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

If you are asked to solve for the force in pounds or the area in square inches, you must isolate the variable you are looking for by moving the known value across the equal sign. If the known variable was the numerator, it becomes the denominator, and vice versa.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \rightarrow \frac{\text{Force}}{\text{Pressure}} = \text{Area}$$

$$\downarrow$$

$$\text{Pressure} \times \text{Area} = \text{Force}$$

Proportions

When the equation is made up of two fractions, we have a ***proportion***.

For instance: $\frac{2}{3} = \frac{4}{6}$ is a proportion in a fractional form.

Another form is the ***proportion form*** (or *ratio form*): 2:3 = 4:6. These forms are read “2 is to 3 as 4 is to 6.”

In solving problems, we will always use the fractional form. Notice that in the proportion $\frac{2}{3} = \frac{4}{6}$, the numerator on the left times the denominator on the right equals the numerator on the right times the denominator on the left:

$$2 \times 6 = 12$$

$$4 \times 3 = 12$$

This is true for every proportion, and the technique involved is called ***cross multiplying***.

Example 1:

If a boiler containing 300 gallons of water requires 8 gallons of chemical treatment, how many gallons of chemical treatment would be required for a boiler containing 400 gallons?

Solution:

$$\frac{8}{300} = \frac{x}{400}$$

Cross multiply:

$$3,200 = 300x$$

Divide both sides by 300.

Answer:

$$x = 10.66 \text{ gallons}$$

Example 2:

One of the basic *fan laws* states that the number of cubic feet of air delivered per minute (CFM) varies in direct proportion to the revolutions per minute (RPM) of the fan. If a fan is turning at 1,000 RPM and delivering 2,000 CFM, how many CFM will it deliver if its speed is increased to 1,200 RPM?

Solution:

$$\frac{\text{CFM}_1}{\text{RPM}_1} = \frac{\text{CFM}_2}{\text{RPM}_2}$$

$$\frac{2,000}{1,000} = \frac{x}{1200}$$

Cross multiply:

$$2,400,000 = 1,000x$$

Divide both sides by 1000.

Answer:

$$x = 2,400 \text{ CFM}$$

Self-Test C-1.2: Transpose Equations and Formulas

Complete Self-Test C-1.2 and check your answers.

If you are using a printed copy, please find Self-Test C-1.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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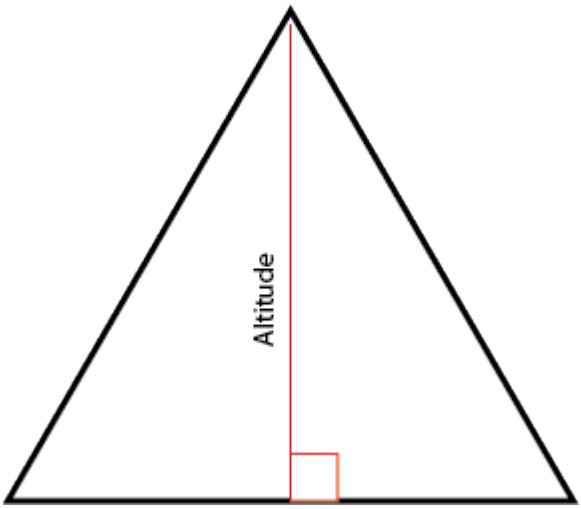
C-1.3 Use Formulas to Calculate Perimeter, Circumference, and Area

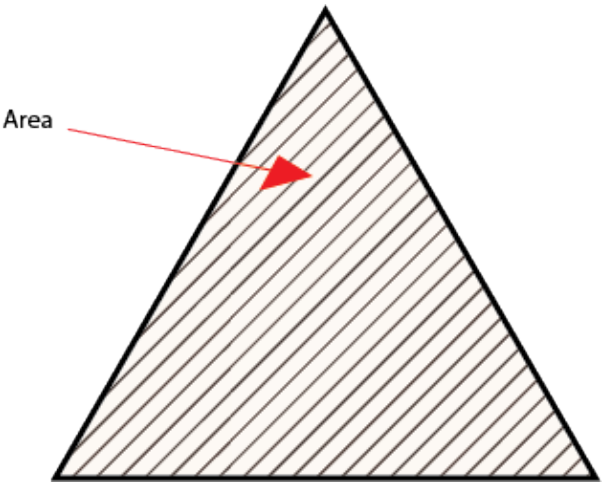
Working with pipe and conduit requires knowledge of the area and volume of circles and cylinders, as do many aspects of engine work in the mechanics trades. Most trades require working with these dimensions on a regular basis. The precise dimensions required for detail and layout work in all trades are equally dependent on careful calculation.

Key Terms

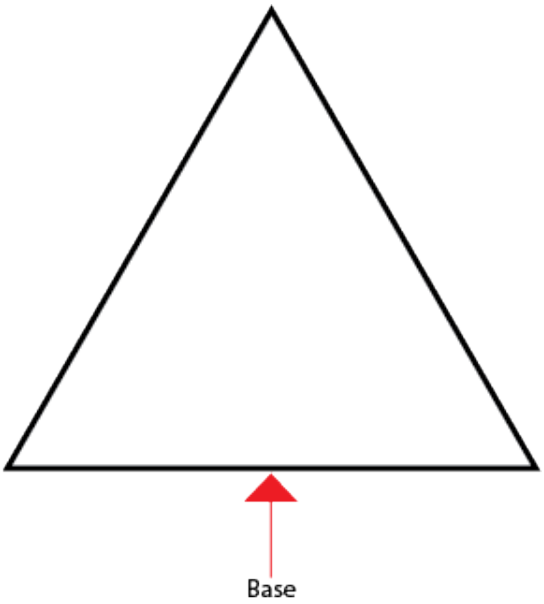
Altitude: Also referred to as height. The perpendicular distance between the base of a triangle or other figure and its uppermost side or point



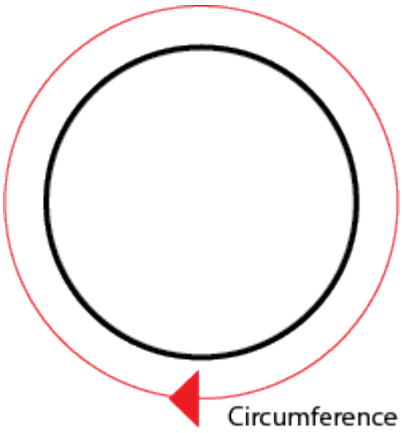
Area: The amount of surface enclosed by a figure



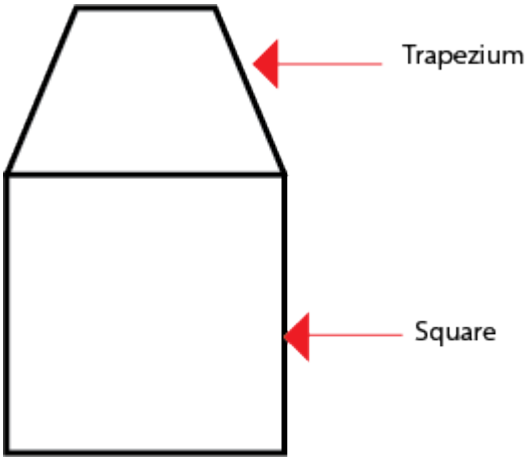
Base: The lower side of a triangle or other figure



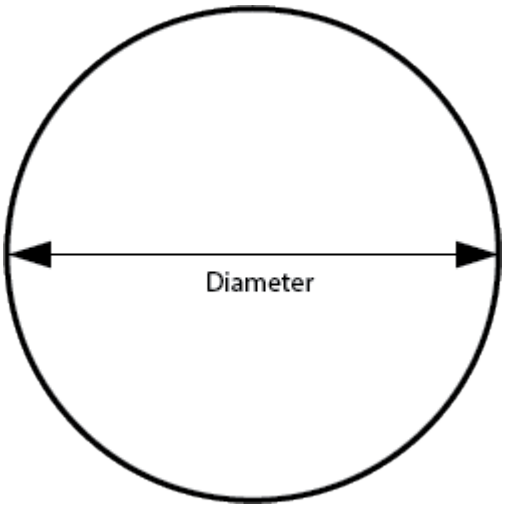
Circumference: The distance around a circle



Composite: Something made up of several simpler parts



Diameter: The line segment that joins two points on a circle and passes through the centre of the circle

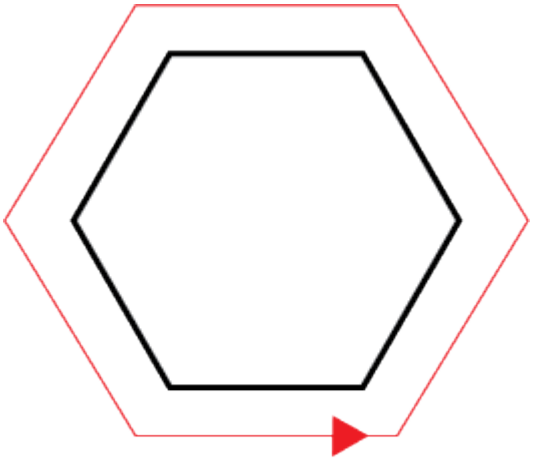


Formula: A shortcut method of finding an unknown numerical quantity when other quantities are known; for example, a formula to find the area of a rectangle:

$$\text{Area} = \text{length} \times \text{width}, \text{ or } A = L \times W$$

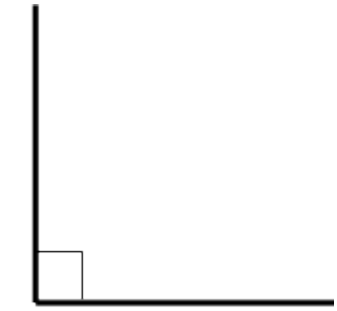
Height: See Altitude

Perimeter: The distance around a figure



Perimeter

Perpendicular: A term used to mean “at right angles.” Two lines are perpendicular when the angle between them is a right angle or has a measure of 90°



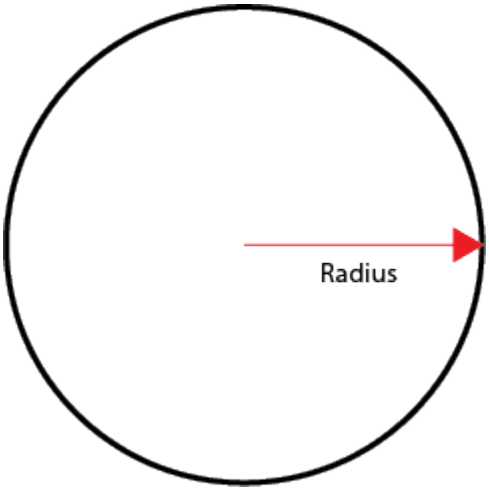
Perpendicular

Pi (π): A Greek letter that stands for the irrational number that begins as 3.14159265…

Quadrilateral: A four-sided figure

Quadilateral

Radius: The line segment from the centre of a circle to any point on the circle. The length of a radius is one-half the length of a diameter



Figures (Shapes)

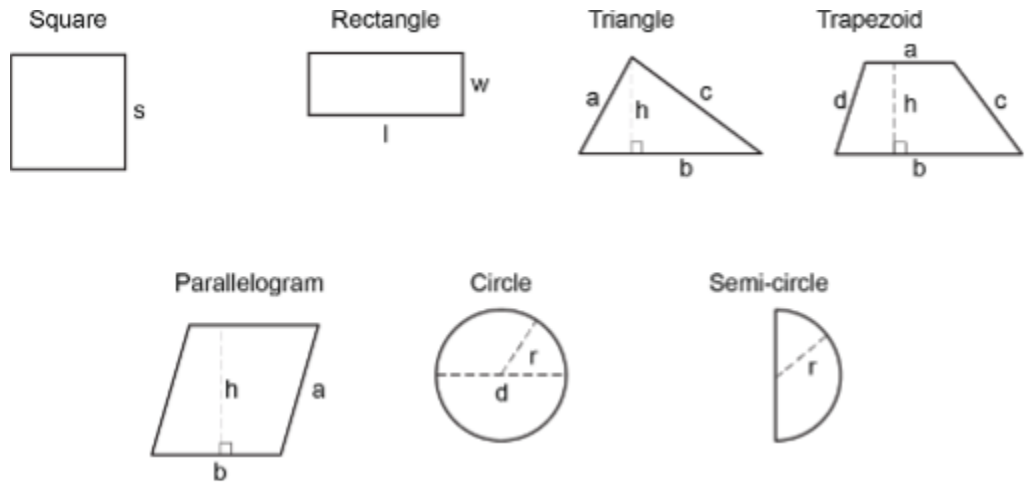


Figure 1 *Figures (or shapes)* (BC *Industry Training Authority*, 2019). *CC BY-NC-SA 4.0*

Perimeter

The ***perimeter*** of a ***figure*** is the total distance around the figure.

Example

Find the perimeter of the quadrilateral shown. (A ***quadrilateral*** is a four-sided figure.)

Solution

Measure and label each side of the figure. Add the four sides.

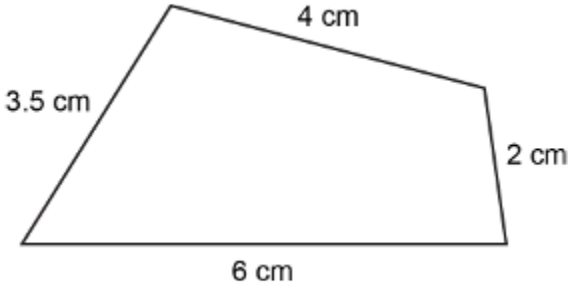


Figure 2 *Find the perimeter (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Finding the perimeter of a figure by measuring all of its sides can sometimes take a long time. For certain figures, such as squares, rectangles and circles, we can use perimeter formulas that shortcut the measuring process. For example, the perimeter of a square can be found by just measuring one side then multiplying by four. The formula is:

$$\text{Perimeter} = 4 \times \text{side}$$

$$\text{P} = 4\text{s}$$

(Recall that "4s" means "4 times s")

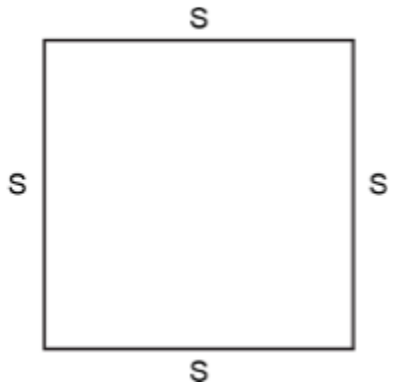


Figure 3 *Perimeter sides (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

$$\text{P} = 4\text{ cm} + 2\text{ cm} + 6\text{ cm} + 3.5\text{ cm} = 15.5\text{ cm}$$

(The letter P is the symbol for perimeter.)

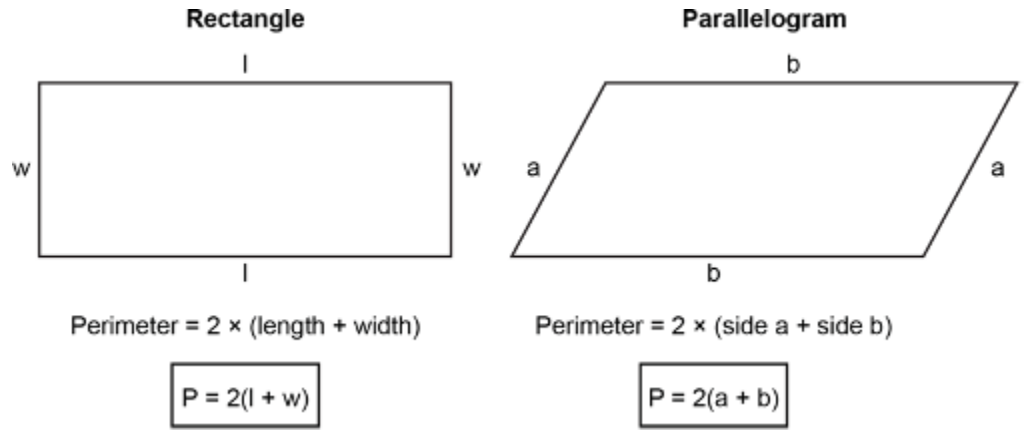


Figure 4 *Finding the perimeter (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Perimeter of Shapes

Find the perimeter of the parallelogram shown.

Solution

Measure two adjacent sides. Use the formula:

$$\mathrm{P} = 2(a + b)$$

$$\mathrm{P} = 2(3.3\ \mathrm{cm} + 5.1\ \mathrm{cm})$$

$$\mathrm{P} = 2(8.4\ \mathrm{cm})$$

$$\mathrm{P} = 16.8\ \mathrm{cm}$$

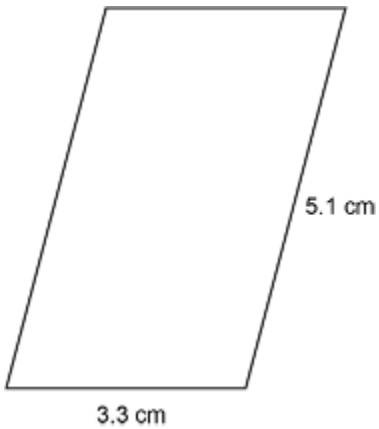


Figure 5 *Finding the perimeter for a parallelogram (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Circles

You already learned that the perimeter is the distance around a shape. However, the distance around a circle is called the ***circumference***. It is the same idea as perimeter, but we use a different word for circles.

Think of it this way: If you could cut a circle's edge and stretch it into a straight line, that length would be the circumference.

A circle has two important measurements:

- **Radius (r):** the distance from the centre of the circle to the edge
- **Diameter (d):** the distance straight across the circle through the centre

The diameter is always **twice the radius**:

$$d = 2r$$

Understanding Circumference

The circumference of a circle is directly related to its diameter.

No matter how big or small the circle is, the ratio of the circumference to the diameter is always the same number. This number is called **pi (π)**.

What is Pi (π)?

The number pi (π) is a special number that is used when working with circles. The symbol π is the Greek letter pronounced "pi." It is a constant used to relate straight-line measurements (radius/diameter) to a curved edge (circumference). The number, pi or π is impossible to state exactly. A good approximation for π is 3.1416. The number π can *only* be approximated. It is one of many irrational numbers and is quite "famous."

- π ≈ 3.1416
- It cannot be written exactly (it goes on forever without repeating)
- Most calculators have a π button

Circumference Formulas

We can use π to calculate the circumference of a circle.

There are two equivalent formulas:

$$C = \pi d$$

$$C = 2\pi r$$

- Use **C = πd** when you know the diameter
- Use **C = 2πr** when you know the radius

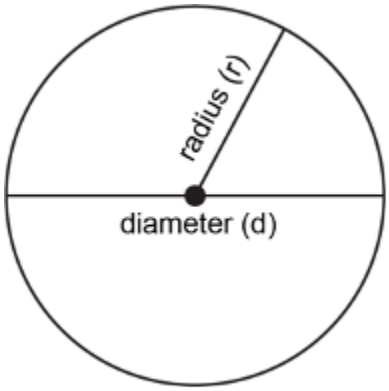


Figure 6 *Solving for the circumference of a circle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 1

Find the circumference of the circle. Round to one decimal place.

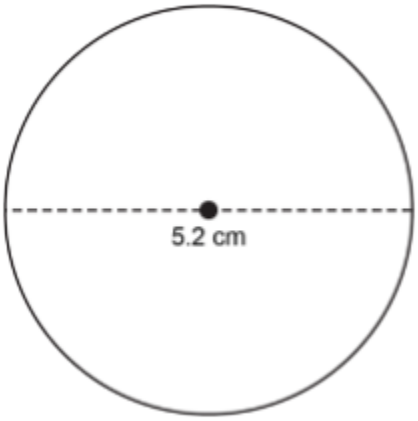


Figure 7 *Finding the circumference of a circle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution

Measure the circumference of the circle. Use the formula:

$$\mathrm{P} = \pi \mathrm{d}$$

$$\mathrm{P} = 3.1416 \times 5.2$$

$$P = 16.33632 \text{ cm} \approx 16.3 \text{ cm}$$

The symbol ≈ means “approximately equal to”

Find the perimeter of the semicircle in Figure 8. Round to one decimal place.

Solution

Measure the diameter. Find the perimeter of the semicircle.

$$P = \pi d \div 2 \quad P = 3.1416 \times 5.8 \text{ cm} \div 2 \quad P = 18.22128 \text{ cm} \div 2 \quad P = 9.11064 \text{ cm}$$

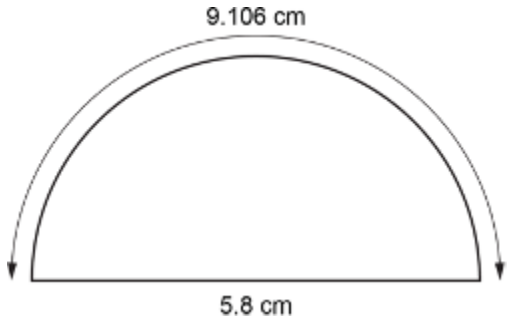


Figure 8 *Finding the perimeter for a semicircle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Now add the diameter length and round the answer to one decimal place.

$$9.11064 + 5.8 \text{ cm} = 14.91064 \approx 14.9 \text{ cm}$$

Area

Area tells us how much surface a shape covers. In the piping and construction trades, we use area to estimate material, plan layouts, and interpret drawings. Area is always expressed in square units, such as square metres (m²), square feet (ft²), or square inches (in²). To calculate area, we multiply one dimension by another. For example, length × width for a rectangle.

Working With Area Units

Because drawings, specifications, and tools can use different units, you will often need to convert between square units. It’s important to remember that square units do not convert the same way ***linear units*** do. For example, since there are 12 inches in a foot, there are 144 square inches in a square foot (12 × 12). This is why converting area requires multiplying or dividing by the square of the ***linear conversion factor***.

In practice, very small units like square millimetres can lead to extremely large numbers, so tradespeople typically

convert their measurements to metres or feet first before calculating area. This keeps the math simple and the results easy to understand.

Area of a Square or Rectangle

This very basic area calculation is simply the length multiplied by the height or width of the surface. Remember to keep the units in the calculation, as they act as a guide in the resulting units in the answer. For example, if you have inches times inches, you end up with an answer in square inches (in.^{2}).

Example:

Find the area of the rectangle in Figure 9.

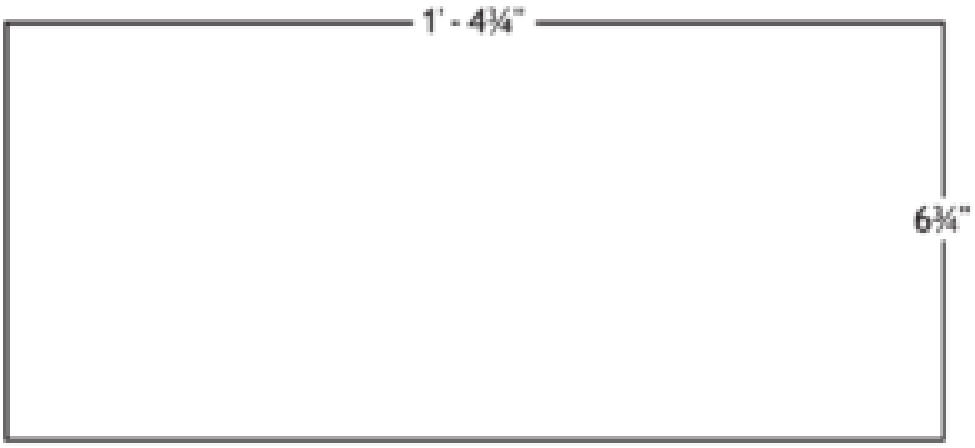


Figure 9 *Illustration for example (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Convert the given dimensions to inches:

$$1'4\frac{3}{4}" = 16.75" \quad 6\frac{3}{4}" = 6.75"$$

Step 2: Solve for the area using $\mathrm{A} = \mathrm{L} \times \mathrm{W}$:

$$\mathrm{A} = 16.75 \times 6.75 \quad \mathrm{A} = 113.07 \text{ in.}^2$$

Area of a Triangle

A triangle's surface is essentially half of a rectangle. To determine the area of a triangle, calculate one half of the area of a rectangle with the same length and width:

$$\text{AREA} = \frac{\text{B} \times \text{H}}{2}$$

This calculation is shown in the example below, using a simple right-angled (90°) triangle.

Example:

Step 1: Convert the millimetres to metres:

$$\text{B} = 0.92 \text{ m } (920 \text{ mm}) \quad \text{H} = 0.81 \text{ m } (810 \text{ mm})$$

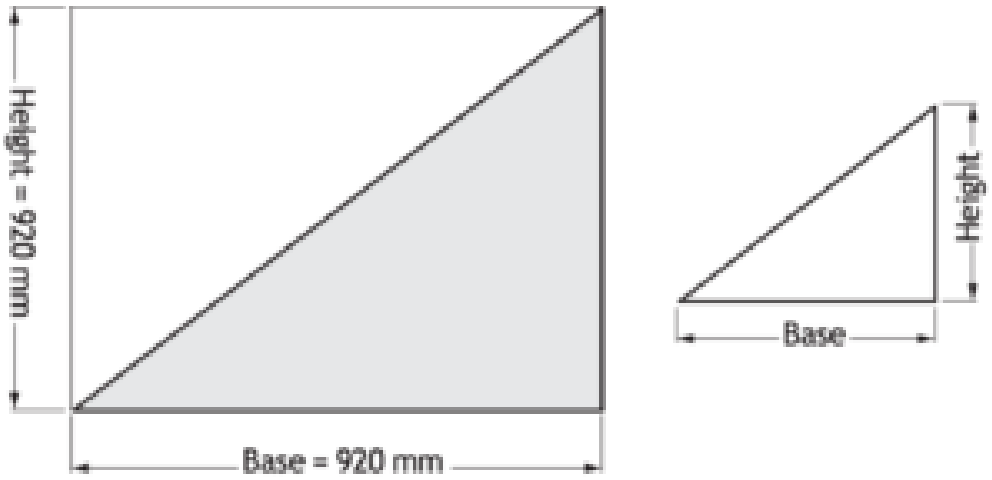


Figure 10 *Illustration for Step 2 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 2: Calculate total surface area:

$$\text{A} = \frac{\text{B} \times \text{H}} \quad \text{A} = \frac{0.92 \times 0.81}{2} \quad \text{A} = 0.373 \text{ m}^2$$

The area of the rectangle would be 0.745 m^2, and the triangle has half that area, or 0.373 m^2.

Area of a Circle

The area of a circle can be calculated by taking the radius of the circle, squaring it, and multiplying by π:

$$\text{A} = \pi \text{r}^2$$

When using the above formula, ensure that you use the radius. Often the diameter of the circle is given, and it must be divided in half to get the radius.

As pipe trades workers, we are usually dealing with the diameter of pipe. If you find it easier, the area of a circle can be found by taking the diameter squared times 0.7854:

$$A = d^2 \times 0.7854 \quad \text{Note: } 0.7854 \text{ is } \frac{1}{4} \text{ of } \pi$$

Example:

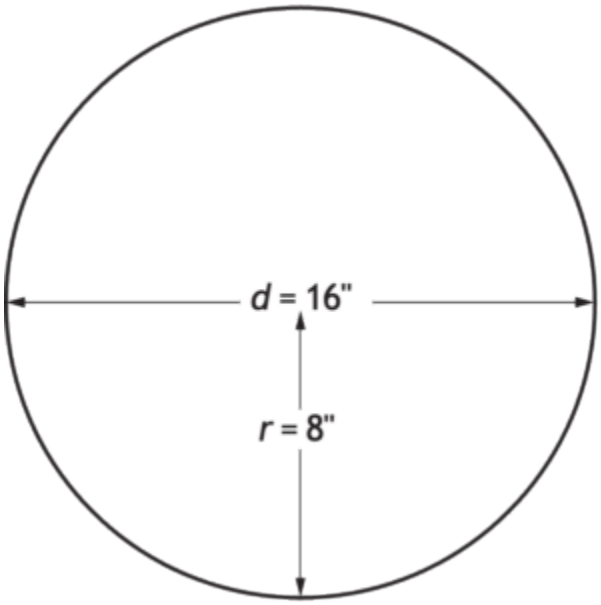


Figure 11 *Illustration for example (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Find the area of the circle shown in Figure 11 using $A = \pi r^2$:

$$A = \pi \times 8^2 \quad A = \pi \times 64 \quad A = 201.06 \text{ in.}^2$$

Find the area of the same circle using $d^2 \times 0.7854$:

$$A = 16^2 \times 0.7854 \quad A = 256 \times 0.7854 \quad A = 201.06 \text{ in.}^2$$

Surface Area of a Square or Rectangular Box

A square or rectangular box has a total of six sides: top and bottom, front and back, and right and left ends (Figure 12). The total surface area of the box is calculated simply by finding the area of each side and adding the areas together.

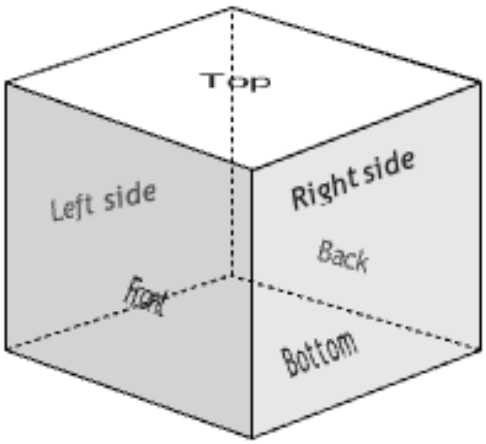


Figure 12 *Surface area of a box (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Note that if the top is open (missing), there are only five sides.

Example:

Calculate the surface area of the totally enclosed rectangular tank shown below.

$$\text{Surface area} = 2(\text{L} \times \text{H}) + 2(\text{L} \times \text{W}) + 2(\text{W} \times \text{H})$$

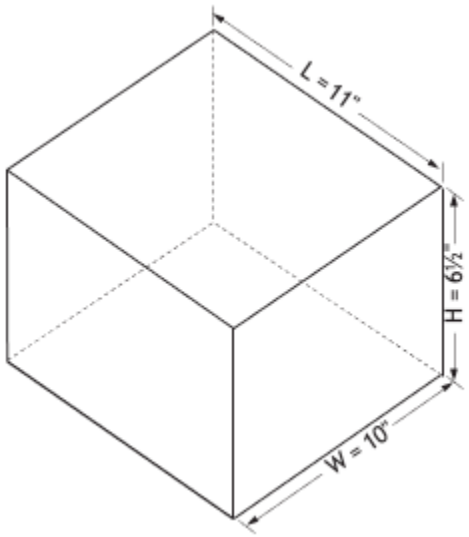


Figure 13 *Calculate surface area (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

$\text{SA} = (\text{two front areas}) + (\text{two top areas}) + (\text{two side areas}) \quad \text{SA} = (\text{L} \times \text{H} \times 2) + (\text{L} \times \text{W} \times 2) + (\text{W} \times \text{H} \times 2) \quad \text{SA} = (11 \times 6.5 \times 2) + (11 \times 10 \times 2) + (10 \times 6.5 \times 2) \quad \text{SA} = 143 + 220 + 130 \quad \text{SA} = 493\ \text{in.}^2$

Area of a Cylinder

A cylinder has three components: two circular ends, which are identical, and a shell (which is really a rolled-up flat sheet or rectangle). The surface area of the cylinder is the sum of the areas of the two circles (ends) and the "rectangle" (shell). If it is an open top tank or vat, there is only one end in the calculation.

The area of the shell (or rectangle) is L × W. The length of the rectangle is the same dimension as the circumference of the end. The width of the rectangle is the same dimension as the height of the cylinder (Figure 14).

To find the circumference of a circle, you multiply the diameter by π:

$$C = \pi d$$

The area of the shell is:

$$A = \pi d \times H, \text{ or } \pi DH$$

The area of each end is:

$$d^2 \times 0.7854.$$

Therefore the formula for the **surface of a cylinder** closed at both ends is:

$$\text{Surface area} = (\pi dH) + (2 \times d^2 \times 0.7854)$$

If one end is open, the formula becomes:

$$\text{Surface area} = (\pi dH) + (d^2 \times 0.7854)$$

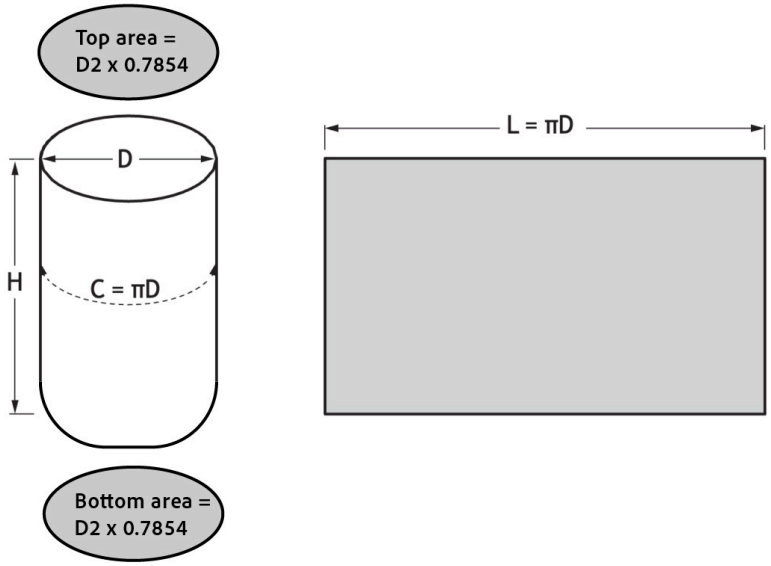


Figure 14 *Area of a cylinder* (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

Example:

Calculate the surface area of the totally enclosed cylinder in Figure 16:

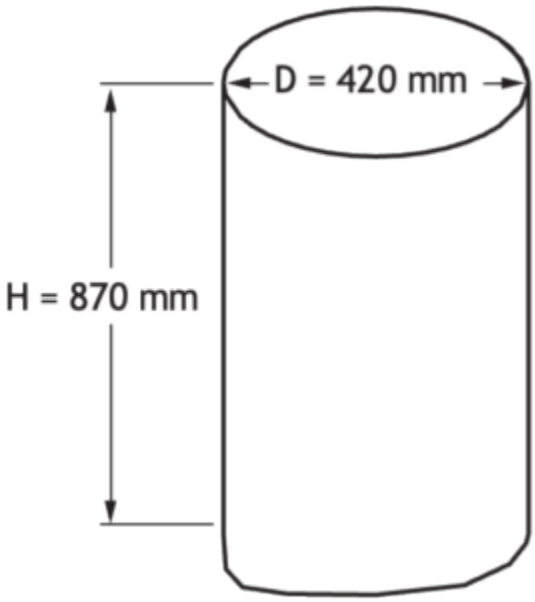


Figure 15 *Illustration for example (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Convert the millimetres to metres:

$$\mathrm{d} = 0.42 \text{ m } (420 \text{ mm}) \quad \mathrm{r} = 0.21 \text{ m } (210 \text{ mm}) \quad \mathrm{H} = 0.87 \text{ m } (870 \text{ mm})$$

Step 2: Calculate total surface area = $(\pi \mathrm{DH}) + (2 \times \mathrm{D}^2 \times 0.7854)$:

$$\mathrm{SA} = (\pi \times 0.42 \times 0.87) + (2 \times 0.42^2 \times 0.7854) \quad \mathrm{SA} = 1.425 \text{ m}^2$$

The total surface area of the totally enclosed cylinder is 1.425 m^2. If the tank or vat had an open top, the resulting surface area would be minus the area of one end or 1.286 m^2.

Self-Test C-1.3: Use Formulas to Calculate Perimeter, Circumference and Area

Complete Self-Test C-1.3 and check your answers.

Complete the following questions. Use the π key on your calculator or 3.1416, when required.

If you are using a printed copy, please find Self-Test C-1.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2421#h5p-7

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- Steamfitter: Competency C-1 Use Mathematics and Science
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C-1.4 Use Formulas to Calculate Volumes

In this section, you will learn how to calculate the ***volume*** of common shapes used in the plumbing trade, including tanks and cylinders. Volume tells us how much space an object can hold, which is important when working with water, gas, and other materials in piping systems. You will learn and apply formulas to calculate volume using consistent ***units***, and practise solving real-world problems related to capacity and storage. These skills are essential for ensuring systems are sized correctly and operate safely and efficiently.

Volume

The definition of volume is the amount of space occupied by a ***three-dimensional (3D)*** object, expressed in ***cubic units***. The term ***volume*** is often expressed as the holding ***capacity*** or the number of cubic units enclosed within an object such as a vat or tank. We can calculate volume using formulas based on the shape of the object. Before calculating volume, all ***dimensions*** must be in the same units, so you may have to convert one or more of the dimensions before calculating to solve the problem.

Volumes are measured in cubic units. The imperial system of volume measurement includes the following typical units:

- Cubic inches
- Cubic yards
- Cubic feet
- Gallons

The metric system of volume measurement includes the following typical units:

- Cubic centimetres
- Cubic metres
- Litres

Volume calculations are three dimensional. They involve three dimensions: ***length***, ***width***, and ***height***. For example, when we multiply the length dimension of a tank (in feet) times the width dimension (in feet) times the height dimension (in feet), we get the volume or capacity measurement of the tank, in cubic feet. So the unit multiplication ft × ft × ft gives the answer ft^3 (or cu. ft). Similarly, the metric unit multiplication m × m × m gives the answer m^3 (or cu. m).

Volume of a Rectangular Tank

Key idea: Volume = length × width × height (for rectangular shapes).

For example, if you have a cube that is 12″ by 12″ by 12″, as shown in Figure 1, you could determine there would be 1,728 one-inch cubes that will fit into the larger cube. Another way of calculating volume is to find the area of the base and multiply that area by the height.

$$\text{Area} \times \text{height} = \text{volume}$$

In the case of a square tank where all sides are equal, you can find the volume (V) by cubing the length of one side (S^3):

$$V = S^3 \quad V = 12^3 \quad V = 1,728 \text{ in.}^3$$

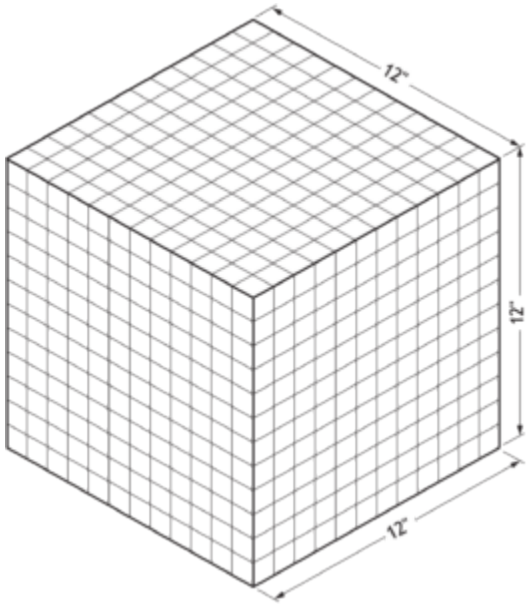

Figure 1 *12 × 12 × 12 cube (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

When solving for a ***rectangular tank***, the volume (V) can be calculated by multiplying the length (L) by the width (W) by the height (H):

$$V = L \times W \times H$$

Example 1:

A rectangular tank has a length of 5′ 3″, a width of 2′ 9″ and a height of 1′ 8″. What is the volume in cubic feet?

Solution:

The first step and most important step is to determine what units you are going to work with.

For the example, you must decide between feet and inches. It is essential that you convert the dimensions to one common unit. It doesn't really matter which one you choose, but all dimensions must be in the same units.

For example, if we used feet, then:

$$\text{Length} = 5\text{'}3\text{''} = 5.25\text{'} \quad \text{Width} = 2\text{'}9\text{''} = 2.75\text{'} \quad \text{Height} = 1\text{'}8\text{''} = 1.667\text{'} \quad V = L \times W \times H \quad V = 5.25\text{'} \times 2.75\text{'} \times 1.667\text{'} = 24.067 \text{ ft}^3$$

If we used inches, then:

$$\text{Length} = 5\text{'}3\text{''} = 63\text{''} \quad \text{Width} = 2\text{'}9\text{''} = 33\text{''} \quad \text{Height} = 1\text{'}8\text{''} = 20\text{''} \quad V = L \times W \times H \quad V = 63\text{''} \times 33\text{''} \times 20\text{''} = 41,580 \text{ in.}^3$$

Or

$$\frac{41,580 \text{ in.}^3}{1,728 \frac{\text{in.}^3}{\text{ft}^3}} = 24.063 \text{ ft}^3$$

The slight difference between the two answers is the result of rounding off the decimals in the conversion of inches to feet. If all of the decimals are used, the difference becomes even less. In answering exercise problems, either answer is acceptable, but note that, for the greatest accuracy, the use of inches produces a more accurate answer.

Example 2:

A rectangular tank has a length of 3.21 m, a width of 4.73 m, and a height of 1,400 mm. What is the volume in cubic metres?

Solution:

The first step is to decide what units you are going to work with. In this example, you have a choice of metres or millimetres. Because a millimetre is a very small unit of measurement, it is recommended to convert millimetres to metres before substituting into the formula for all volume questions.

$$\text{Length} = 3.21 \text{ m} \quad \text{Width} = 4.73 \text{ m} \quad \text{Height} = 1,400 \text{ mm} = 1.4 \text{ m} \quad \text{V} = \text{L} \times \text{W} \times \text{H} \quad \text{V} = 3.21 \text{ m} \times 4.73 \text{ m} \times 1.4 \text{ m} = 21.257 \text{ m}^3$$

Volume of a Cylinder

Finding the volume of a *cylinder* requires two calculations:

First, calculate the area of the base in the same way that you would find the area of a circle $(\text{d}^2 \times 0.7854)$.

Note: The value 0.7854 is equal to π ÷ 4, so this formula is another way of writing πr² using diameter instead of *radius*.

Second, multiply the base area by the height of the cylinder $(\text{d}^2 \times 0.7854 \times \text{H})$.

The height of the cylinder is opposite to the round end, no matter which position the cylinder is in (Figure 2).

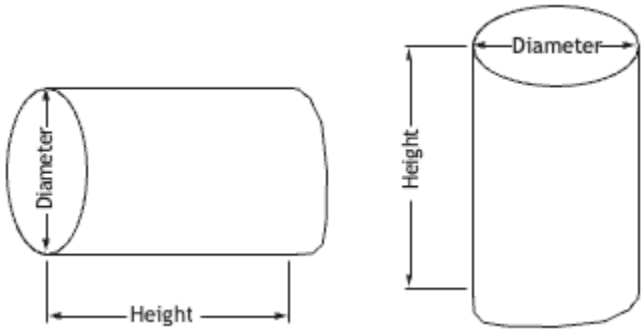

Figure 2 *Dimensions of a cylinder (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 1:

A cylindrical tank has a ***diameter*** of 4′ 9″ and a height of 11′ 3″. What is the volume of the tank in ft^3?

Solution:

Change all of the dimensions to feet:

$$\text{Diameter} = 4\text{'}9\text{''} = 4.75\text{'} \quad \text{Height} = 11\text{'}3\text{''} = 11.25\text{'} \quad V = d^2 \times 0.7854 \times H \quad V = 4.75^2 \times 0.7854 \times 11.25 \quad V = 199.357\ ft^3$$

Example 2:

A cylindrical tank has a diameter of 1,200 mm and a height of 3,700 mm. What is the volume of the tank in m^3?

Solution:

Change the dimensions to metres:

$$\text{Diameter} = 1,200\ mm = 1.2\ m \quad \text{Height} = 3,700\ mm = 3.7\ m \quad V = d^2 \times 0.7854 \times H \quad V = 1.2^2 \times 0.7854 \times 3.7 \quad V = 4.185\ m^3$$

Self-Test C-1.4: Use Formulas to Calculate Volumes

Complete Self-Test C-1.4 and check your answers.

If you are using a printed copy, please find Self-Test C-1.4 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2423#h5p-8

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C-1.5 Use Formula to Calculate Capacity

Capacity vs. Volume

The definitions of volume and capacity are very similar, and the two terms are often used interchangeably. However, there is an important difference:

- ***Volume*** is the amount of space an object takes up.
- ***Capacity*** is the measure of how much a container can hold.

Volume is measured in ***cubic units*** (such as cubic metres or cubic feet), while capacity is usually measured in ***liquid units*** (such as litres or gallons). The cubic metre and cubic centimetre are most often used to measure the volume of solid objects, while kilolitres, litres, and millilitres are used to measure fluid (liquid and gas) volumes. In some trade applications, capacity may also be expressed in other units. For example, propane stored in a cylinder or tanks is measured in US gallons or pounds of liquid propane.

For safety, containers are often not filled to their full volume. This reduced amount is called ***design capacity***. For example, a propane cylinder may have an internal volume of 2 ft^3, but its design capacity would be 80% of that volume (as specified by codes and standards), or 1.6 ft^3. This 20% reduction allows space for thermal expansion of the liquid and for vapour storage for use by the appliance. This concept will be discussed further in later sections.

Converting Volumes to Capacities

When working in the trades, you will often need to convert between volume and capacity. This means converting from cubic units (such as ft^3 or m^3) to liquid units (such as litres or gallons). The "³" in volume measurements means "cubed," which tells us the measurement is in three dimensions (length × width × height).

Volume and Capacity Relationships

Some volume and capacity relationships are as follows:

Table 1: Volume and Capacity Relationships

Unit	Symbol	Relationship
kilolitre	kL	1 kL = 1000 L
cubic metre	m^3	1 m^3 = 1 kL
litre	L	1 L = 1000 mL
cubic centimetre	cm^3	1 cm^3 = 1 mL
millilitre	mL	1 mL = 1 cm^3

Common Trade Conversions

To convert volumes to capacities, Use the following:

- **cubic feet → imperial gallons:** multiply by $6.24 \frac{\text{imp. gal.}}{\text{ft}^3}$
- **cubic feet → US gallons:** multiply $7.48 \frac{\text{US gal.}}{\text{ft}^3}$
- **cubic inches → imperial gallons:** divide by $277 \frac{\text{in.}^3}{\text{imp. gal.}}$
- **cubic inches → US gallons:** divide by $231 \frac{\text{in.}^3}{\text{US gal.}}$
- **cubic metres → litres:** multiply by $1,000 \frac{\text{L}}{\text{m}^3}$

Additional Useful Relationships

$$1 \text{ imperial gallon (water)} = 10 \text{ pounds (lb.)} \quad 1 \text{ US gallon (water)} = 8.333 \text{ pounds (lb.)} \quad 1 \text{ litre (water)} = 1 \text{ kg}$$

Example 1:

What would be the capacity in imperial gallons of a storage tank with a volume of 29 ft^3?

Solution:

$$29 \text{ ft}^3 \times 6.24 \frac{\text{imperial gallons}}{\text{ft}^3} = 180.96 \text{ imp. gallons}$$

Example 2:

What would be the capacity in US gallons of a storm sump with a volume of 84 ft^3?

Solution:

$$84 \text{ ft}^3 \times 7.48 \frac{\text{US gallons}}{\text{ft}^3} = 628.32 \text{ US gallons}$$

Example 3:

What is the volume of a tank that has a capacity of 1,700 litres?

Solution:

$$\frac{1,700 \text{ litres}}{1,000 \frac{\text{litres}}{\text{m}^3}} = 1.7 \text{ m}^3$$

Self-Test C-1.5: Use Formula to Calculate Capacity

Complete Self-Test C-1.5 and check your answers.

If you are using a printed copy, please find Self-Test C-1.5 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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C-1.6 Perform Conversions

Metric System

The ***International System of Units*** (SI, from the French *Le Système international d'unités*) is the modern The International System of Units (SI) is the modern version of the ***metric system*** and is the most widely used system of measurement in the world—used in both everyday commerce and science.

In the United States, metric units are not commonly used outside of science, medicine, and the government. In Canada, both metric and imperial units are used. While metric units are standard for science and government, imperial units are still common in the building trades. As a result, trades workers must be comfortable working in both systems.

In the metric (SI) system, there is a standard unit for each type of measurement. The ***metre*** is used for length or distance, the ***gram*** is used for weight or ***mass***, and the ***litre*** is used for ***capacity*** or ***volume***. There is also a series of prefixes that are added to the standard units to indicate measures greater than the standard units or less than the standard units.

Many consider the metric system to be easier to use than the ***imperial system***. One reason is that all measures greater than or less than the standard unit are in powers of 10. Changing from larger to smaller, or from smaller to larger measures simply requires multiplying or dividing by 10 or a power of 10. Another reason the metric system is easier to use than the imperial system is that the prefixes used with the standard unit represent the power of 10 by which the standard unit is to be divided or multiplied.

Prefixes of the Metric System

Before we start our study of metric measurements, look at the ***prefixes*** that are used in the metric system. Keep in mind that the prefix will have the same meaning no matter which unit (metre, gram, or litre) the prefix is attached to.

The prefixes used in this section for *smaller* units than the standard unit are:

$$\text{deci} = \frac{1}{10} \text{ of} \quad \text{centi} = \frac{1}{100} \text{ of} \quad \text{milli} = \frac{1}{1,000} \text{ of}$$

The prefixes used for *larger* units than the standard unit are:

$$\text{deca} = 10 \text{ times} \quad \text{hecto} = 1,00 \text{ times} \quad \text{kilo} = 1000 \text{ times}$$

There are other prefixes that are used with very large and very small measures, but they will not be discussed in this section.

The use of prefixes can be related to our ***decimal system*** of numeration. Let's compare our decimal-place-value chart, shown below, with these prefixes. The standard unit (whether metre, gram, or litre) corresponds to the *ones* place. All the places to the left are powers of the standard unit. That is, the value of *deca-* is 10 times the standard unit; the value of *hecto-* is 100 times this unit; the value of *kilo-* is 1,000 times this unit; and so on.

All the places to the right of the standard unit are subdivisions of the standard unit. That is, the value of *deci-* is $\frac{1}{10}$ of the standard unit; the value of *centi-* is $\frac{1}{100}$ of this unit; the value of *milli-* is $\frac{1}{1,000}$ of this unit; and so on.

Table 1: Metric Prefixes

Prefix	Abbreviation	Unit Place Value
Kilo	**k**	Thousands (1,000)
Hecto	**h**	Hundreds (100)
Deca	**da**	Tens (10)
Standard Unit		Units of Ones (1)
Deci	**d**	Tenths ($\frac{1}{10}$)
Centi	**c**	Hundredths ($\frac{1}{100}$)
Milli	**m**	Thousandths ($\frac{1}{1,000}$)

Fractions and Decimals in the Trades

In the piping trades, measurements are often written as fractions (such as $\frac{1}{2}''$ or $\frac{3}{4}''$) or as decimals (such as 0.50 or 0.75). Being able to change between fractions and decimals is an important skill when reading drawings, using measuring tools, and completing calculations.

Changing a fraction to a decimal:
Divide the top number (numerator) by the bottom number (denominator).

Example:

$$\frac{3}{4} = 3 \div 4 = 0.75$$

Changing a decimal to a fraction:
Write the decimal as a fraction over 10, 100, or 1000, then simplify if needed.

Example:

$$0.75 = \frac{75}{100} = \frac{3}{4}$$

Why This Matters in Plumbing

Tradespeople often:

- Read measurements on drawings that use fractions
- Use calculators or formulas that give answers in decimals
- Convert between systems (imperial and metric)

Being able to switch between fractions and decimals helps ensure accurate measurements, proper fitting, and safe installations.

Convert Length, Area, Volume, Weight, and Capacity

Measures of Length

Metre: The metre is the standard unit for measuring length. One metre is equal to 3.281 ft or 39.37 in. The metre is the appropriate unit to use to measure lengths and distances like room dimensions, site dimensions and heights of buildings. The abbreviation for metre is "m".

Kilometre: To measure long distances, a larger measuring unit is typically used. One kilometre is 1,000 metres and is used for these longer distances. The abbreviation for kilometre is km. The prefix *kilo* attached to the word *metre* means "1,000."

Centimetre: When measuring objects less than 1 m long, one of the most common units used is the centimetre (cm).

Since the prefix *centi-* means "$\frac{1}{100}$ of," a centimetre is one hundredth of a metre. One centimetre is about the width of a thumbtack head, somewhat less than "$\frac{1}{2}$".

Millimetre: Many objects are too small to be measured in centimetres, so an even smaller unit of measure is needed. One millimetre (mm) is $\frac{1}{1,000}$ of a meter, or about the thickness of a plastic credit card or a dime. Many modern projects will state the size of pipe and fittings in millimetres.

Other units and their abbreviations are decimetre (dm), decametre (dam) and hectometre (hm).

Measures of Area and Volume

Square metre: A square metre occupies an area that is 1 metre long and 1 metre wide. It is a little larger than a square yard since the metre is a little longer than a yard. A square that is 10 metres on each side would have an area of 100 square metres.

There are 1,000,000 square metres in a square kilometre, just as there are 1,000,000 square millimetres in a square metre. For comparison, you might think of a square millimetre as the area of a pinhead and a square metre as the area of a desktop. The 10-metre square (10 m × 10 m) or *area* is about the floor area of a large classroom, and the 100-metre square (100 m × 100 m) or *hectare* is about the area of two football fields. The square kilometre is about 200 acres, or roughly a third of a square mile.

Cubic units were used to measure volumes long before the metric system was defined. Cubic inches of ice (ice cubes), cubic feet of gas (measured through a gas meter) and cubic yards of dirt, gravel or concrete are still in common use. The cubic metre is 30% larger than the cubic yard. There are exactly 1 billion cubic millimetres in a cubic metre, and 1 billion cubic metres in a cubic kilometre.

Calculating area (square units) and volume (cubed units) in the metric system is done in the same way as with the imperial system. Only the units of measure change.

Area of a Rectangle: $\text{Area} = \text{length} \times \text{width}$

Example:
A sheet of material is 2.5 m long and 1.2 m wide.

$$\text{Area} = 2.5 \times 1.2$$

$$\text{Area} = 3.0 \text{ m}^2$$

The area of the sheet is **3.0 m²**

Area of a Circle: $\text{Area} = \text{d}^2 \times 0.7854$

Example:
A pipe has a diameter of 0.4 m.

$$\text{Area} = (0.4)^2 \times 0.7854$$

$$\text{Area} = 0.16 \times 0.7854$$

$$\text{Area} = 0.1257 \text{ m}^2$$

The cross-sectional area of the pipe is **0.126 m²** (rounded)

Volume of a rectangular solid: $\text{Volume} = \text{length} \times \text{width} \times \text{height}$

Example:
A tank is 2.0 m long, 1.5 m wide, and 1.2 m high.

$$\text{Volume} = 2.0 \times 1.5 \times 1.2$$

$$\text{Volume} = 3.6\ \text{m}^3$$

The volume of the tank is **3.6 m³**

Volume of a cylinder (pipe): $$\text{Volume} = \text{d}^2 \times 0.7854 \times \text{H}$$

Example:
A pipe has a diameter of 0.3 m and a length (height) of 5 m.

$$\text{Volume} = (0.3)^2 \times 0.7854 \times 5$$

$$\text{Volume} = 0.09 \times 0.7854 \times 5$$

$$\text{Volume} = 0.3534\ \text{m}^3$$

The volume inside the pipe is **0.353 m³**

Measures of Weight

Gram: The standard unit for measuring weight in the metric system is the gram. A gram is described as the weight of 1 cubic centimetre (cm^3) of water. A cubic centimetre is a cube in which each edge is equal to 1 centimetre in length. It is a little smaller than a sugar cube. The abbreviation g is used for gram. The gram is used for measuring small, light objects.

Kilogram: One kilogram (kg) is 1,000 grams. Since a cube 10 cm on each edge (1 dm^3) can be divided into 1,000 cm^3, the weight of the amount of water required to fill this cube would be 1,000 grams or 1 kilogram. One kilogram is equivalent to approximately 2.2 lb.

Milligram: The milligram ($\frac{1}{1,000}$ of a gram) is used to measure very small weights. Milligrams (mg) are used when measuring very small amounts of chemicals that may be present in a fluid sample, for example. One $\frac{\text{mg}}{\text{L}}$ is equal to one part per million (ppm) when discussing mineral concentrations in water treatment systems.

Other units and their abbreviations are decigram, dg; centigram, cg; decagram, dag; and hectogram, hg.

Measures of Capacity

Litre: One litre (L) is the volume of a cube 10 cm on each edge, equal to one decimetre (dm). It is the standard metric unit of capacity. Since a cube 10 cm on each edge filled with water (at 4°C) weighs 1 kg, then 1 L of water weighs 1 kg. One litre is just a little smaller than a liquid quart (an imperial unit for measuring capacity). There are nearly four litres per US gallon, and approximately 4.5 litres per imperial gallon. Water storage tanks are often listed by their capacity in litres.

Millilitre: Since one litre is 1,000 cm^3, one millilitre has the same capacity or volume as a cubic centimetre. Most liquid medicine is labelled and sold in millilitres (mL) or cubic centimetres (cc or cm^3). Liquids available in very small quantities are measured in millilitres.

Some other units and their abbreviations are decilitre (dL); centilitre (cL); decalitre (daL); hectolitre (hL); and kilolitre (kL).

Example:

If you were to find the capacity of the pipe from our **Volume of a Cylinder (Pipe)** example above:

Convert to Litres (Capacity)

Since the volume of inside the pipe is **0.353 m^3**:

$$1\ \mathrm{m}^3 = 1000\ \mathrm{L}$$

$$0.3534 \times 1000 = 353.4\ \mathrm{L}$$

The pipe can hold **353.4 L of water**

Imperial to Metric (SI) Conversions

Learning to convert between the imperial system and the metric (SI) system is important because both systems are used in the piping trades. While working within one system is straightforward, converting between systems requires careful attention.

To convert measurements, you only need one ***conversion factor*** for each type of measurement (length, area, volume, mass, and capacity).

It is important to note that U.S. and imperial measurements are not the same, particularly for capacity. For example, a U.S. gallon is 32 ounces, or 3.785 L, while an imperial gallon is 40 ounces, or 4.546 L. Because of these differences, always make sure you are using the correct conversion factor for the system specified in your problem.

Table 2 lists commonly used conversion factors between metric and imperial units. Some values have been rounded for practical use in the trades.

Note: It is not necessary to memorize these values. In practice, tradespeople refer to charts, calculators, or reference manuals when performing conversions.

Table 2: Factors for Converting Between Metric and Imperial Measures

From	To	Multiply by
inches	millimetres	25.4
millimetres	inches	0.0394
inches	centimetres	2.54
centimetres	inches	0.3937
feet	metres	0.3048
metres	feet	3.281
yards	metres	0.9144
metres	yards	1.094
miles	kilometres	1.609
kilometres	miles	0.6214
sq. inches	sq. centimetres	6.452
sq. centimetres	sq. inches	0.155
sq. metres	sq. feet	10.76
sq. feet	sq. metres	0.0929
sq. yards	sq. metres	0.8361
sq. metres	sq. yards	1.196
sq. miles	sq. kilometres	2.589
sq. kilometres	sq. miles	0.3861
acres	hectares	0.4047
hectares	acres	2.471
cu. inches	cu. centimetres	16.39
cu. centimetres	cu. inches	0.06102
cu. feet	cu. metres	0.02832
cu. metres	cu. feet	35.315
cu. yards	cu. metres	0.7646
cu. metres	cu. yards	1.308
cu. inches	litres	0.01639
litres	cu. inches	61.03
imp. pints	litres	0.5682

litres	imp. pints	1.76
US pints	litres	0.47311
litres	US pints	2.114
US gallon	litres	3.785
imp. gallons	litres	4.546
litres	US gallons	0.2642
litres	imp. gallons	0.22
grains	grams	0.0648
grams	grains	15.43
ounces	grams	28.35
grams	ounces	0.03527
pounds	grams	453.6
grams	pounds	0.002205
pounds	kilograms	0.4536
kilograms	pounds	2.205
tons	kilograms	1,016.05
kilograms	tons	0.0009842

Self-Test C-1.6.1: Perform Conversions

Complete Self-Test C-1.6.1 and check your answers.

If you are using a printed copy, please find Self-Test C-1.6.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2427#h5p-10

Convert Heat Energy, Temperature, and Pressures

Heat Energy Conversions

Heat energy can be measured in many different units. The most common units for heat are:

- British thermal unit (BTU)
- kilowatt hour (kWh)
- calorie (cal)
- joule (J)

British Thermal Unit (BTU): The unit of energy in the imperial system—the BTU—is the amount of heat required to raise or lower the temperature of one pound of water 1 °F. BTUs are commonly used in heating systems to describe how much heat energy is produced. One BTU is approximately equal to the energy released when a wood match burns. How quickly this energy is converted to do work is a measurement of power. Typically, in the piping industry, power requirements and outputs are calculated on a per-hour basis. For example, heating 100 pounds of water 100°F would require 100,000 BTUs of energy; doing that amount of work in 2 hours would require a power output of 50,000 BTU *per hour*, whereas it would require 200,000 $\frac{\text{BTU}}{\text{hr}}$ for an appliance to perform that work in 30 minutes.

$$1 \text{ BTU} = 1,055 \text{ joules} = 0.00029295 \text{ kilowatt hours} = 252 \text{ calories}$$

A boiler firing at 1 kilowatt generates the equivalent of 3,412 BTU of heat energy in the combustion chamber.

Calorie: One ***calorie*** is the amount of heat required to raise the temperature of 1 gram of water 1°C. The calorie is outdated and commonly replaced by the metric unit ***joule***.

$$1 \text{ calorie} = 4.187 \text{ joules} = 0.003968 \text{ BTU} = 1.1629 \times 10^{-6} \text{ kilowatt hour}$$

Note: that number is written in ***scientific notation***.

Some very large or very small numbers are written using scientific notation. In general, a number written in scientific notation will be multiplied by 10 raised to an exponent. When the exponent is positive, move the decimal point to the right the number of places indicated by the exponent: $6.45 \times 10^{3} = 6{,}450$

When the exponent is negative, move the decimal point to the left the number of places indicated by the exponent:

$6.45 \times 10^{-3} = .00645$

Joule: A *joule* is the general metric unit in measuring energy. Cooling down a mug of hot coffee to room temperature will free about 100,000 joules. 4.187 joules of heat energy (or 1 calorie) is required to raise the temperature of a unit weight (1 g) of water 1°C.

$$1 \text{ J (joule)} = 0.2388 \text{ calories} = 2.778 \times 10^{-7} \text{ kWh} = 9.478 \times 10^{-4} \text{ BTU} \quad 1 \text{ Gigajoule is } 1{,}000{,}000{,}000 \text{ joules or } 238{,}834{,}488 \text{ calories.}$$

Table 3: Conversion Factors for Energy Units

Metric Units		Imperial Units	
Joules	**Kilowatt Hours**	**Calories**	**BTUs**
1	2.778×10^{-7}	0.2388	0.0009478
4.187	1.1629×10^{-6}	1	0.003968
1,055	0.00029295	252	1
3,600,000	1	859,824	3,412

Power

Power is the rate of doing work. It is the equivalent to an amount of energy used per unit of time.

Kilowatt (kW): The ***kilowatt*** is the metric unit typically used for power. The watt is named after Scottish engineer James

Watt, who pioneered the success of the steam engine. Watts are a measurement of the rate of energy transfer and are equal to 1 joule per second ($\frac{\text{J}}{\text{sec}}$).

$$1 \text{ kilowatt} = 1,000 \text{ watts} = 3,412 \frac{\text{BTU}}{\text{hr}} = 3,600,000 \frac{\text{joules}}{\text{hr}} = 859,824 \frac{\text{calories}}{\text{hr}} \quad = 0.0036 \text{ Gigajoules}$$

A furnace operated at a rate of 100,000 BTU per hour is operating at a rate of 29.3 kilowatts.

Temperature Conversions

Many vocational-technical applications require conversions between different temperature scales. In this section, we will be concerned with temperature conversions involving the Celsius, Kelvin, Rankin and Fahrenheit scales.

Celsius–Kelvin Conversions

One scale used to measure temperature in the metric system of measurement is called the ***Kelvin scale***. Units on this scale are abbreviated with a capital K (without the symbol ° because these units are simply called *Kelvins*) and are measured from absolute zero, the temperature at which all heat is said to be removed from matter. Another metric temperature scale is the ***Celsius scale*** (abbreviated °C), sometimes referred to as the centigrade scale, which has zero as the freezing point of water. Kelvin is often used in science, while Celsius is used in everyday temperature measurements. The Kelvin and Celsius scales are related, so that each unit of change on the Kelvin scale is equal to one degree of change on the Celsius scale. That is, the size of a Kelvin and a Celsius degree are the same on both scales. Absolute zero (the zero for the Kelvin scale) corresponds to 273 degrees below zero on the Celsius scale.

To convert Celsius to Kelvin:

K = °C + 273

$$\text{K} = {}^{\circ}\text{C} + 273$$

To convert Kelvin to Celsius:

°C = K – 273

$${}^{\circ}\text{C} = \text{K} - 273$$

Rankin–Fahrenheit Conversions

The imperial system temperature scale that starts at absolute zero is called the ***Rankin scale***. It is related to the ***Fahrenheit scale***, which places the freezing point of water at 32 °F. The Rankin (°R) and Fahrenheit (°F) scales have the same relationship as the Kelvin and Celsius scales in the metric system. That is, one degree of change on the Rankin

scale is equal to one degree of change on the Fahrenheit scale. Absolute zero (the zero for the Rankin scale) corresponds to 460 degrees below zero on the Fahrenheit scale.

To convert Fahrenheit to Rankin:

$$^{\circ}\mathrm{R} = {}^{\circ}\mathrm{F} + 460$$

To convert Rankin to Fahrenheit:

$$^{\circ}\mathrm{F} = {}^{\circ}\mathrm{R} - 460$$

Because both the Kelvin and Rankin scales originate from absolute zero, their respective temperatures are frequently referred to as the *absolute temperature* of a substance.

Fahrenheit–Celsius Conversions

The Celsius and Fahrenheit scales are the most common temperature scales used for reporting air and fluid temperatures. Since we still use both scales, we need to be able to convert Fahrenheit temperatures to Celsius and Celsius temperatures to Fahrenheit. The formulas used for converting temperatures using these two scales are more complicated than the previous ones because one degree of change on the Celsius scale does not equal one degree of change on the Fahrenheit scale.

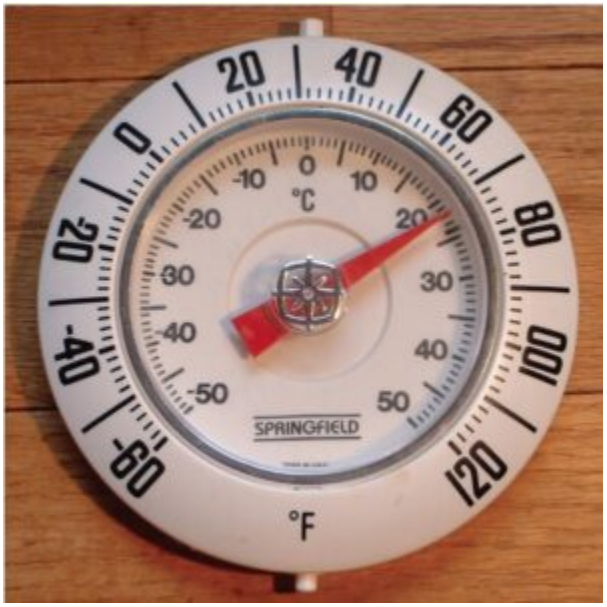

Figure 1 *Thermometer with Fahrenheit and Celcius units (Camosun College/BCcampus) CC BY-NC-SA 4.0*

To convert Fahrenheit to Celsius:

$$^{\circ}\mathrm{C} = \frac{5}{9} \times ({}^{\circ}\mathrm{F} - 32)$$

To convert Celsius to Fahrenheit:

$$^{\circ}\mathrm{F} = \frac{9}{5} \times (^{\circ}\mathrm{C} + 32)$$

Pressure Measurement Conversions

All pressure measurements are ***relative measurements***, which means the measurement of pressure at the measurement point is always relative to a ***reference pressure***. The reference pressure can be local atmospheric pressure, a perfect vacuum or the pressure at some other location. The type of reference pressure partially describes the measurement. Following are definitions of pressure terminology, types of pressure and different ways of measuring pressure.

Atmospheric pressure: There is a layer of atmosphere surrounding the Earth that is held in place by gravity. Although it is only $\frac{1}{100}$ the diameter of the Earth, this film increases in density as it approaches the surface of the Earth. At the surface, the weight of the mixture of mostly nitrogen (78%) and oxygen (21%) that we call ***air*** creates a pressure on the surface of the Earth that we measure at approximately 14.73 psia (pounds per square inch absolute). 14.73 psia is generally accepted as ***atmospheric pressure*** at sea level. This pressure varies depending on your location and altitude.

Gauge pressure: Pressure gauges and most other pressure measuring devices generally measure pressures above atmospheric pressure. In other words, a gauge not attached to any pressure source will show the "gauge" pressure as 0 even though, as stated above, the atmospheric or "absolute" pressure is actually 14.73 *psia*. In general, we are interested in the difference between the atmospheric pressure and what is in our pipe, so we want to know the ***gauge pressure***. This is sometimes referred to as ***overpressure***. For example, if the gauge needle indicates 10 pounds, the pressure in the pipe is 10 pounds greater than the atmospheric pressure, or 10 psig. In psi units, it should be referred to as *psig*, but the "g" is sometimes assumed.

Gauge pressure = the difference between a measured pressure and atmospheric pressure.

Figure 2 *Pressure gauge showing 0 psig (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Absolute pressure: ***Absolute pressure*** is measured relative to absolute zero pressure, which would occur at absolute vacuum, or zero pounds per square inch (0 ***psia***). Absolute pressure is the total pressure, which includes both the pressure you measure (gauge pressure) and the pressure from the air around us (atmospheric pressure). If we add the

gauge pressure of 10 pounds to an atmospheric pressure of 14.73 pounds, we get 24.73 pounds absolute (psia) pressure. This pressure is sometimes referred to as ***total system pressure***.

Absolute pressure = gauge pressure + atmospheric pressure (a "perfect" vacuum).

$$P_{\text{absolute}} = P_{\text{gauge}} + P_{\text{atmospheric}}$$

Vacuum: When atmospheric pressure is removed from a closed vessel, such as an evacuated refrigeration system, a ***vacuum*** is created. A vacuum is created when pressure is lower than atmospheric pressure. The more atmospheric pressure removed, the greater the vacuum. A perfect vacuum is attained only when all atmospheric pressure is exhausted, and is practically impossible to achieve. The amount of vacuum is registered on a ***vacuum gauge***, which operates on the same principle as a ***standard pressure gauge***, except that the face is typically graduated in inches or millimetres of mercury (***in. Hg or mm Hg***) instead of psi. Each inch of graduation is equal to 0.491 pound of absolute pressure.

This mean if the absolute pressure is 10 psia, or 4.73 psi below atmosphere, this would read as 9.6 in. of Hg vacuum (245 mm or Hg vacuum). At 0 psia, a perfect vacuum, this measures approximately 29.92 in. of Hg vacuum (760 mm Hg vacuum). As the vacuum increases (pressure decreases), the mercury reading (in. Hg or mm Hg) becomes larger.

More vacuum = higher Hg reading

or

Low pressure = high vacuum = high Hg reading

$$(0.491 \frac{\text{lb.}}{\text{in.}^3} \times 30 \text{ in.} = 14.73 \text{ psia})$$

Figure 3 *Compound Vacuum and Pressure Gauge (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Differential pressure: For applications like backflow prevention, you need to know ***differential pressures***, or the difference between two measured pressures. Differential pressure measurements are designated with the suffix "d." so that in imperial units the pressure might be measured in ***psid***, meaning *pounds per square inch differential*. Often differential pressure is stated as *delta* P, or ΔP.

Note that the use of the Greek letter delta (Δ) indicates that there is a difference assumed between two measuring points, such as two pressure or temperature readings.

Differential pressure = the difference between two measured pressures.

Figure 4 *Differential Pressure Gauge (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Gauge pressure is actually a differential pressure where one of the measured pressures is atmospheric pressure.

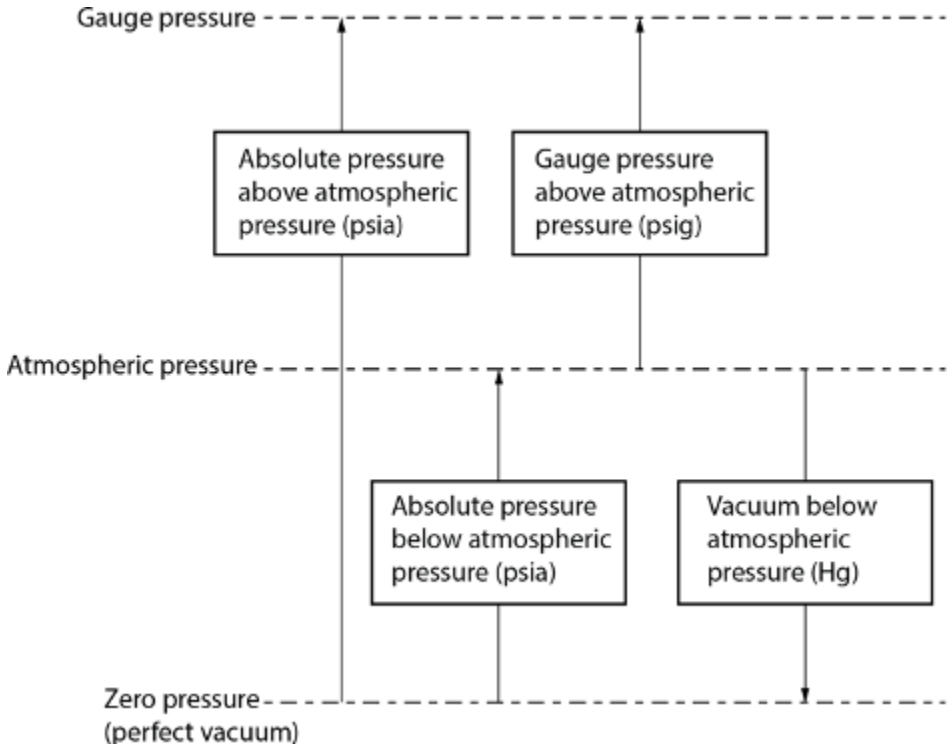

Figure 5 *Pressure measurements (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Pressure Scales

The metric unit for pressure is ***pascal (Pa)***. Some other units are ***pounds per square inch (psi)*** and ***bar*** (1 bar is = 100 kPa). There are actually many varied units to express pressure. Every field of science and discipline has different preferences, and it is the same with various regions and organizations.

At times, pressure is expressed as a depth of a particular fluid. The most commonly used are mercury (Hg), based on its high density, and water (H_2O), based on its availability. However, measuring pressure with a column of liquid is not always precise. Density of the fluid and gravity can vary in any given region. These pressure units are still used as standard increments on many ***analogue gauges***. There are also other kinds of pressure units, such as ***atmospheres***.

Table 4: Pressure conversion factors

Pressure Units	psi	kPa	Inches of Hg	Inches of H_20	Atmospheres (atm)
1 psi =	1	6.895	2.036	27.68	.068
1 kPa =	0.145	1	.295	4.015	.009869
1 in. of Hg =	0.491	3.386	1	13.6	.03342
1 in. of H_2O =	0.036	.249	.07355	1	.002458
1 atmosphere (atm) =	14.73	101.325	29.92	406.9	1

Things to Remember

- Absolute pressure is measured in relation to a perfect vacuum, while gauge pressure is the difference between the absolute pressure and the atmospheric pressure.
- Gauge pressure is what is most commonly used in the piping trades, while absolute pressure is used more often for scientific experimentations and calculations.
- Due to varying atmospheric pressure, gauge pressure measurement is not precise at all times, while absolute pressure is always definite.

Self-Test C-1.6.2: Perform Conversions

Complete Self-Test C-1.6.2 and check your answers.

If you are using a printed copy, please find Self-Test C-1.6.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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- Steamfitter: Competency C-1 Use Mathematics and Science
- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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Note: these videos align with the open textbooks *Math for Trades: Volume 1* and *Math for Trades: Volume 2*. All videos are by Chad Flinn and available under a Creative Commons Attribution 4.0 Licence.:

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- **Figure 1** Thermometer with Fahrenheit and Celcius units is by Camosun College/BCcampus (2019 and are used under the CC BY-NC-SA 4.0license.

C-1.7 Calculate Piping Measurements

You will require the IPT's Pipe Trades Training Manual for this section. This resource may also be useful to keep and refer to throughout your apprenticeship and into your career in the trades.

Threaded Pipe

When installing ***threaded fittings*** in a piping system, you must cut the pipe, thread its ends and screw fittings onto the threaded ends. Because the fittings actually add length to the pipeline, you must take measurements and perform calculations to determine how long to cut the pipe (which will be less than the centre-to-centre [C–C] measurement of the fittings). When pipe trades workers install pipe and fittings, a thorough knowledge of fractions and decimals is essential. In addition, the calculations require you to be familiar with the terminology associated with this piping practice.

Terminology

Fitting allowance (FA): The measured distance from the end of the pipe inside a fitting to the centre of the fitting. This value changes depending on the type and size of the fitting.

Thread engagement (TE): The distance from the face of a fitting to how far the pipe screws into it. This distance changes depending on the size of the pipe.

Take off (TO): The total amount of length removed from a pipe measurement to account for all fittings in a connection. It is usually the sum of two fitting allowances—one at each end of the pipe. When the two fitting allowances are added together, the dimension is called the ***total take off***.

Throw: Also known as *centre to face* (C-to-F), this is the distance from the centre of a fitting to its *face* (end opening) and is also equal to the sum of the fitting *allowance* (FA) and the *thread engagement* (TE) (Figure 1).

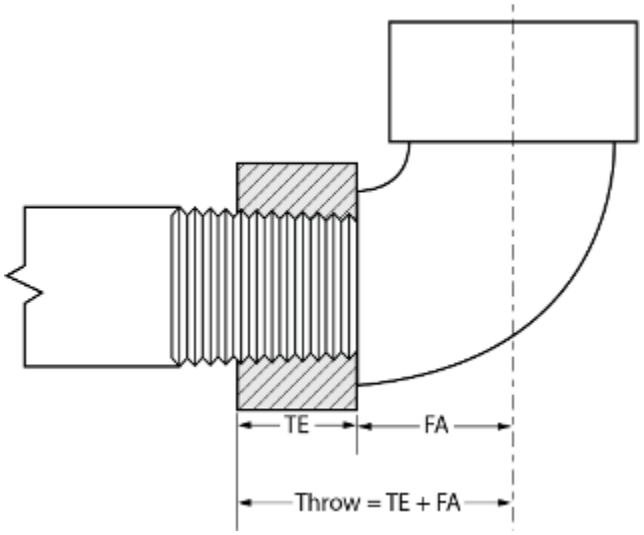

Figure 1 *Throw, TE, and FA (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Allowance for Thread Engagement

Whenever a fitting is threaded onto a pipe, a certain allowance must be made in the length of the pipe to account for the thread engagement, or the ***thread allowance***.

Example:

A length of $_{1}$" pipe has an elbow at one end and a tee at the other. It is $_{17}$" from the centre of the elbow to the centre of the tee. The distance from the centre of the elbow to its face (throw) is $1\frac{1}{2}$" . The distance from the centre of the tee to its face (throw) is also $1\frac{1}{2}$" . The thread engagement for all $_{1}$" threaded fittings is $\frac{11}{16}$" .

Figure 2 *Pipe assembly with elbow and tee fittings (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

The length of the pipe will be 17" minus $1\frac{1}{2}$" at each end plus $\frac{11}{16}$" at each end, or $15\frac{3}{8}$" end to end.

Common mistake: Forgetting to subtract fitting allowances at both ends of a pipe. Always account for fittings on both sides when calculating cut length.

Measuring Threaded Pipe

There are seven general methods of measuring ***threaded pipe*** in piping installations (Figure 3):

- ***End–to–end (E–E):*** The measurement from one end of a piece of pipe to the other end.
- ***End–to–centre (E–C):*** The measurement from one end of the pipe to the centre of the fitting on the other end of the pipe.
- ***End–to–back (E–B):*** The measurement one end of the pipe to the back of the fitting on the other end of the pipe.
- ***Centre–to–centre (C–C):*** The measurement from the centre of the fitting on one end of a piece of pipe to the centre of the fitting at the other end.
- ***Face–to–face (F–F):*** The measurement from the face of the fitting on one end of a piece of pipe to the face of the fitting at the other end.
- ***Centre–to–back (C–B):*** The measurement from the centre of the fitting on one end of the pipe to the back of the fitting on the other end of the pipe.
- ***Back–to–back (B–B):*** The measurement from the back of the fitting on one end of a piece of pipe to the back of the fitting at the other end.
- ***Overall centre–to–centre:*** The total distance from the centre of the first fitting to the centre of the last fitting in a pipe assembly, including all fittings in between.

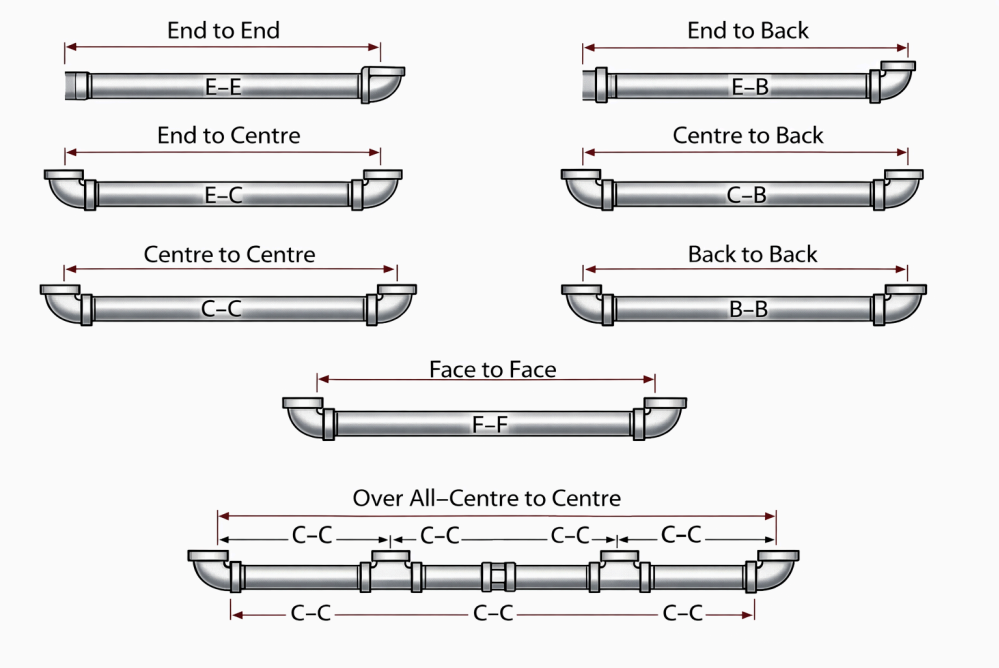

Figure 3 *Measuring threaded pipe (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Centre-to-centre is the measurement most commonly used when laying out and installing pipe in the field. A centre-to-centre measurement is the distance from the centre of one fitting to the centre of another fitting. That distance remains the same regardless of pipe size because it is measured between fitting centres, not pipe length. However, because the fitting allowance and thread engagement vary with the size of the pipe, the cut length of the pipe will vary for different pipe sizes.

End-to-end measurements and end-to-centre measurements will sometimes be used when installing fittings that have no thread engagement (***hubless fittings***). With butt weld fittings and most ***mechanical joint fittings***, the pipe does not penetrate the fitting; therefore only the throw for each fitting is considered when calculating the required cut length.

Figure 4 *Butt weld fittings (adapted from Ghasemimoshref/Wikimedia Commons) CC BY-SA 4.0*

Figure 5 *Mechanical joint fittings (adapted from ThisIsEngineering/Pexels) Pexels License*

Each size and type of *pipe fitting* has specifications for its manufacture that are standardized throughout the industry. Most pipe trades training manuals contain tables that provide fitting specifications. For this section, you will be using *IPT's Pipe Trades Training Manual*.

"Dimensions for Malleable Iron Fittings" in *IPT's Pipe Trades Training Manual* (Table #48A, B Diagrams p. 181 in the February 2010 edition) shows some of the more common threaded fittings. The measurement designating the thread engagement or fitted thread length (T) for each size of pipe is in the lower right-hand corner. Their specifications are shown in the two tables that follow, one for imperial, and one for metric. The measurements indicated by letters in the drawings (A, B, C, etc.) are the throw dimensions (face to centre) for the fittings. The specifications for reducing tees and reducing elbows for threaded fittings are not included in *IPT's Pipe Trades Training Manual*.

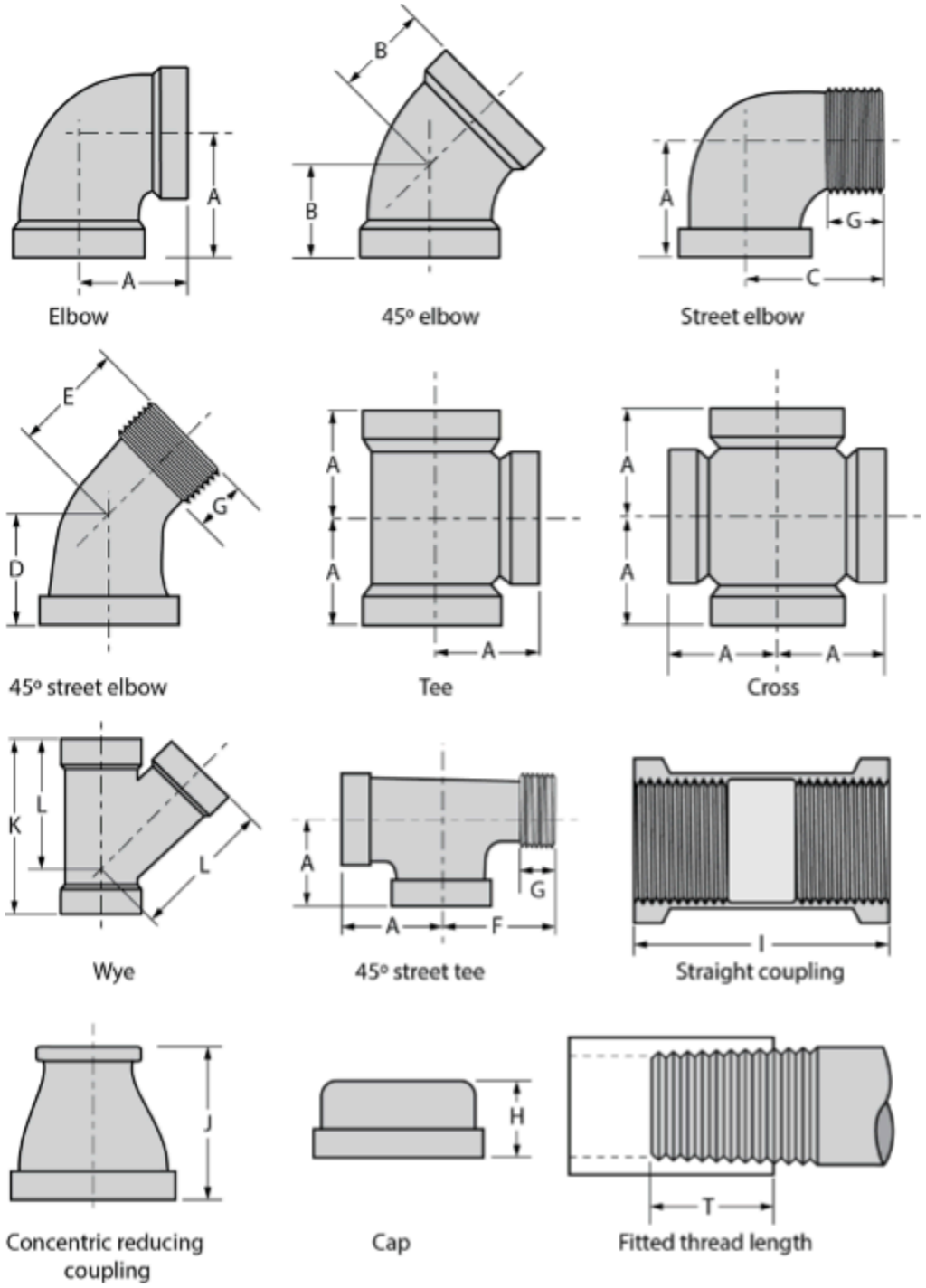

Figure 6 *Dimensions for malleable iron fittings (IPT Publishing Ltd., 2010)*

Example 1:

Calculate the required end-to-end lengths of the two pieces (A and B) of 1″ pipe in Figure 7 (to the nearest $\frac{1}{8}$″). The 90° elbows are standard and the tee is 1″ × 1″ × 1″.

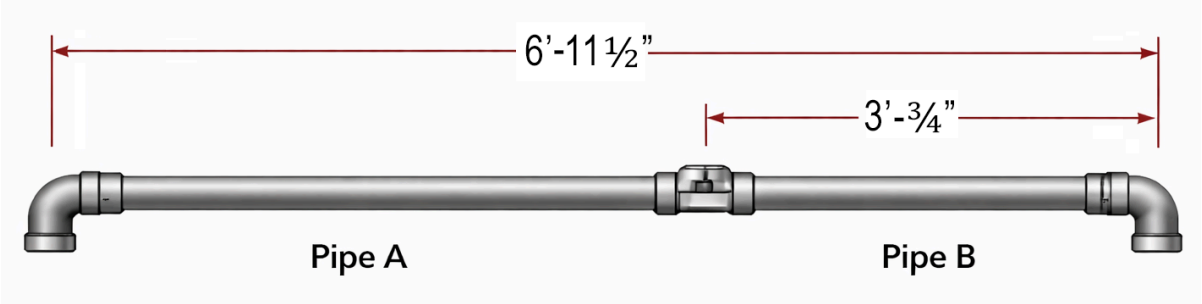

Figure 7 *Example 1 Pipe assembly with labeled dimensions (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

First, obtain the unknown centre-to-centre measurement (Pipe A) from the centre-to-centre overall measurement:

$$6’11\frac{1}{2}” - 3’\frac{3}{4}” = 3’10\frac{3}{4}”$$

Next, obtain the proper specifications for the fittings. Table 1 gives the throw dimension for both the 90° elbows. The tee is given as dimension A, and the thread engagement is given as dimension T.

Now solve for the required fitting allowance. Table 1 gives the throw dimension A (Column A, Row 1″) as 1.5″ for both the 90° elbows and the tee. Dimension T (Column T, Row 1″) is given as 0.58″.

$$\text{Fitting allowance} = \text{Throw} - \text{thread engagement} \quad \text{FA (for 1” 90}^\circ\text{ elbow/tee)} = 1.5” - 0.58” \quad \text{FA} = 0.92”$$

Table 1: Imperial Dimensions for Malleable Iron Fittings (IPT Publishing Ltd., 2010))

DIMENSIONS FOR MALLEABLE IRON FITTINGS (CLASS 150)													
Nominal Pipe Size Inches	**Dimensions – Inches**												
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**T**
$\frac{1}{8}$	0.69	–	1.00	–	–	–	0.26	0.53	0.96	–	–	–	0.25
$\frac{1}{4}$	0.81	0.73	1.19	0.73	0.94	1.19	0.40	0.63	1.06	1.00	–	–	0.32
$\frac{3}{8}$	0.95	0.80	1.44	0.80	1.03	1.44	0.41	0.74	1.16	1.13	1.93	1.43	0.36
$\frac{1}{2}$	1.12	0.88	1.63	0.88	1.15	1.63	0.53	0.87	1.34	1.25	2.32	1.71	0.43
$\frac{3}{4}$	1.31	0.98	1.89	0.98	1.29	1.89	0.55	0.97	1.52	1.44	2.77	2.05	0.50
1	1.50	1.12	2.14	1.12	1.47	2.14	0.68	1.16	1.67	1.69	3.28	2.43	0.58
$1\frac{1}{4}$	1.75	1.29	2.45	1.29	1.71	2.45	0.71	1.28	1.93	2.06	3.94	2.92	0.67
$1\frac{1}{2}$	1.94	1.43	2.69	1.43	1.88	2.69	0.72	1.33	2.15	2.31	4.38	3.28	0.70
2	2.25	1.68	3.26	1.68	2.22	3.26	0.76	1.45	2.53	2.81	5.17	3.93	0.75
$2\frac{1}{2}$	2.70	1.95	3.86	1.95	2.57	–	1.14	1.70	2.88	3.25	6.25	4.73	0.92
3	3.08	2.17	4.51	2.17	3.00	–	1.20	1.80	3.18	3.69	7.26	5.55	0.98
$3\frac{1}{2}$	3.42	2.39	–	–	–	–	–	1.90	–	–	–	–	1.03
4	3.79	2.61	5.69	2.61	3.70	5.69	1.30	2.08	3.69	4.38	8.98	6.97	1.08
5	4.50	3.05	6.86	–	–	–	1.41	2.32	–	–	–	–	1.18
6	5.13	3.46	8.03	–	–	–	1.51	2.55	–	–	–	–	1.28
NOTE: Dimensions for table are based on fittings manufactured to ANSI/ASME B16.3 Standard.													

Now calculate the length of the first piece of pipe (Pipe A). Change the measurement to decimal inches for ease of calculation. The centre-to-centre measurement includes a 90° elbow on one end and half of a tee on the other:

$$3\text{'}\ 10\frac{3}{4}\text{"} = 46.75\text{"} \quad \text{Length} = 46.75\text{"} - 0.92\text{" (FA tee)} - 0.92\text{" (FA elbow)} = 44.91\text{"}$$

Convert back to feet, inches and fractions of an inch:

$$44.91\text{"} = 3\text{'}\ 8\frac{7}{8}\text{"}$$

The second piece (Pipe B) has the same allowance subtracted as the first (one 90° elbow and one tee):

$$3\text{'}\frac{3}{4}\text{"} = 36.75\text{"} \quad 36.75\text{"} - (2 \times 0.92\text{"}) = 34.91\text{"} = 2\text{'}\ 10\frac{7}{8}\text{"}$$

Example 2:

Calculate the required end-to-end length of three pieces (A, B, and C) of 50 mm pipe (to the nearest millimetre) (Figure 8). The 90° elbows are standard, and the tee is 50 mm × 50 mm × 50 mm.

First, obtain the unknown centre-to-centre measurement (Pipe A) from the centre-to-centre overall measurement:

$$912 \text{ mm} - 385 \text{ mm} = 527 \text{ mm}$$

Next, obtain the proper specifications for the fittings from *IPT's Pipe Trades Training Manual.*

Now solve for the required fitting allowance. Table 1 gives the throw dimension A (Column A, Row 50 mm) as 57.2 mm for both the 90° elbows and the tee. Dimension H (Column H, Row 50 mm) is given as 36.8 mm (throw) for the cap. Dimension T (Column T, Row 50 mm) is given as 19.1 mm (the thread engagement for any 50-mm fitting).

$$\text{Fitting allowance} = \text{Throw} - \text{thread engagement} \quad \text{FA (for 50mm 90° elbow/tee)} = 57.2 \text{ mm} - 19.1 \text{ mm} \quad \text{FA} = 38.1 \text{ mm} \quad \text{FA (for 50mm cap)} = 36.8 \text{ mm} - 19.1 \text{ mm} \quad \text{FA} = 17.7 \text{ mm}$$

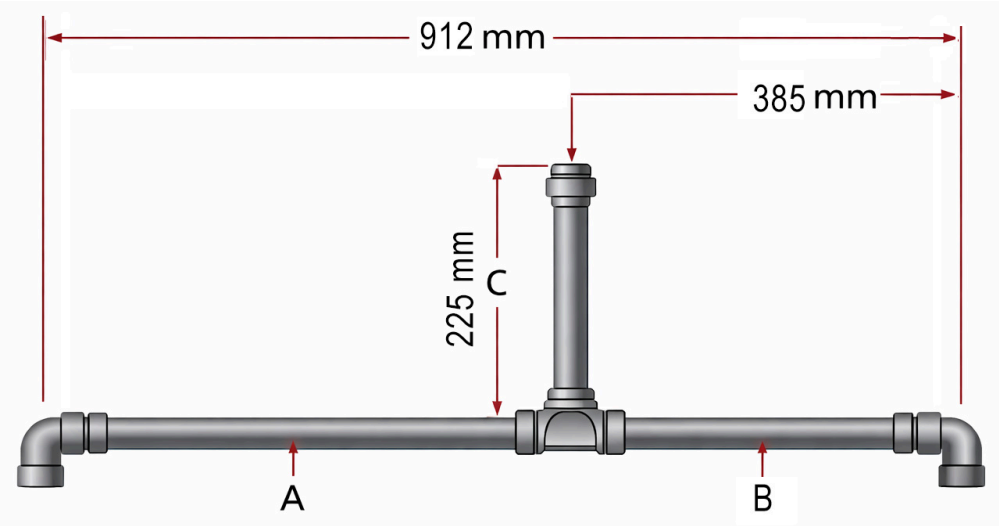

Figure 8 *Illustration for Example 2 (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

1. Calculate the end-to-end length of piece A: $527\text{ mm} - (2 \times 38.1\text{ mm}) = 450.8\text{ mm}$
2. Calculate the end-to-end length of piece B: $385\text{ mm} - (2 \times 38.1\text{ mm}) = 308.8\text{ mm}$
3. Calculate the end-to-end length of the riser C: $225\text{ mm} - 38.1 - 17.7 = 169.2\text{ mm}$

Example 3:

Calculate the end-to-end length of the three pieces (A, B and C) of 25 mm pipe (to the nearest millimetre). The 45° elbows and cap are standard.

Obtain the proper specifications for the fittings from *IPT's Pipe Trades Training Manual*.

Note that you will be using 45° fittings and caps in this exercise, so refer to the diagrams page for the proper throw dimension.

Solve for the fitting allowance. Table 1 gives B (Column B, Row 25 mm) as 28.5 mm for both the 45° elbows. Table 1 gives H (Column H, Row 25 mm) as 29.5 mm (throw) for the cap. T (Column T, Row 25 mm) as 14.7 mm will be the thread engagement for any 25 mm fitting.

$$\text{Fitting allowance} = \text{Throw} - \text{thread engagement} \quad \text{FA } 45^\circ \text{ elbows} = 28.5\text{ mm} - 14.7\text{ mm} = 13.8\text{ mm} \quad \text{FA caps} = 29.5\text{ mm} - 14.7\text{ mm} = 14.8\text{ mm}$$

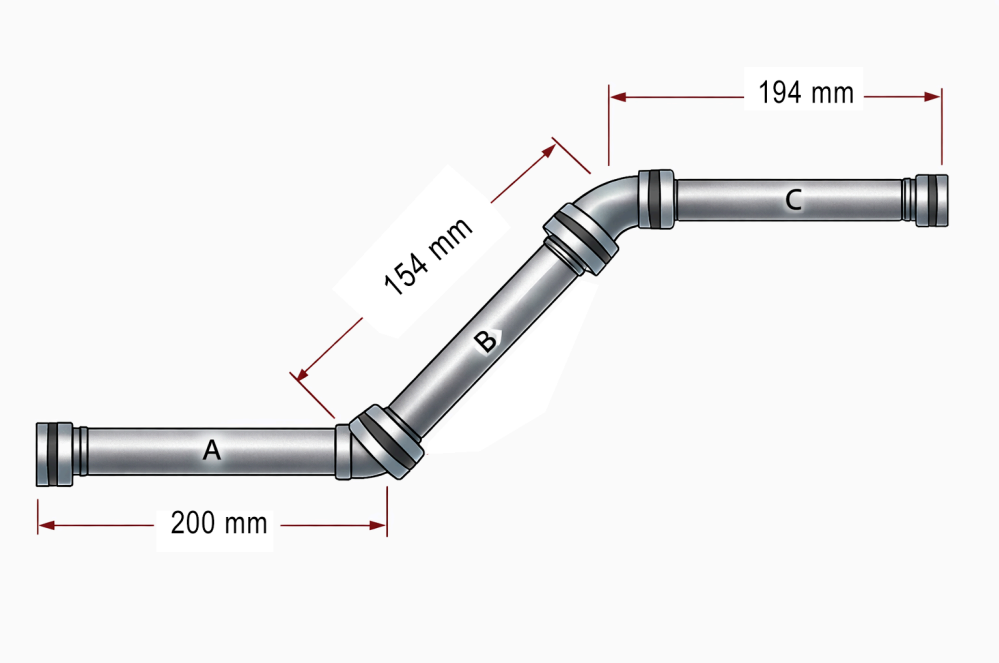

Figure 9 *Illustration for Example 3 (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

4. Calculate the end-to-end length of piece A: $200\text{ mm} - 13.8\text{ mm} - 14.8\text{ mm} = 171.4\text{ mm}$
5. Calculate the end-to-end length of piece B: $154\text{ mm} - (2 \times 13.8\text{ mm}) = 126.4\text{ mm}$
6. Calculate the end-to-end length of piece C: $194\text{ mm} - 13.8\text{ mm} - 14.8\text{ mm} = 165.4\text{ mm}$

Butt-Welded Pipe and Fittings

Butt-weld steel fittings are standardized in the pipe trades. An important specification for ***butt-weld fittings*** is the throw measurement. The lessons learned in this section could also be used on other types of piping materials using mechanical joint (MJ) connectors.

Fitting allowances for butt-weld pipe fittings are easier to calculate than for threaded pipe, because you do not have to allow for a thread engagement. You do, however, have to allow for ***weld gaps***.

While the gap used for the production of a weld itself is not large ($\frac{1}{8}$„ , $\frac{3}{32}$„ , etc.), over a long ***run*** with a lot of fittings, the gaps add up, which can cause the piping to be too long and out of alignment if not accounted for.

Radius of a Weld Elbow

The ***radius of an elbow*** is measured from its centreline to a point that marks the centre of its bend (Figure 10). For a 90° elbow, the radius and the throw are the same.

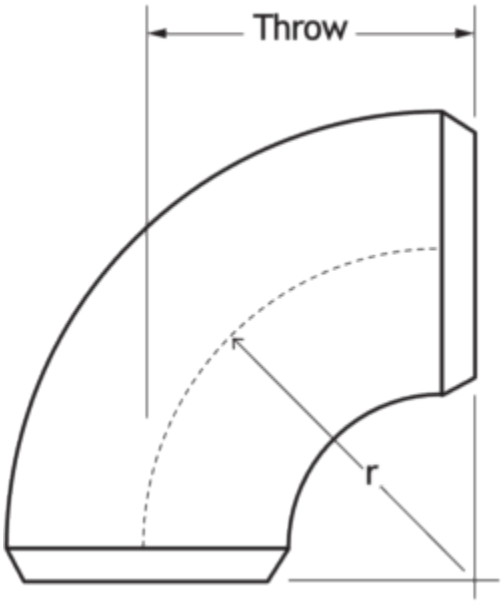

Figure 10 *Radius of a weld elbow (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A standard 90° elbow (sometimes called a ***long-radius elbow***) normally has a radius of 1.5 times the nominal pipe size. For example, a 2″ elbow would have a radius of 3″. Long-radius elbows are usually designated by the number of times the radius is greater than the nominal pipe size (2d, 3d, etc.). A ***short-radius elbow*** has a radius equal to the nominal pipe size.

Illustration number 76 in the IPT manual (also shown in Figure 11 below) shows an assortment of the most commonly

used butt-weld fittings. The measurements that correspond to the indicated throws are in Tables 53 and 54. Note that the IPT manual includes the dimensions of reducing-butt-weld tees and crosses in Tables 55 and 56.

The throw and gap of a butt-weld fitting must be subtracted from the centre-to-centre measurement to find the (end-to-end) cut length. Remember that the throw dimension is the portion of a centre-to-centre measurement that is not straight pipe.

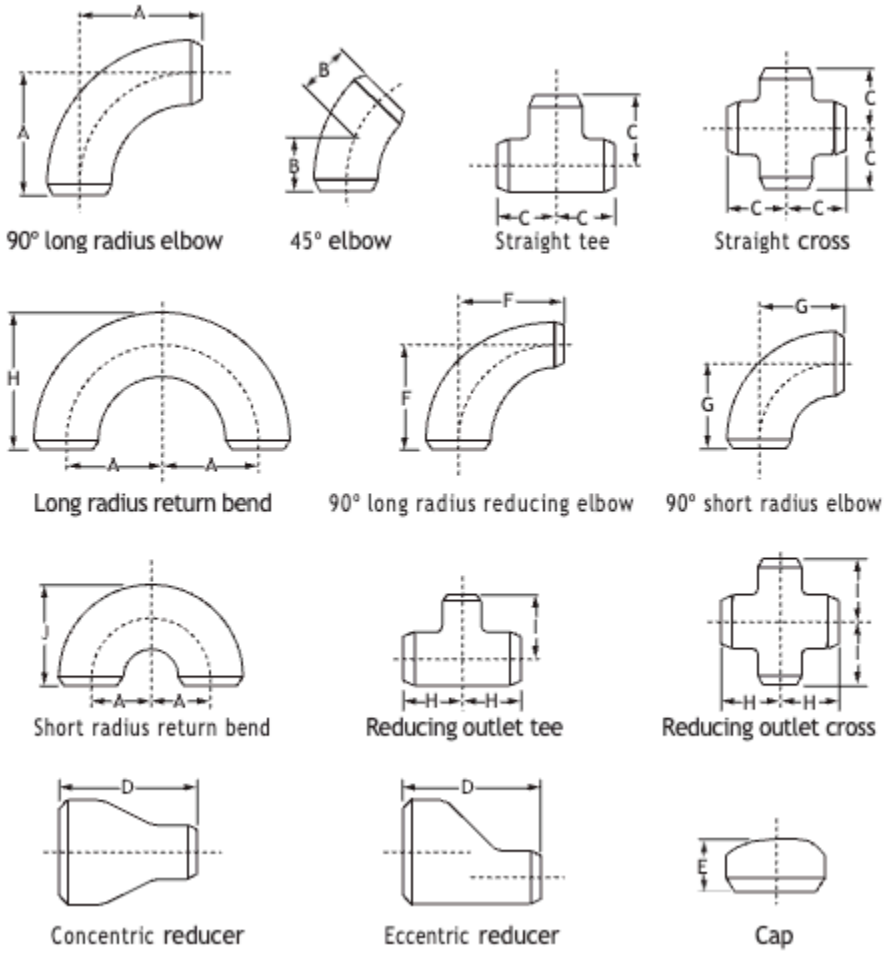

Figure 11 *Dimensions for butt-weld fittings (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 4:

Find the end-to-end cut lengths for 3″ schedule 40 piping shown in Figure 12. The 90° long-radius elbows are standard, and the specified weld gap is $\frac{1}{8}$″ .

In Figure 11, you can see that dimension A is the measurement for the throw of a 90° long-radius elbow, and dimension E is the length of a cap. The IPT manual gives the length of A as $3' 4\frac{1}{2}$″ (1.5 times the nominal pipe size) and the length for a cap as 2″ .

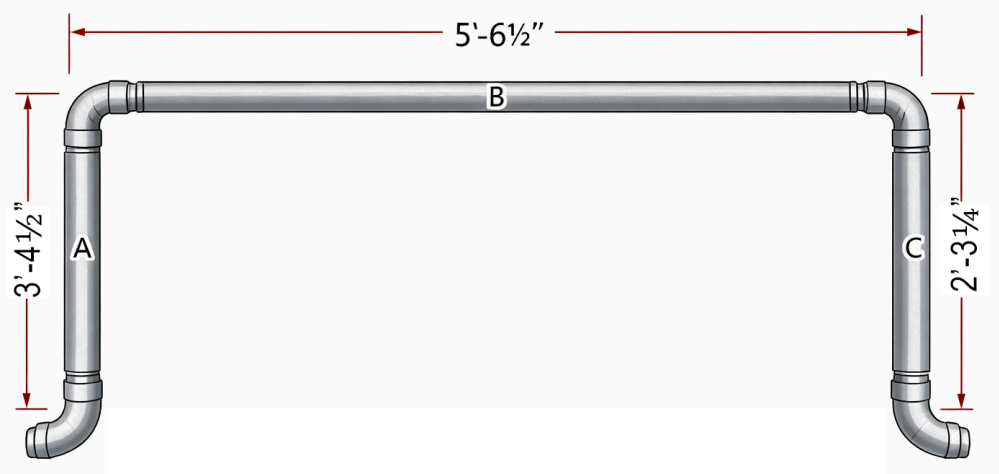

Figure 12 *Illustration for Example 4 (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Solve for the end-to-end length of piece A. You must subtract a throw and a weld gap from each end.

Convert to inches:

$$3'\ 4\tfrac{1}{2}" = 40\tfrac{1}{2}" \quad A = 40\tfrac{1}{2}" - 2\ \text{throws} - 2\ \text{weld gaps} \quad A = 40\tfrac{1}{2}" - (2 \times 4\tfrac{1}{2}") - (2 \times \tfrac{1}{8}") = 31\tfrac{1}{4}"\ \text{or} \quad 2'\ 7\tfrac{1}{4}"$$

Step 2: Solve for the end-to-end length of piece B. Convert to inches:

$$5'\ 6\tfrac{1}{2}" = 66\tfrac{1}{2}" \quad A = 66\tfrac{1}{2}" - 2\ \text{throws} - 2\ \text{weld gaps} \quad A = 66\tfrac{1}{2}" - (2 \times 4\tfrac{1}{2}") - (2 \times \tfrac{1}{8}") = 57\tfrac{1}{4}"\ \text{or}\ 4'\ 9\tfrac{1}{4}"$$

Step 3: Solve for the end-to-end length of piece C. Convert to inches:

$$2'\ 3\tfrac{1}{4}" = 27\tfrac{1}{4}" \quad A = 27\tfrac{1}{4}" - 1\ \text{throw} - 1\ \text{cap length (E)} - 2\ \text{weld gaps} \quad A = 27\tfrac{1}{4}" - 4\tfrac{1}{2}" - 2 - (2 \times \tfrac{1}{8}") = 20\tfrac{1}{2}"\ \text{or}\ 1'\ 8\tfrac{1}{2}"$$

Example 5:

Find the end-to-end cut length for 50 mm schedule 40 piping (Figure 13). The 90° long-radius elbows are standard, and the specified weld gap is 3 mm.

From the table in the IPT manual you can see that dimension A is the measurement for the throw of a 90° long-radius elbow, dimension C is the measurement for the throw of a tee, and dimension E is used for the length of a cap.

The IPT manual gives the length of A as 76 mm (1.5 times the nominal ID), C as 64 mm and E as 38 mm.

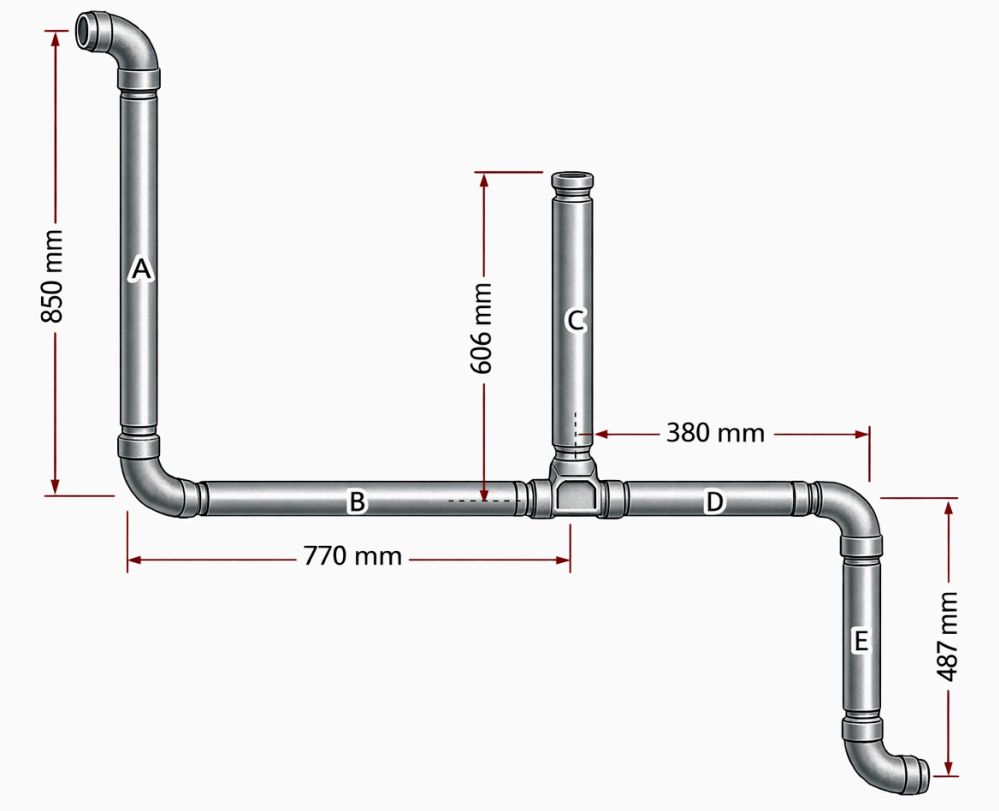

Figure 13 *Illustration for Example 5 (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Solve for the end-to-end length of piece A. You must subtract 2 throws (90 deg ell) and a weld gap from each end.

$$\mathrm{A} = 850\ \mathrm{mm} - 2\ \text{throws} - 2\ \text{weld gaps} \quad \mathrm{A} = 850\ \mathrm{mm} - (2 \times 76\ \mathrm{mm}) - (2 \times 3\ \mathrm{mm}) = 692\ \mathrm{mm}$$

Step 2: Solve for the end-to-end length of piece B. You must subtract 1 throw (90 deg ell), 1 throw (tee) and a weld gap at each end.

$$\mathrm{B} = 770\ \mathrm{mm} - 76\ \mathrm{mm} - 64\ \mathrm{mm} - (2 \times 3\ \mathrm{mm}) = 624\ \mathrm{mm}$$

Step 3: Solve for the end-to-end length of piece C. You must subtract 1 throw (tee), the length of the cap (E) and a weld gap at each end.

$$\mathrm{C} = 606\ \mathrm{mm} - 64\ \mathrm{mm} - 38\ \mathrm{mm} - (2 \times 3\ \mathrm{mm}) = 498\ \mathrm{mm}$$

Step 4: Solve for the end-to-end length of piece D. You must subtract 1 throw (90 deg ell), 1 throw (tee) and a weld gap at each end.

$$\mathrm{D} = 380\ \mathrm{mm} - 76\ \mathrm{mm} - 64\ \mathrm{mm} - (2 \times 3\ \mathrm{mm}) = 234\ \mathrm{mm}$$

Step 5: Solve for the end-to-end length of piece E. You must subtract 2 throws (90 deg ell) and a weld gap from each end.

$$\mathrm{E} = 487\ \mathrm{mm} - (2 \times 76\ \mathrm{mm}) - (2 \times 3\ \mathrm{mm}) = 329\ \mathrm{mm}$$

Socket-Weld Fittings

Socket-weld fittings are used to join smaller sizes of pipe, usually 2″ and under, that require the strength and security of a welded joint. Like threaded fittings, socket-weld fittings have a length of pipe that fits into the fitting, meaning that the throw and the fitting allowance have two different values. Calculating the end-to-end measurements for socket-weld fittings is more complex because a small gap must be left between the pipe and the bottom of the socket. (Figure 14).

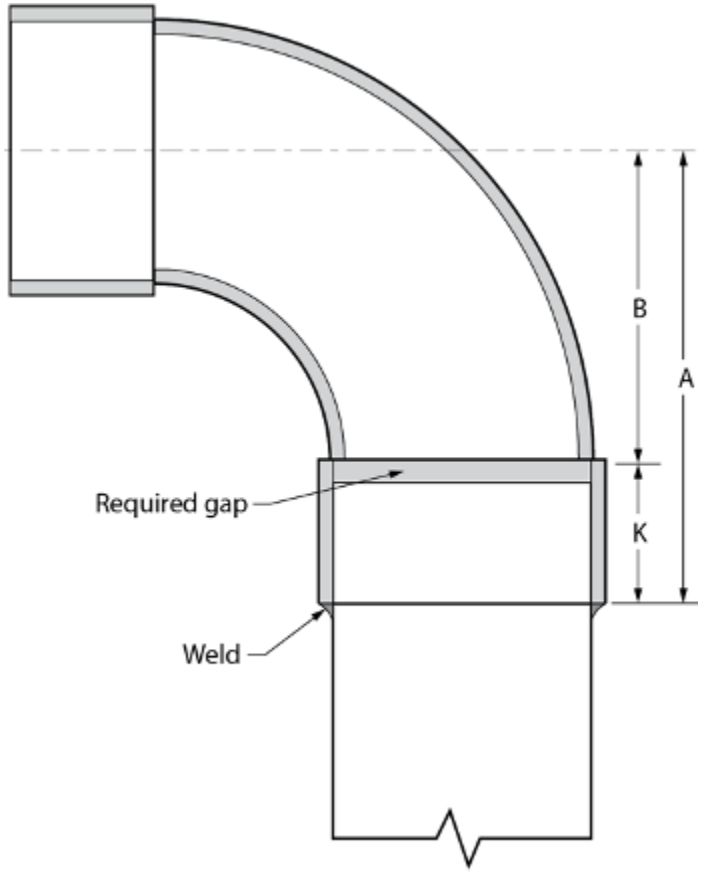

Figure 14 *Socket-weld fitting (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

This gap is required to allow for expansion of the pipe in the fitting. If the pipe were to bottom out in the fitting, a large temperature change might cause the pipe to expand enough to break the weld. The gap mentioned in the IPT manual is

$\frac{1}{16}$„ or 1.6 mm, but it may be different, depending on the job specifications.

The diagrams in Tables 51 and 52 in the IPT manual show an assortment of the most commonly used socket-weld fittings (also shown in Figure 15 below). The measurements that correspond to the indicated throws are on the following pages.

Along with the throw (dimension A) of the fitting, the fitting allowance (dimension B, which already includes a $\frac{1}{16}$„ gap) is given. ***Socket depth*** is given as dimension K in the lower right-hand corner, which could be used if the job specifies a different gap dimension.

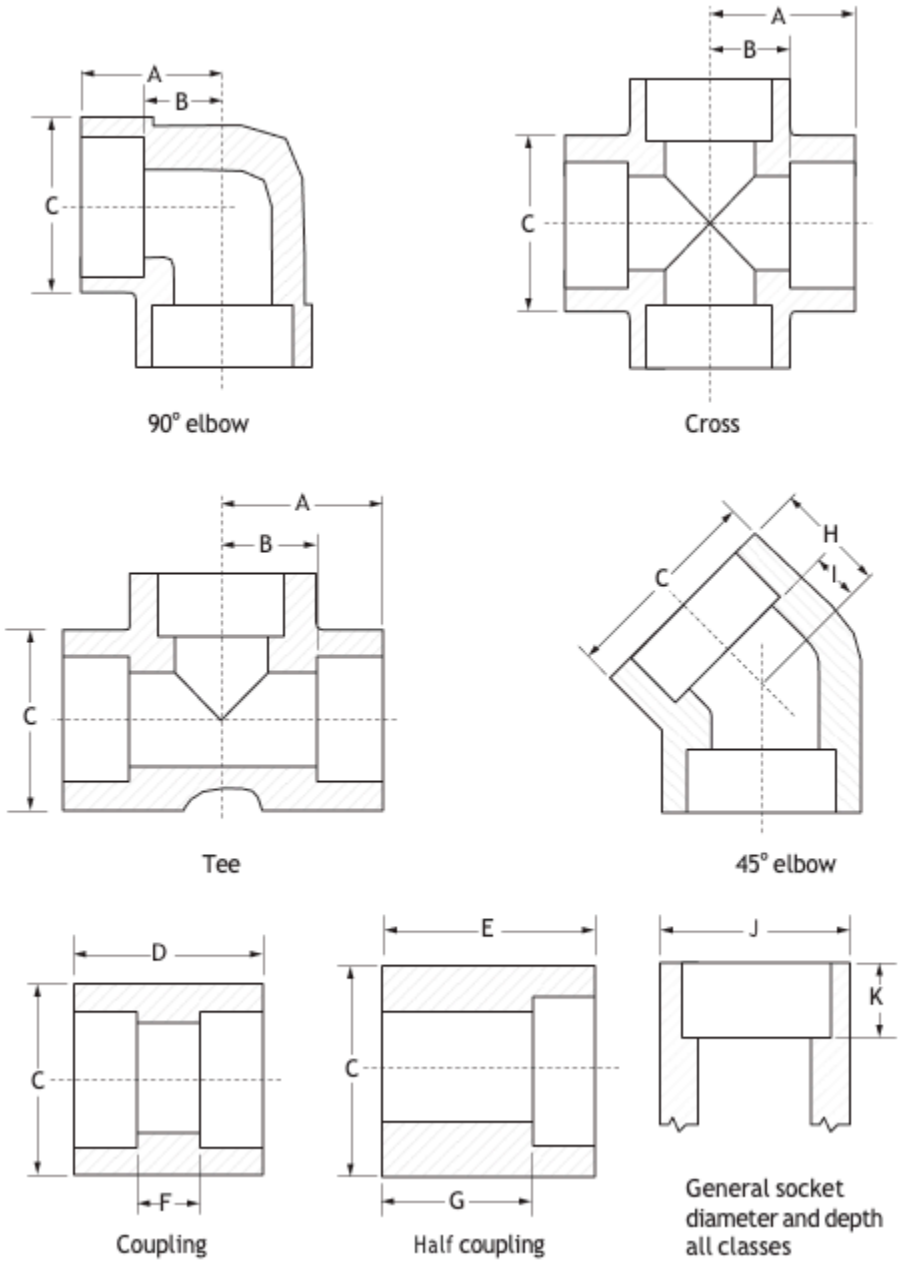

Figure 15 *Dimensions for forged steel socket-weld fittings (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 6:

Find the end-to-end cut lengths for the four pieces of pipe shown in Figure 16. The fittings are $1\frac{1}{4}$" , 3,000#, schedule 80. The specified weld gap is $\frac{1}{16}$" .

From the table in the IPT manual you can see that dimension B is the measurement for the fitting allowance of a 90° elbow and a tee (gap included). The IPT manual gives the length of dimension B as 1.06″.

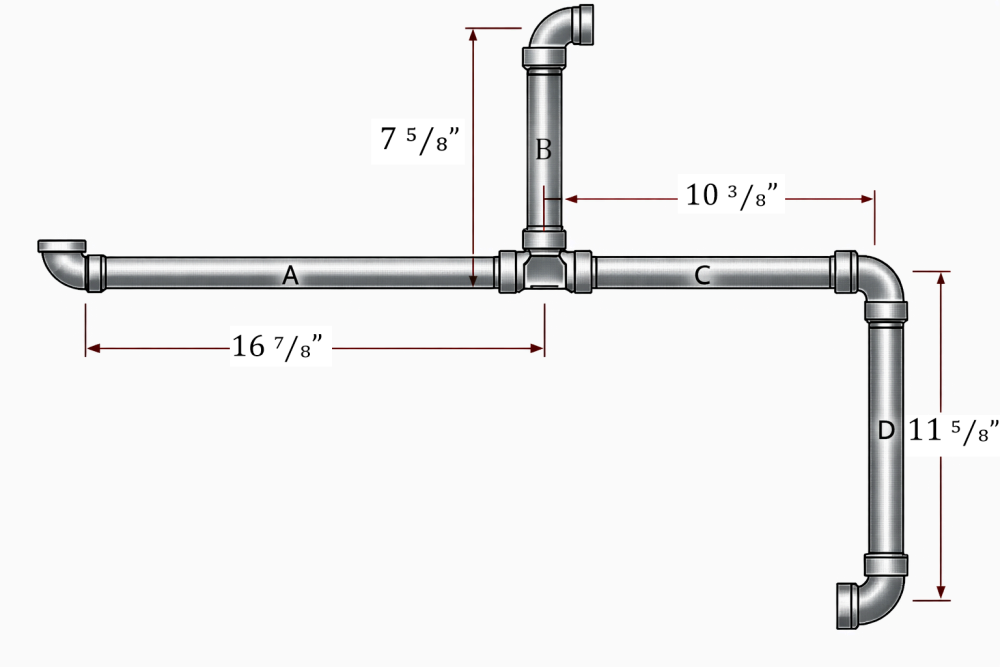

Figure 16 *Illustration for Example 6 (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Solve for the end-to-end length of piece A. You must subtract 2 fitting allowances (90 deg ell and tee).

Step 2: Convert the fitting allowance given to the fractional equivalent.

$$\text{Fitting allowance} = 1.06\text{”} = 1\frac{1}{16}\text{”} \quad \text{A} = 16\frac{7}{8}\text{”} - 2 \text{ fitting allowances} \quad \text{A} = 16\frac{7}{8}\text{”} - (2 \times 1\frac{1}{16}\text{”}) \quad \text{A} = 16\frac{7}{8}\text{”} - 2\frac{1}{8}\text{”} = 14\frac{3}{4}\text{”}$$

Step 3: Solve for the end-to-end length of piece B. You must subtract 2 fitting allowances (90 deg ell and tee).

$$\text{B} = 7\frac{5}{8}\text{”} - 2 \text{ fitting allowances} \quad \text{B} = 7\frac{5}{8}\text{”} - (2 \times 1\frac{1}{16}\text{”}) \quad \text{B} = 7\frac{5}{8}\text{”} - 2\frac{1}{8}\text{”} = 5\frac{1}{2}\text{”}$$

Step 4: Solve for the end-to-end length of piece C. You must subtract 2 fitting allowances (90 deg ell and tee).

$$\text{C} = 10\frac{3}{8}\text{”} - 2 \text{ fitting allowances} \quad \text{C} = 10\frac{3}{8}\text{”} - (2 \times 1\frac{1}{16}\text{”}) \quad \text{C} = 10\frac{3}{8}\text{”} - 2\frac{1}{8}\text{”} = 8\frac{1}{4}\text{”}$$

Step 5: Solve for the end-to-end length of piece D. You must subtract 2 fitting allowances (90 deg ell).

$$\text{D} = 11\frac{5}{8}\text{”} - 2 \text{ fitting allowances} \quad \text{D} = 11\frac{5}{8}\text{”} - (2 \times 1\frac{1}{16}\text{”}) \quad \text{D} = 11\frac{5}{8}\text{”} - 2\frac{1}{8}\text{”} = 9\frac{1}{2}\text{”}$$

Example 7:

Find the end-to-end cut lengths of the six pieces of pipe shown in Figure 17. The fittings are 25 mm, 6,000#, schedule 160. The specified weld gap is 1.6 mm.

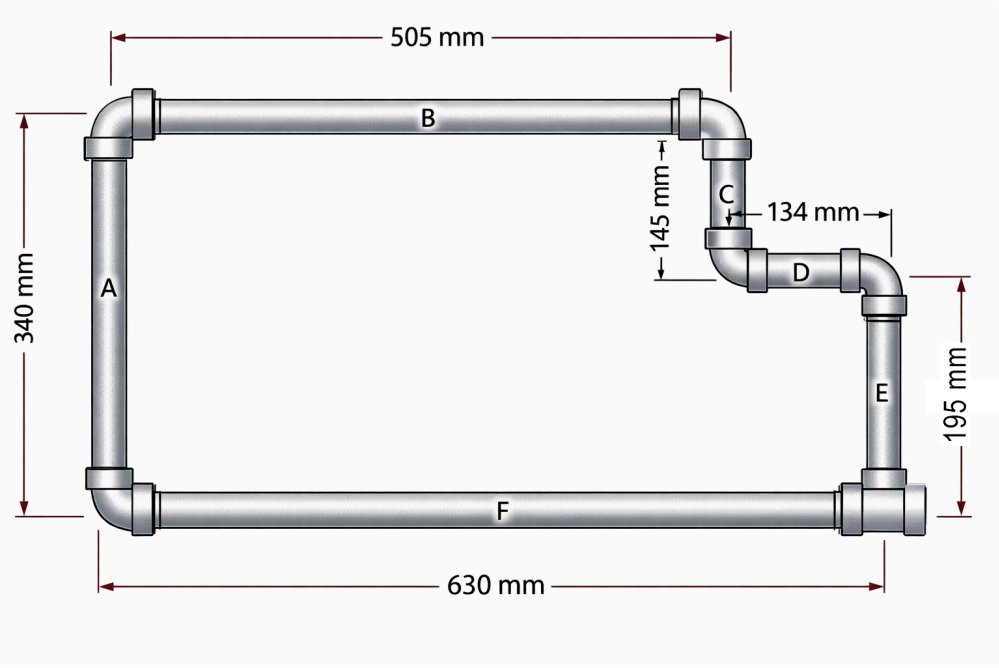

Figure 17 *Illustration for Example 7 (TRU Open Press/OpenAI, 2026 – adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Solve for the end-to-end length of piece A. You must subtract 2 fitting allowances (90 deg ell).

$$\text{A} = 340\text{ mm} - 2\text{ fitting allowances} \quad \text{A} = 340\text{ mm} - (2 \times 26.92\text{ mm}) \quad \text{A} = 340\text{ mm} - 53.84\text{ mm} = 286.16\text{ mm}$$

Step 2: Solve for the end-to-end length of piece B. You must subtract 2 fitting allowances (90 deg ell).

$$\text{B} = 505\text{ mm} - 2\text{ fitting allowances} \quad \text{B} = 505\text{ mm} - (2 \times 26.92\text{ mm}) \quad \text{B} = 505\text{ mm} - 53.84\text{ mm} = 451.16\text{ mm}$$

Step 3: Solve for the end-to-end length of piece C. You must subtract 2 fitting allowances (90 deg ell).

$$\text{C} = 145\text{ mm} - 2\text{ fitting allowances} \quad \text{C} = 145\text{ mm} - (2 \times 26.92\text{ mm}) \quad \text{C} = 145\text{ mm} - 53.84\text{ mm} = 91.16\text{ mm}$$

Step 4: Solve for the end-to-end length of piece D. You must subtract 2 fitting allowances (90 deg ell).

$$\text{D} = 134\text{ mm} - 2\text{ fitting allowances} \quad \text{D} = 134\text{ mm} - (2 \times 26.92\text{ mm}) \quad \text{D} = 134\text{ mm} - 53.84\text{ mm} = 80.16\text{ mm}$$

Step 5: Solve for the end-to-end length of piece E. You must subtract 2 fitting allowances (90 deg ell and tee).

$$\text{E} = 195\text{ mm} - 2\text{ fitting allowances} \quad \text{E} = 195\text{ mm} - (2 \times 26.92\text{ mm}) \quad \text{E} = 195\text{ mm} - 53.84\text{ mm} = 141.16\text{ mm}$$

Step 6: Solve for the end-to-end length of piece F. You must subtract 2 fitting allowances (90 deg ell and tee).

$$\text{F} = 630\text{ mm} - 2\text{ fitting allowances} \quad \text{F} = 630\text{ mm} - (2 \times 26.92\text{ mm}) \quad \text{F} = 630\text{ mm} - 53.84\text{ mm} = 576.16\text{ mm}$$

Tube and Tubing

Tube and tubing are commonly joined by ***soldering*** or ***compression joints***. Calculations for making these joints are similar to socket-weld joints in that these joints have a pipe engagement rather than a thread engagement. However, the joints do not have a weld gap, and the pipe is engaged to the shoulder of the fitting before soldering or compression.

Self-Test C-1.7.1: Calculate Piping Measurements

Complete Self-Test C-1.7.1 and check your answers.

If you are using a printed copy, please find Self-Test C-1.7.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2429#h5p-12

Grade, Elevation, and Benchmarks

It is often necessary to install drainage pipe with a slope so that liquids may flow by gravity to a sewer, sump or drain point. Condensate lines and steam return mains must achieve minimum slope in order to function properly. Ensuring proper slope, or grade, in a drainage system is very important for the system to function properly. If the piping doesn't have enough grade, drains could run slowly and blockage problems could arise. If the piping has too much grade, the pipe could be too low in elevation, and it would become impossible to connect the building sewer to the public sewer in the street.

The term ***grade*** refers to a vertical distance (rise or fall) divided by the horizontal distance (run). When a grade is specified on a drawing (for example, 1:50), it means that for 50 feet of run in the horizontal direction, there will be a

1-foot vertical drop, resulting in a downward slope in the direction of flow. In this way, the specified grade is stated as a ratio of the rise over run.

Another important skill used in the piping trades is being able to determine the height (elevation) and location at which piping is to be located in and below a building.

On some job sites, there may be no single source for this information. Elevation information may be given on a drawing, may have to be calculated from available information, or may even have to be determined on the job site with physical measurements.

Grade

In the construction trades, grade is used to determine the degree of rise or fall of a sloping surface such as a ramp or a roof pitch. Within the pipe trades, the slope of a pipe is expressed as the amount of grade (slope) the pipe has on it. Grade is usually expressed in one of three ways:

- **Fraction of an inch per foot:** For example, $\frac{\frac{1}{4}"}{\text{ft.}}$ means that for every 1 foot of length or run the pipe is going to slope up or down $\frac{1}{4}"$. The National Plumbing Code specify a minimum grade of $\frac{1}{4}"$ per foot or 1:50 on all drainage piping 3″ and less in diameter.
- **Percentage** of length as compared to the rise or drop: For example, 1% means that for every unit of length the pipe is going to slope up or down 1%. This method is appropriate for both imperial and metric units.
- **Ratio** of the drop or rise to the length: For example, 1:50 means for every 50 units of length the pipe will slope up or down 1 unit. This method is appropriate for both imperial and metric units.

There are many times when the same grade can be written in different ways. Although these grades are expressed in different forms, they all refer to the amount of fall for each measurement length of piping.

Examples:

1% grade:

- 1% grade = 1 foot of drop for 100 feet of run
- 1:100 grade = 1 foot of drop for 100 feet of run
- $\frac{\frac{1}{8}"}{\text{ft.}}$ is approx. 1 foot of drop for 100 feet of run. (More accurately = 1-foot drop in 96-foot run)

2% grade:

- 2% grade = 1 foot of drop for 50 feet of run
- 1:50 grade = 1 foot of drop for 50 feet of run
- $\frac{\frac{1}{4}"}{\text{ft.}}$ is approx. 1 foot of drop for 50 feet of run. (More accurately = 1-foot drop in 48-foot run)

Calculating Total Fall

There are three factors you must consider when calculating grade problems (Figure 18): the length or *run* of the pipe, the *grade* on the pipe and the ***total fall*** of the pipe. In drainage systems, total fall is the distance the nominally horizontal pipe falls over a given length of pipe at a given grade.

It is important to always include the units of measurement in the calculation, as they are the best indicator of the correctness of your answer. If the answer has unfamiliar units, it is probably incorrect. It is especially important to keep the units in calculations using fractions per foot because some of the units will cancel out.

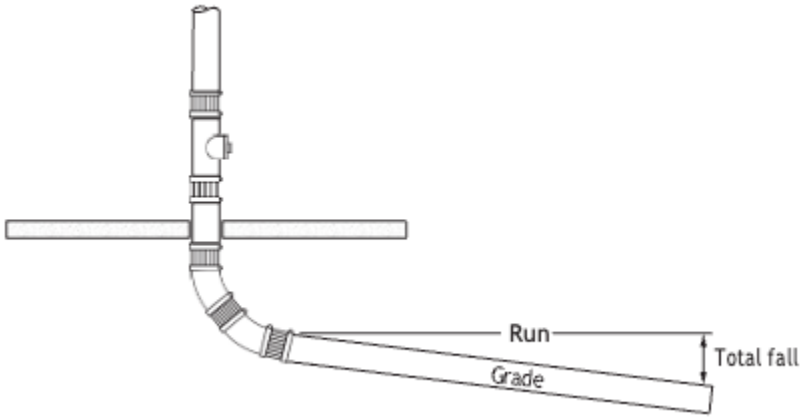

Figure 18 *Run, grade, and total fall* (*BC Industry Training Authority*, 2019). *CC BY-NC-SA 4.0*

The formula for calculating total fall is:

$$\text{Total fall} = \text{Grade} \times \text{Run}$$

This formula can be placed into a formula triangle and any unknown can be calculated (Figure 19)

Figure 19 *Formula triangle for calculating grade, run and total fall (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

$$\text{Total Fall} = \text{Grade} \times \text{Run} \quad \text{Grade} = \frac{\text{Total Fall}}{\text{Run}} \quad \text{Run} = \frac{\text{Total Fall}}{\text{Grade}}$$

Of the three factors mentioned above, at least two must be known before the third can be calculated.

> **Tip:** Always check your units. If your answer is in the wrong unit (for example, feet instead of inches), the calculation is likely incorrect.

Fraction per Foot Calculations

When you are solving a problem and the grade is provided as a fraction of an inch per foot of run, the total fall must be expressed in inches and the length must be expressed in feet.

Example 1:

Calculate the total fall of a sewer line 150′ long and with a grade of $\frac{1}{4}$„ per foot.

$$\text{Total fall (in inches)} = \text{Grade (in inches per foot)} \times \text{Run (in feet)}$$

Solution:

$$\text{Total Fall} = \text{Grade} \times \text{Run} \quad \text{Total Fall} = \frac{\frac{1}{4}\text{”}}{\text{ft.}} \times 150 \text{ ft.} = \quad \text{Total Fall} = \frac{0.25\text{”}}{\text{ft.}} \times 150 \text{ ft.} = 37.5\text{”}$$

Answer:

Total fall is 37.5″ over the run of 150′.

Note: The run or length of the pipe is 150 FEET while the total fall is in INCHES.

Example 2:

Find the grade on an 80′ long sewer line that has a total fall of 10″.

$$\text{Grade (in inches per foot)} = \frac{\text{Total fall (in inches)}}{\text{Run (in feet)}}$$

Solution:

$$\text{Grade} = \text{Total Fall} \times \text{Run} \quad \text{Total Fall} = \frac{10”}{80 \text{ ft.}} = \frac{0.125”}{\text{ft.}} = \frac{\frac{1}{8}”}{\text{ft.}}$$

Answer:

The grade on the pipe is $\frac{\frac{1}{8}”}{\text{ft.}}$.

Example 3:

Find the length of a sewer line when the grade is $\frac{3}{16}„$ per foot and the total fall is $22\frac{1}{2}„$.

Note: This is an example where the total fall is given and the grade is given. In this case we have to solve for the run.

$$\text{Run (in feet)} = \frac{\text{Total fall (in inches)}}{\text{Grade (in inches per foot)}}$$

Solution:

$$\text{Run} = \text{Total Fall} \times \text{Grade} \quad \text{Run} = \frac{22.5”}{\frac{3}{16}”/\text{ ft.}} = \frac{22.5”}{0.1875”/\text{ ft.}} = 120 \text{ ft.}$$

Answer:

The length of the pipe is 120 ft.

Percentage Calculations

Unlike fraction calculations, which are used only in the imperial system, percentage calculations can be used for either imperial or metric measurements. Similarly, the units of length and fall in percentage problems are not going to vary. If

you are solving for the total fall and start with a length in metres, you will end up with an answer (for total fall) in metres. If you are solving for the length and start with a total fall in millimetres, you will end up with an answer (for length) in millimetres, and so on.

Example 1:

A 75-m length of piping is to be graded down at 2%. Calculate the amount of fall over the entire length of the pipe.

Solution:

$$\begin{aligned}\text{TF} &= \text{Grade} \times \text{Length} \\ &= 75\,\text{m} \times 2\% \\ &= 75\,\text{m} \times 0.02 \\ &= 1.5\,\text{m}\end{aligned}$$

Answer:

The total fall is 1.5 m or 1,500 mm.

Example 2:

A building sewer falls 400 mm over its length. It is graded at 1%. Calculate the length of the run.

Solution:

$$\text{Length} = \frac{\text{TF}}{\text{Grade}} \quad \text{Length} = \frac{400\text{ mm}}{0.01} = 40,000\text{ mm} \quad \text{Length} = 40,000\text{ mm}$$

Answer:

The length is 40,000 mm or 40 m.

Example 3:

A pipeline falls 750 mm over its length of 50 m. Calculate the percentage grade at which the line is sloped.

Solution:

First, change to the same units:

$$50\text{ m} = 50,000\text{ mm} \quad .$$

Percentage calculations represent comparisons of the same units, and therefore require that all units be expressed in equal terms.

$$\begin{aligned}\text{Grade} &= \frac{\text{TF}}{\text{Length}} \\ &= \frac{750\,\text{mm}}{50{,}000\,\text{mm}} \\ &= 0.015 \\ &= 1.5\%\end{aligned}$$

Answer:

The grade on the pipe is 1.5%.

Ratio Calculations

Much like percentage calculations, ratio calculations can be used for either imperial or metric measurements. Ratios can be written and treated exactly the same as a fraction. When grades are expressed as ratios (e.g., 1:50 or $\frac{1}{50}$), the answer will be in the same units of measure that are being used for the known dimension (feet, inches, metres, centimetres, etc.). Ratio grades are defined as the ratio of fall per unit of length. For example, a pipe graded at 1:50 will fall 1 unit of measure for every 50 units of measure of length or run.

Example 1:

A pipe is to be graded at 1:50. The length of the run is to be 25 metres. Calculate the fall on the entire pipe.

Solution:

The pipe will have a total fall equal to $\frac{1}{50}$ of its total length.

$$\text{TF} = \text{Grade} \times \text{Length} \quad \text{TF} = \frac{1\,\text{m}}{50\,\text{m}} \times 25\,\text{m} \quad \text{TF} = 0.5\,\text{m}$$

Answer:

The total fall on the pipe is 0.5 m or 500 mm.

Example 2:

A line graded at 1:133 has a drop (fall) over its entire length of 700 mm. Calculate the length of the run.

Solution:

$$\text{Length} = \frac{\text{TF}}{\text{Grade}} \quad \text{Length} = \frac{700\,\text{mm}}{\frac{1}{133}} = 700 \times \frac{133}{1} = 93,100\,\text{mm} \quad \text{Length} = 93,100\,\text{mm}$$

Answer:

The length on the pipe is 93,100 mm or 93.1 m.

Example 3:

A pipe falls 51″ over its entire length of 425′. Calculate the ratio grade on the pipe.

Solution:

Convert to the length of the run into inches (or the fall on the pipe into feet) to remain in same units for the calculation:

$$425 \text{ feet} \times \frac{12 \text{ inches}}{1 \text{ ft.}} = 5,100 \text{ inches} \quad \text{Length} = 5,100” \quad \text{Grade} = \frac{\text{TF}}{\text{Length}} \quad \text{Grade} = \frac{51}{5,100”} = \frac{1}{100} = 1:100$$

Answer:

Grade on the pipe is 1:100.

Elevation

An ***elevation*** is the distance above or below a fixed point. On construction sites the architect may specify building elevations based on a reference point called the ***benchmark***. The benchmark is some non-moving spot on the job site such as the street curb or a manhole cover.

Normally the main subfloor is assigned a reference elevation such as 100.00 metres or 100.00 feet, depending on the units used on the project. For example, if the main subfloor (elev. = 100.00′) was to be 2 feet above the curb (or the chosen benchmark), then the site benchmark would be given the elevation of 98.00 feet. Since all subsequent elevations are related to the subfloor, the architectural elevation for the “top of plate” at the ceiling (see Figure 20) would be 100.00′ plus 8.00′, or 108.00′.

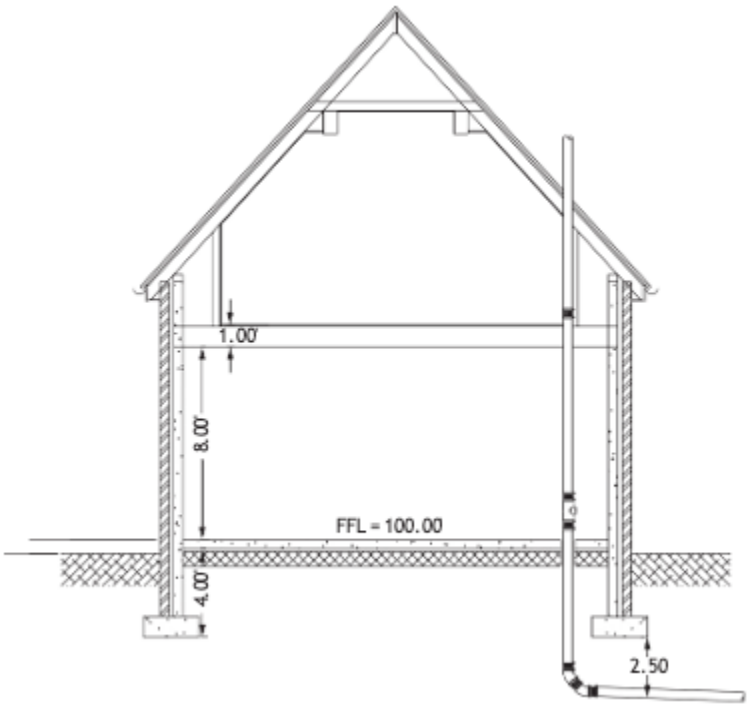

Figure 20 *Building elevation drawing showing first floor elevation as 100.00′ (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The elevation of the second floor would be 109.00′ due to the 1.00′ depth of the floor joists and the floor sheeting above it. The elevation of the bottom of the footing would be 96.00′, and the trench bottom for the building drain would be 93.50′.

Tradespeople use the project benchmark to establish the subsurface elevations because some parts of systems must be installed before the main floor is poured. Once the structure progresses above the main floor the tradesperson has a choice to use the main floor, elevation, or the benchmark for their reference point, whichever is more convenient.

In order to determine the elevations on the construction project, a pipe trades worker would use a ***builder's level***. Using a builder's level requires you to know how to calculate elevations from a benchmark or from a previously calculated elevation. Most often, the level is set up in one spot and all of the readings are taken from that location. Sometimes, the level must be moved many times, using previous sightings to calculate new elevations. When this happens, accuracy in readings and calculations becomes even more important.

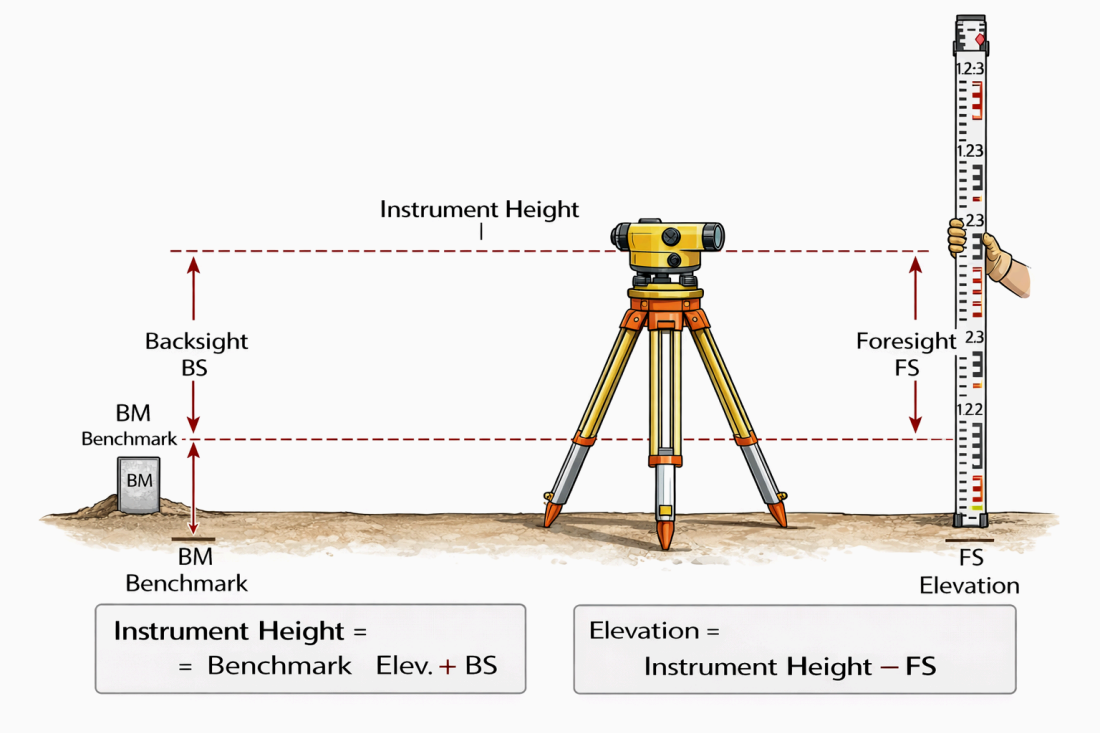

Figure 21 *Elevations measurement using builder's level (TRU Open Press/OpenAI, 2026). CC BY-NC-SA 4.0*

Figure 22 *Builder's level (circa 1856) (Gampe/Wikimedia Commons) CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons*

Land or geographic elevations are distances above or below mean sea level. When large projects are constructed and a local benchmark is impractical (e.g., a residential subdivision), ***geodetic elevations*** are used. When geodetic elevations are used on a building project, it is sometimes beneficial to omit the first one or two digits of the elevation to make calculations easier. When these digits are omitted, the elevation is referred to as ***modified or abbreviated geodetic***.

Invert Level of a Pipe

In addition to slope and length, tradespeople must also determine the exact vertical position of piping. This is done using elevation and invert measurements. The ***invert*** level of a pipe is the elevation measured at the bottom inside surface of the pipe (see Figure 23). This is the lowest point inside the pipe where fluid flows.

When working with pipe elevations, tradespeople do not measure to the top or centre of the pipe. Instead, they measure to the invert because it represents the actual flow line of the system.

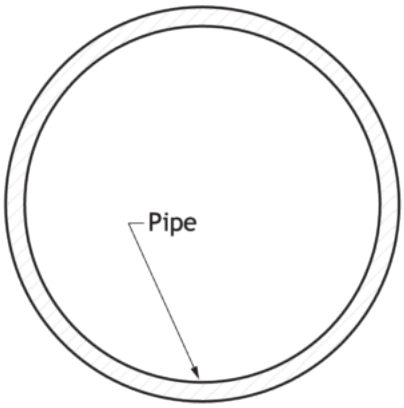

Figure 23 *Pipe invert (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

In drainage and piping systems, the invert is used because it ensures:

- Proper flow of water or waste
- Correct pipe slope (grade)
- Accurate installation elevations

Even small errors in ***invert elevation*** can cause problems such as poor drainage, standing water, or system failure.

All pipe elevations are measured from a reference point, such as a benchmark or main floor elevation. The invert elevation tells you how high or low the pipe must be installed relative to that reference. For example: If the benchmark elevation is 98.00 ft and the invert of a pipe must be installed at 95.50 ft, the pipe will be positioned 2.50 ft below the benchmark.

Practical Application:

When installing a building drain, the required slope may be specified (e.g., $\frac{1}{4}$ ″ per foot). The tradesperson will:

1. Determine the starting invert elevation.
2. Calculate the required drop over distance.
3. Set the ending invert elevation.

All measurements are taken from the invert, not the top of the pipe.

Invert = bottom inside of pipe (flow line)
Centre = middle of pipe
Crown = top inside of pipe

The following example shows how slope and invert are used together in real trade applications.

Example (Slope and Invert Calculation):

A building drain must be installed with a slope of $\frac{1}{4}$" per foot . The pipe runs 20 ft from the building to the main.

The starting invert elevation at the building is 95.50 ft. Find the required invert elevation at the end of the pipe.

Step 1: Calculate Total Drop

Slope tells us how much the pipe must drop per foot of length.

$$\begin{aligned}\text{Total Drop} &= \text{slope} \times \text{length} \\ \text{Total Drop} &= \frac{1}{4}\text{" per foot} \times 20\,\text{ft} \\ &= 5\text{"}\end{aligned}$$

Step 2: Convert Inches to Feet

Because elevations are in feet, convert 5 inches to feet:

$$5\text{"} = \frac{5}{12} = 0.417\,\text{ft (rounded)}$$

Step 3: Calculate Ending Invert Elevation

$$\text{Ending invert} = 95.50 - 0.417\,\text{ft} = 95.08\ \text{(rounded)}$$

Answer: The required invert elevation at the end of the pipe is 95.08 ft. (See Figure 24.)

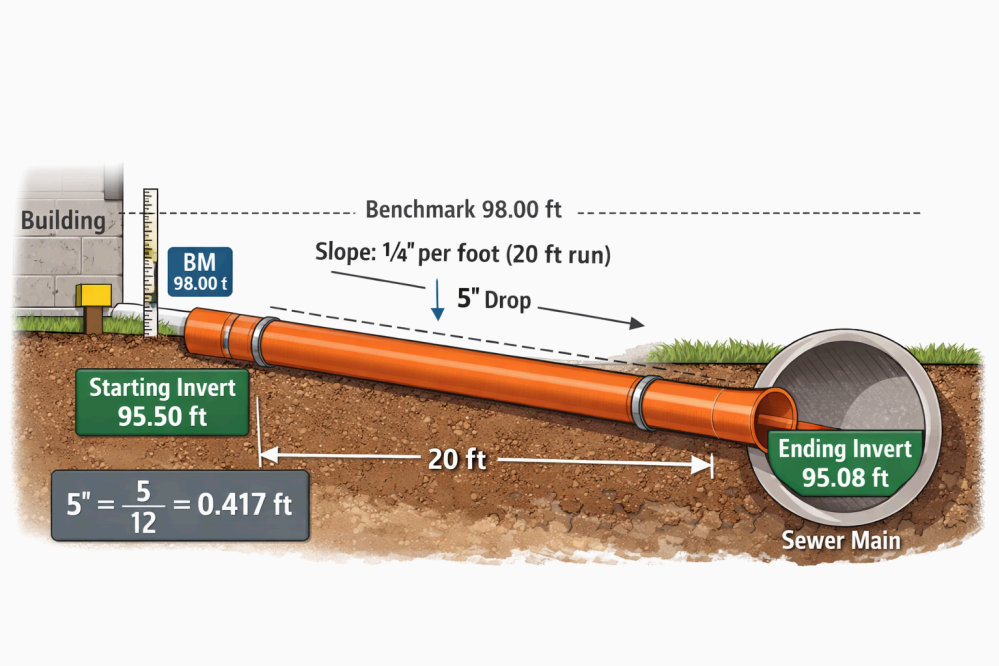

Figure 24 *Pipe slope and invert calculation diagram (TRU Open Press/OpenAI, 2026). CC BY-NC-SA 4.0*

This calculation ensures that:

- The pipe has the correct slope for drainage.
- Water flows properly through the system.
- The pipe is installed at the correct elevation relative to the benchmark.

Converting Between Engineer's Measure and Builder's Measure

Elevations can be expressed in both metric and imperial dimensions. In the metric system, calculations are straightforward, with centimetres or millimetres typically used as the smallest unit of measurement. In the imperial system, surveyors and civil engineers often use elevation measurements in feet and decimal parts of a foot. One one-hundredth (0.01) of a foot is the smallest elevation difference. Trades workers, however, often use tape measures marked in feet, inches, and fractions of an inch to the nearest $\frac{1}{16}$". Because both systems are used in the trades, it is often necessary to convert between ***engineer's measure*** (decimal feet) *and* ***builder's measure*** (feet, inches and fractions of an inch) when working with elevations.

Most shops have conversion charts that give the conversions between the metric and imperial systems most useful to your trade. Specification guides will usually give you both metric and imperial measurements if appropriate. Your calculator may also have the capacity to convert between the two systems. Read your calculator's instructions carefully; ask your instructor if you need help in figuring out how to use this feature.

Example:

Convert the decimal 14.37 ft. into feet and inches to the nearest $\frac{1}{16}$ of an inch.

Step 1: The 14 is a whole number and is already expressed in feet. Whole feet before the decimal require no conversion; therefore set the 14 aside as “14 feet” in your calculation.

Step 2: Start with the decimal 0.37. This is the number that you want to convert to inches and fractions of an inch.

Step 3: Multiply 0.37 by 12 to convert to inches:

$$0.37 \times 12 = 4.44$$

The whole number 4 represents whole inches. Whole inches before the decimal require no conversion. Set the number 4 aside as “4 inches” in your calculation.

Step 4: Multiply the decimal parts of an inch, 0.44, by 16 (the denominator commonly chosen if not otherwise specified) to solve for $\frac{1}{16}$„ :

$$0.44 \times 16 = 7.04$$

This illustrates that 0.44 of an inch (in decimal form) is equal to exactly 7.04 sixteenths of an inch. For practical purposes, round off 7.04 to the nearest whole number (7) to solve for the closest sixteenth, giving you $\frac{7}{16}$ of an inch.

Step 5: Put together the results of each equation to total:

$$14 \text{ feet, } 4 \text{ and } \frac{7}{16} \text{ inches}$$

Converting feet, inches and fractions of an inch to feet and decimal parts of a foot is the reverse of the earlier procedure.

Example:

Convert 14 feet, 4 and $\frac{7}{16}$ inches into feet and decimal parts of a foot.

Step 1: The 14 is a whole number, and it is already expressed in feet. Whole feet before the decimal require no conversion, so set the 14 aside as “14 feet” in your calculation.

Step 2: Convert $\frac{7}{16}$ of an inch into a decimal of an inch by dividing the numerator into the denominator:

$$\frac{7}{16} \text{ of an inch } = 0.4375 \text{ of an inch, therefore } 4\frac{7}{16} \text{ inches } = 4.4375 \text{ inches}$$

Step 3: Divide 4.4375 inches by 12 to determine the decimal foot equivalent:

$$\frac{4.4375 \text{ inches}}{12 \text{ inches per foot}} = 0.3698 \text{ of a foot.}$$

Round to the nearest two decimals (to represent tens and hundredths of feet) to get 0.37 feet.

Step 4: Add 14 whole feet to the result you obtained in step 3, 0.37. The total is 14.37 feet.

Sample Problems and Solutions

1. Convert $8' \, 4\frac{5}{8}"$ to engineer's measure.

$$8' = 8.00' \quad 4\frac{5}{8}" = 4.625" \quad \frac{4.625}{12\frac{\text{in.}}{\text{ft.}}} = 0.38' \quad \therefore 8' \, 4\frac{5}{8}" = 8.00' + 0.38' \quad = 8.38'$$

2. Convert 94.28′ to a builder's measure.

$$94' = 94.00' \quad 0.28' = 0.28' \times 12\frac{\text{in.}}{\text{ft.}} = 3.36" \quad 3.36 = 3" + (0.36" \times 16) = 3\frac{6}{16}" = 3\frac{3}{8}" \quad \therefore 94.28' \; = 94' \, 3\frac{3}{8}"$$

3. The benchmark is 100.00 feet elevation. The basement floor is 94.70 feet elevation. The first floor is 102.95 feet elevation.
   a. How far below the benchmark is the basement floor?

$$100.00' - 94.70' \; = 5.30' \text{ or } 5' \, 3\frac{5}{8}" \text{ below benchmark}$$

   b. How far above the benchmark is the first floor?

$$102.95' - 100.00' = 2.95' \text{ or } 2' \, 11\frac{3}{8}" \text{ above benchmark}$$

   c. How far is it from the basement floor to the first floor?

$$102.95' - 94.70' = 8.25' \text{ or } 8' \, 3" \text{ between basement and first floors}$$

4. A house drain has a run of 30 feet at a grade of $\frac{1}{8}$ inch per foot. The low end has elevation of 93.50 feet. What elevation is the high end?

$$30' \times \frac{1}{8}" = 3\frac{3}{4}" \text{ difference in elevation} \quad 93.50 = 93' \, 6" \quad 93' \, 6" + 3\frac{3}{4}" = 93' \, 9\frac{3}{4}"$$

Self-Test C-1.7.2: Grade, Elevation, and Benchmarks

Complete Self-Test C-1.7.2 and check your answers.

If you are using a printed copy, please find Self-Test C-1.7.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2429#h5p-13

Notes for Question 29:

- Main line (pipe sections 1 & 4) are 12″ in diameter
- Branch line (pipe sections 2, 3, 5 & 6) are 6″ in diameter

- Grade on all pipe sections is $\frac{\frac{1}{8}\text{”}}{\text{ft.}}$

Sump:

- Liquid depth = 24″
- Inlet is 4″ higher than outlet
- Sump height = 60″

Catch basin:

- Liquid depth = 18″

- Catch basin height = 36″ Pipe lengths:
- Main sections:

    ▸ Pipe section 1 = 30′

    ▸ Pipe section 4 = 125′

- **Branches:**

    ▸ Pipe section 2 = 75′

    ▸ Pipe section 3 = 21′

    ▸ Pipe section 5 = 40′

    ▸ Pipe section 6 = 64′

Remember: The invert level of a pipe is the level taken from the bottom inside of the pipe (Figure 23).

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- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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C-1.8 Use the Pythagorean Theorem of Right Angles

The Pythagorean Theorem

In mathematics, the *Pythagorean theorem* (or *Pythagoras's theorem*) is a statement about the sides of a ***right triangle***.

One of the angles of a right triangle is always equal to 90 degrees. This angle is called a ***right angle***. The two sides next to the right angle are called the ***legs***, and the other side is called the ***hypotenuse***. The hypotenuse is the side opposite the right angle, and it is always the longest side.

The Pythagorean theorem states that the area of a square on the hypotenuse is equal to the sum of the areas of the squares on the legs. In Figure 1, the area of square "a" added to the area of square "b" equals the area of square "c."

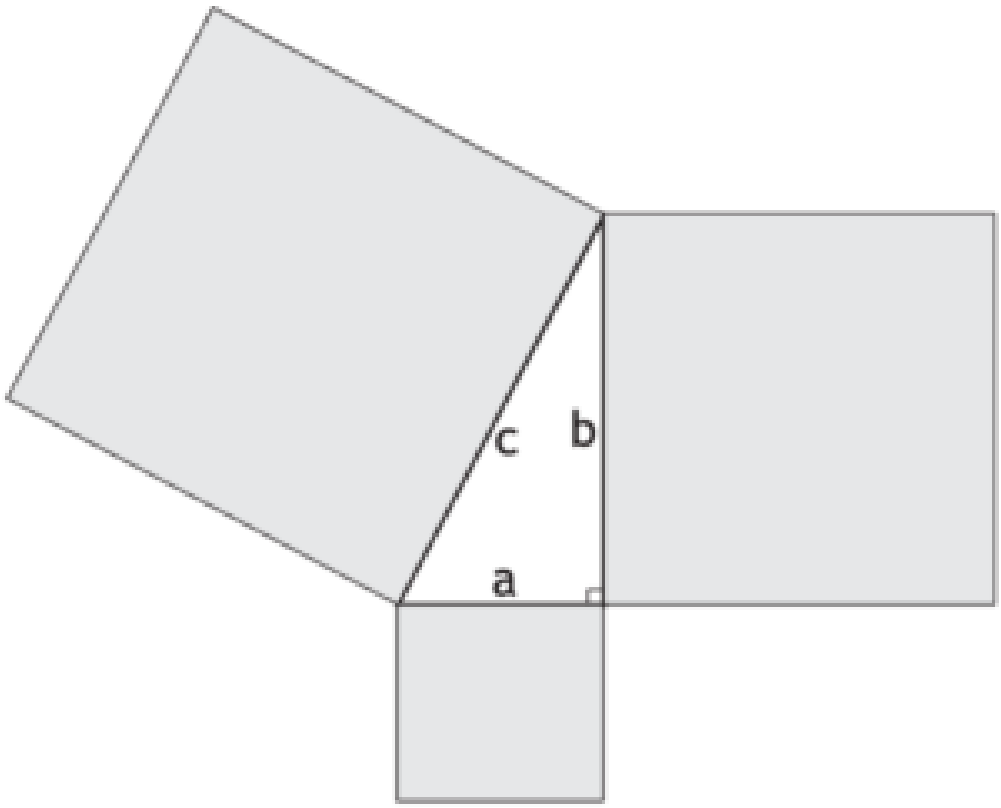

Figure 1 *Pythagorean theorem illustrated (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

If the lengths of the legs are "a" and "b" and the length of the hypotenuse is "c," then:

$$a^2 + b^2 = c^2$$

In a practical application, if you know the lengths of two of the shorter sides (legs), you can solve for the hypotenuse by using the following equation:

$$c = \sqrt{a^2 + b^2}$$

If you know the lengths of one of the shorter sides and the hypotenuse, you can solve for the other shorter side by using the following equations:

$$a = \sqrt{c^2 - b^2} \quad \text{or} \quad b = \sqrt{c^2 - a^2}$$

Example 1:

Use the Pythagorean theorem to solve for the length of the pipe C shown in Figure 2, when A = 3′ and B = 7.25′.

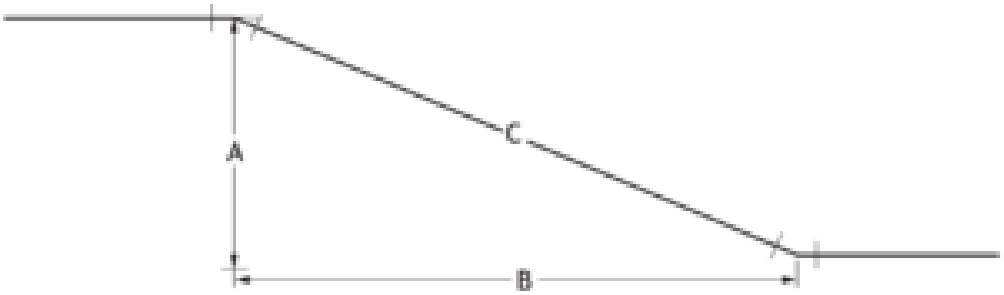

Figure 2 *Illustration for Examples 1, 2, and 3 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

$$\text{C} = \sqrt{3^2 + 7.25^2} \quad \text{C} = \sqrt{9 + 52.56} \quad \text{C} = \sqrt{61.56} \quad \text{C} = 7.85\text{'}$$

Example 2:

Using Figure 2 as your reference, solve for the length of the pipe B, when C = 55 cm and B = 47 cm.

Solution:

$$\text{A} = \sqrt{55^2 - 47^2} \quad \text{A} = \sqrt{3,025 - 2,209} \quad \text{A} = \sqrt{816} \quad \text{A} = 28.57 \text{ cm}$$

Example 3:

Solve for the length of pipe B in Figure 2, when C = 18 m and A = 4.5 m.

Solution:

$$\text{B} = \sqrt{18^2 - 4.5^2} \quad \text{B} = \sqrt{324 - 20.25} \quad \text{B} = \sqrt{303.75} \quad \text{B} = 17.43 \text{ m}$$

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Self-Test C-1.8: Use the Pythagorean Theorem of Right Angles

Complete Self-Test C-1.8 and check your answers.

Calculate the length of the missing side in the following *right-angle triangles*. Round your answers to two decimal places.

If you are using a printed copy, please find Self-Test C-1.8 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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- Steamfitter: Competency C-1 Use Mathematics and Science
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C-1.9 Calculate Offsets Using the Applicable Trigonometric Function

Both the ***Pythagorean theorem*** and ***trigonometry*** work with ***right-angle triangles***. It is important to remember the following:

- All right-angle triangles have three sides: ***hypotenuse***, ***opposite*** and ***adjacent***. In the trades, the sides are often called ***travel***, ***rise***, and ***run***.
- One angle in a right-angle triangle is always 90°.
- The sum of the three angles in a triangle is always equal to 180°.
- The *travel* (*hypotenuse*) is always the longest side and is opposite the right angle (90°).

Table 1: Trade Terms vs. Math Terms

Trade Term	Math Term	Meaning
Travel	Hypotenuse	The longest side of the triangle (diagonal)
Run	Adjacent side	The horizontal distance (beside the angle)
Rise	Opposite side	The vertical distance (across from the angle)

Tip:

- *Opposite* = across from the angle
- *Adjacent* = next to the angle
- *Hypotenuse* = longest side (always across from 90°)

Using trigonometry to solve for the length of the sides of a right-angle triangle, we label the sides with names that we use to set up our calculations. Before we begin solving for the lengths of the sides, we must determine what they are going to be called.

Right Triangle Side Names

θ is the Greek letter *theta*. It is used to represent an unknown angle in any problem using trigonometry.

The longest side of a right triangle is called the *hypotenuse*. It will always be the side that is opposite the largest angle in the triangle, the right angle. The two shorter sides are named depending on which of the two smaller angles you choose to use as your *reference angle*. The reference angle can be either of the two smaller angles, and we use it as our anchor to label the sides of the triangle.

In Figure 1, the angle ***theta (θ)*** is the reference angle. In Figure 2, the side across the triangle from the reference angle (θ) is called the *opposite side* because it is located on the opposite side of the triangle from the reference angle.

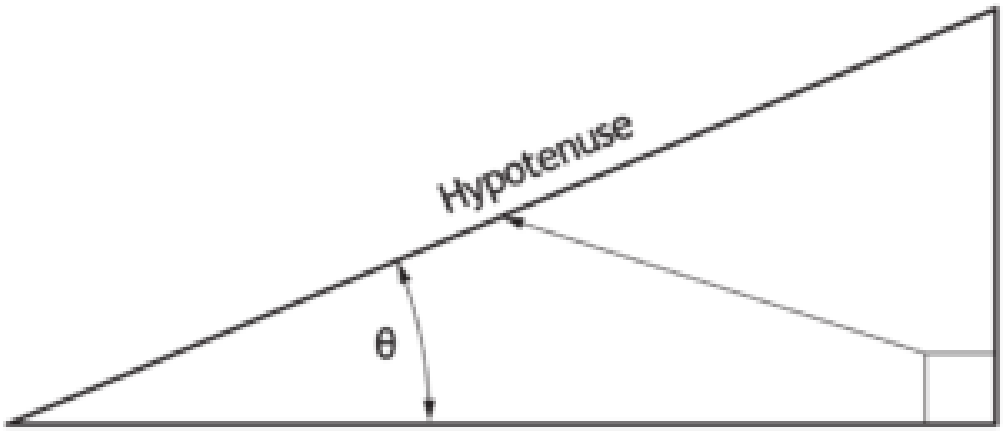

Figure 1 *Right triangle showing hypotenuse and theta (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

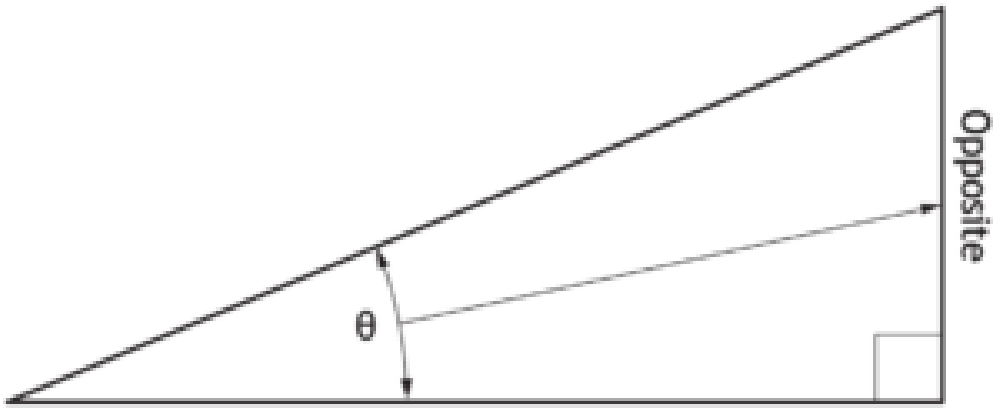

Figure 2 *Right triangle showing "opposite" side (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The side of the triangle beside the reference angle is called the *adjacent* side (Figure 3). In our case this is the side adjacent to, or beside, the reference angle (θ).

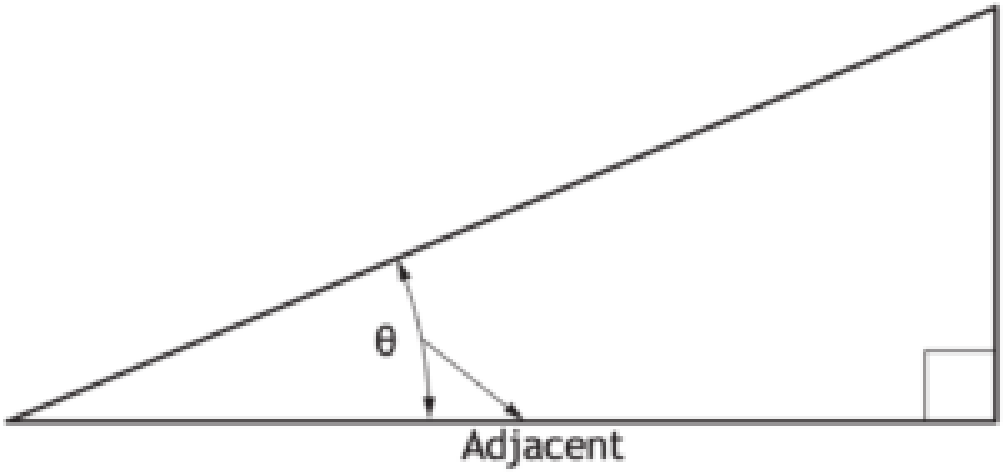

Figure 3 *Right triangle showing "adjacent" side (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

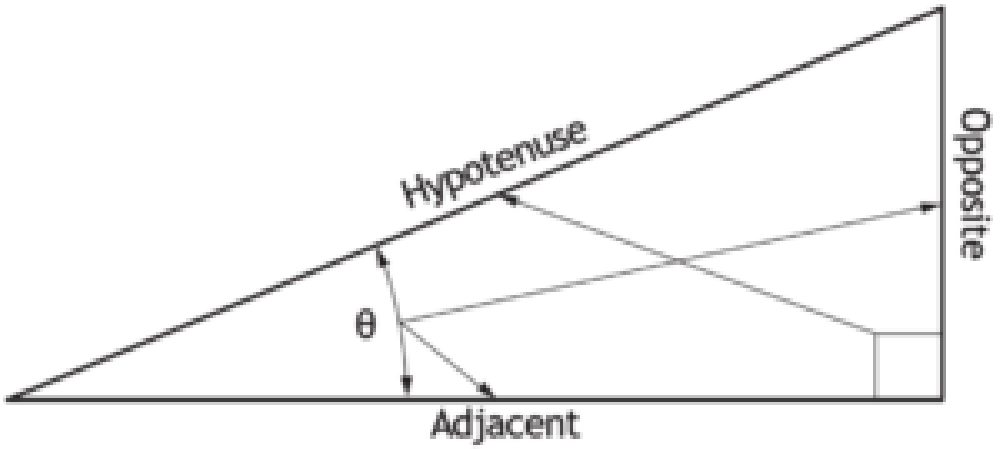

Figure 4 *Parts of a right triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

If the reference angle (θ) is switched to the other angle at the top right, then the adjacent and the opposite side also change positions (Figure 5). The hypotenuse remains the same, as it is always across from the right angle.

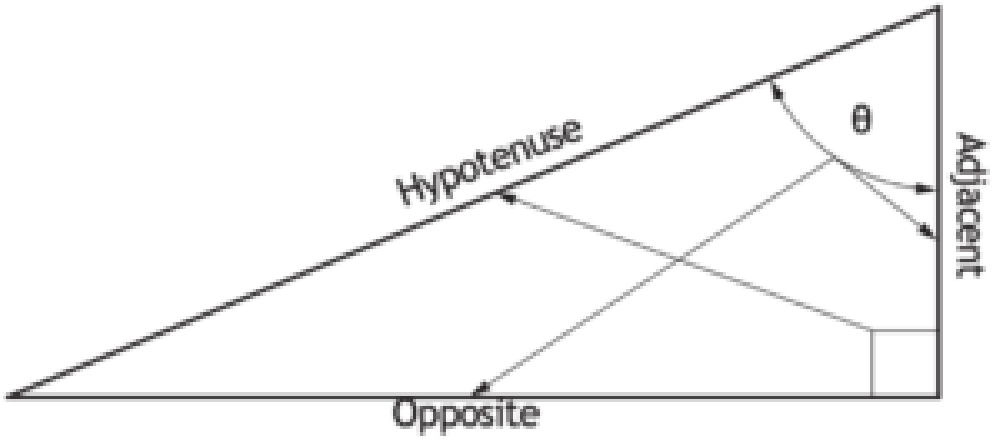

Figure 5 *Effect of switching the reference angle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Self-Test C-1.9.1: Calculate Offsets Using the Applicable Trigonometric Function

Complete Self-Test C-1.9.1 and check your answers.

Identify the opposite and adjacent sides of the following right-angle triangles using the identified angle θ as the reference angle. Place the letter associated with the side in the space provided.

If you are using a printed copy, please find Self-Test C-1.9.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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Trigonometry (Trig) Functions

Trigonometry is the branch of mathematics that deals with the relationships between the angles and sides of triangles. In the piping trades, trigonometry is essential for calculating lengths, offsets, slopes, and angles when laying out pipe runs or determining measurements that cannot be reached directly. By understanding how sine, cosine, and tangent relationships work, students can turn real-world piping problems into simple geometric calculations, making layout work faster, more accurate, and easier to visualize.

Although right-angle triangles contain two smaller (***acute***) angles, trigonometry only considers one angle at a time. For any particular size of a right-angle triangle, the ratio of the lengths of the same two designated sides will always be the same constant number. This statement is true no matter how large the triangle becomes.

The term ***ratio*** describes the proportional relationship between two values. The three sides of a right-angle triangle—*hypotenuse*, *opposite* and *adjacent*—have a fixed relationship with each other. This means that as one of the three sides increases or decreases in length, the other two sides increase or decrease proportionally. The ratios of the lengths of the sides of triangles are the ***trigonometric functions*** of the acute angles used to form the triangles.

In trigonometry, you must know at least two values in order to solve for the lengths of the sides of a triangle. You can solve a right-angle triangle if you know one of the acute angles and the length of one of the three sides. Remember: the ***hypotenuse (travel)*** is always the longest side and is always opposite the right angle.

As discussed earlier, the *opposite* and *adjacent* sides of a right triangle change depending on which angle is considered the *reference angle*. It is important to learn how to identify the sides in a right triangle because it will make trigonometry easier to understand.

Note: Trigonometric values for all possible right-angle triangles can be found in a single table. See the *IPT Pipe Trades Manual Table* #73A. pages 287–292.

There are three basic *trigonometric functions* (ratios):

- Sine
- Cosine
- Tangent

The *sine* of an angle is the ratio of the length of the opposite side to the length of the hypotenuse. The abbreviation of sine is *sin*.

$$\sin = \frac{\text{opposite side}}{\text{hypotenuse}}$$

The *cosine* of an angle is the ratio of the length of the adjacent side to the length of the hypotenuse. The abbreviation of cosine is *cos*.

$$\cos = \frac{\text{adjacent side}}{\text{hypotenuse}}$$

The *tangent* of an angle is the ratio of the length of the opposite side to the length of the adjacent side. The abbreviation of tangent is *tan*.

$$\tan = \frac{\text{opposite side}}{\text{adjacent side}}$$

One way to remember these three trigonometric functions is using the term SOH-CAH-TOA, which is derived from the relationships shown below:

$$\text{SOH} \quad \sin = \frac{\text{opp}}{\text{hyp}} \quad \text{CAH} \quad \cos = \frac{\text{adj}}{\text{hyp}} \quad \text{TOA} \quad \tan = \frac{\text{opp}}{\text{adj}}$$

When solving trig problems, using a memory device called *compartment triangles* (Figure 6) makes it easier to determine when to multiply or divide when solving for an unknown side or angle.

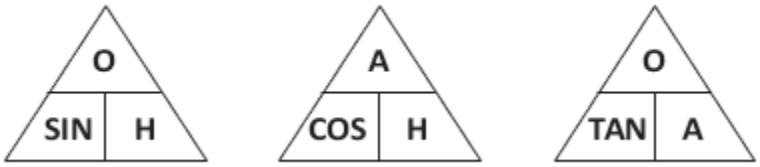

Figure 6 *"Compartment triangles" memory device (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 1:

To use the compartment triangles, cover the unknown value with your thumb. If the two values that remain are beside each other, multiply them.

To use the compartment triangles, cover the unknown value (in Figure 7 the length of the opposite side) with your thumb. If the two remaining values are beside each other, multiply them. If the unknown value is in the bottom corner of the compartment triangle, divide the top value by the trig ratio.

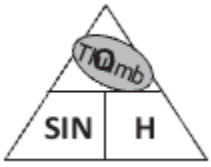

Figure 7 *Opposite side unknown (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

$$\text{Length of the opposite side} = \sin \text{ of known angle} \times \text{length of the hypotenuse}$$

Example 2:

If the unknown value is in the bottom corner of the compartment triangle (in this case the length of the hypotenuse), divide the top value by the trig ratio of your reference angle located in the other bottom corner.

Figure 8 *Adjacent known (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

$$\text{Hypotenuse} = \frac{\text{opposite}}{\sin(\theta)}$$

Important Reminder

To use any trigonometric ratio, you must know:

- One of the *acute angles*, and
- The length of one of the three sides

The trig function that you choose to solve your problem must contain the length of the side of the triangle that you know, and the length of the side of the triangle that you are looking for (the unknown side).

Example 3:

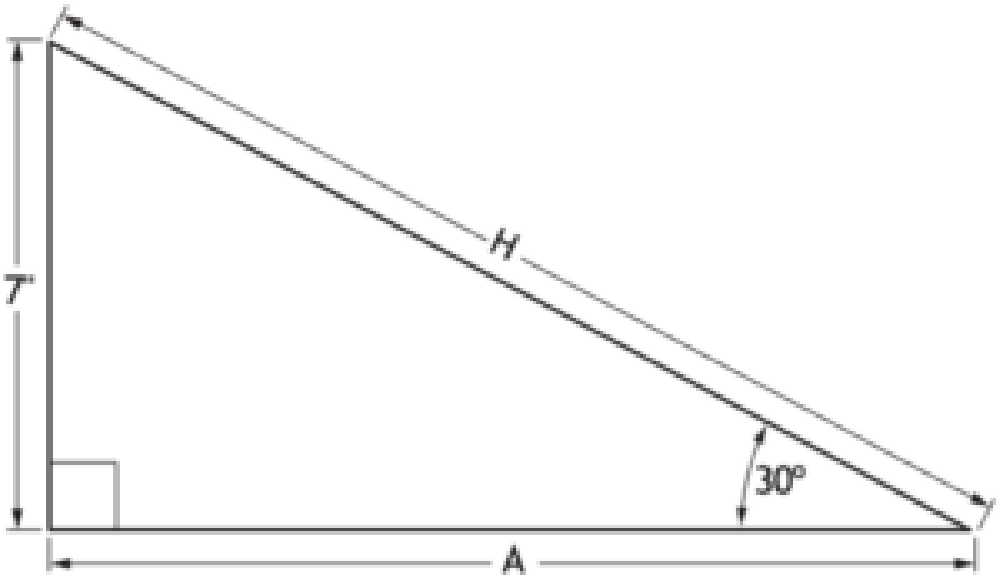

Figure 9 *Illustration for Example 3 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

In Figure 9, the reference angle used is 30°, as it is the only angle given. The known dimension is 7′, which is the opposite side of the triangle when we use the 30° angle as our reference angle. To solve the length of side A (side adjacent), we must find a trig ratio that contains both the adjacent and the opposite side.

From the three triangles available, the tan triangle is the appropriate one to use. To solve for the length of the adjacent side, put your thumb over the A (Figure 10).

Figure 10 *Adjacent side unknown (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Note: When entering the calculation string into your calculator, you must ensure that the angular unit for input is in degrees. You should see a "deg" symbol on the display.

Also, after you choose which trig function to use you must input the value of your reference angle. In this example it is 30 degrees.

Enter the following into your calculator:

$$\frac{7}{\tan(30)} = 12.124$$

Depending on the order of operation for your specific calculator, you may have to use brackets around tan 30 (*tan* 30) or change the order (30 *tan*).

A triangle that has an opposite side measuring 7′, with a reference angle equal to 30°, has an adjacent side equal to 12.12′. Because this is a ratio of the length of the opposite compared to the length of the adjacent, if the opposite side length were doubled to measure 14′, the adjacent side length would also double to 24.248′.

Using the same triangle but now solving for the length of the hypotenuse (Figure 9) means that you would require a trig ratio that includes the value you know (length of the opposite side) and the value you are looking for (length of hypotenuse).

From the available trig ratio triangles, the sin ratio is what is needed to solve this problem. To solve for the length of the hypotenuse, put your thumb over the H.

$$\frac{\text{opposite}}{\sin(30)} = \frac{7}{\sin(30)} = 14$$

This example proves that by knowing one acute angle and the length of one side, we can solve for the other two sides of the triangle.

Calculating Piping Offsets

When using trigonometry to solve piping offsets, the procedure is the same as for any other right-angle triangle calculation. The key skill is *visualizing* where the triangle exists within the offset and identifying the *reference angle*. In Figure 11, a piping offset is made with two $22\frac{1}{2}$ ° fittings. In Figure 11, a piping offset is made with two 22½° fittings. The dimension lines create a right-angle triangle, with the pipe's *travel* acting as the *hypotenuse*. The easiest reference angle to use would be the pipe's fitting angle, which would make the known dimension (2′) the adjacent side. Another acceptable method would be to use the other acute angle as the reference. In this example, this would be $67\frac{1}{2}$ °, as we know that the two acute angles must add up to 90°:

$$90^\circ - 22\frac{1}{2}^\circ = 67\frac{1}{2}^\circ$$

If you use the larger $67\frac{1}{2}$ ° as the reference angle, the known dimension (2′) now becomes the opposite side and the unknown rise is the adjacent side.

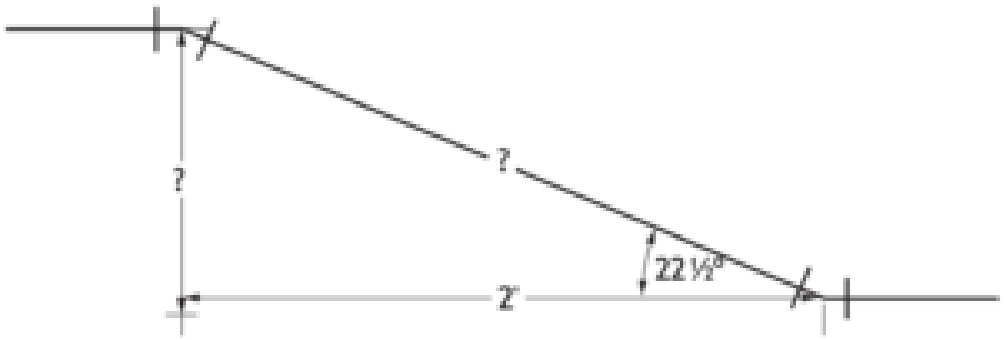

Figure 11 *Piping offset with two \(22\frac{1}{2}°\) fittings (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 1:

Using the 45° offset shown in Figure 12, calculate the centre-to-centre length of the pipe's rise and its travel.

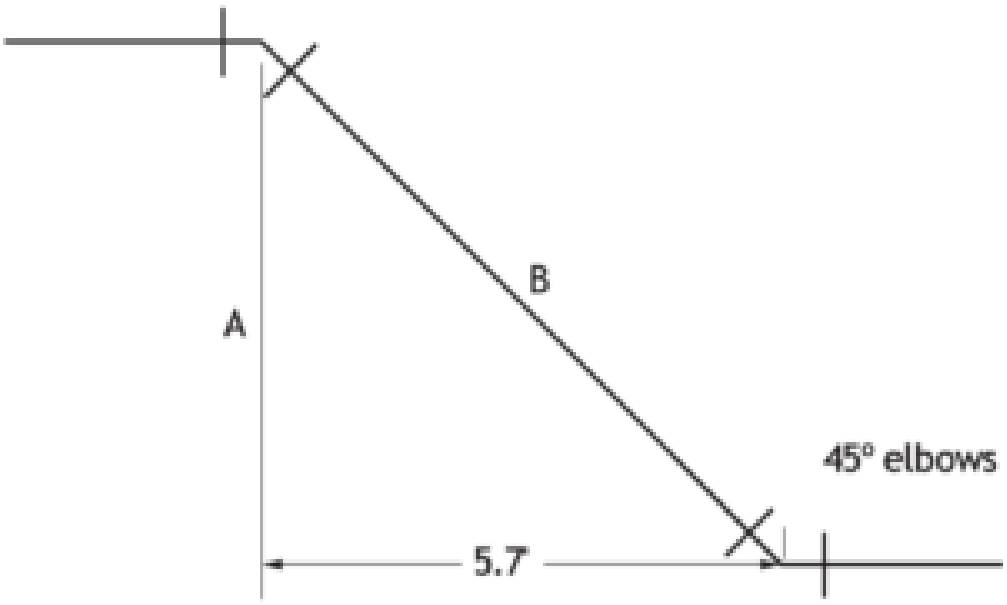

Figure 12 *Illustration for Example 1 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: Start with the side represented by letter A (rise).

Solution:

Using the 45° fitting as our angle of reference, the side of the triangle we are solving for is the opposite side. The known dimension is the adjacent side.

The given dimension is in feet and decimal parts of a foot, and can be converted to inches (67″), if preferred. We will use 67″ in our example.

As before, find a trig function that has both the adjacent and the opposite located in ratio. The tangent triangle has both of these values, so we cover over the O to get the following equation:

$$\tan(45) \times 67 = 67”$$

The calculation shows that the opposite side of the triangle is the same length as the adjacent side. This is true for all 45° triangles. Because the acute angles are equal, so are the lengths of the short sides (rise and run).

Step 2: Now calculate the amount of pipe travel represented by letter B.

Solution:

Once again using the 45° fitting as our angle of reference, the side of the triangle we are solving for is the hypotenuse. The known dimension we will use is still the adjacent side.

We find a trig function that has both the adjacent and the hypotenuse located in ratio. The cosine triangle has both of these values, so we cover over the H and see that:

$$\frac{67}{\cos(45)} = 94.75”$$

The following calculation shows that the hypotenuse of the triangle is longer than either of the two equal shorter sides by a factor of 1.414:

$$\frac{94.75}{67} = 1.414$$

This is true for all 45° triangles and can be summarized as:

- A 45° triangle will have short sides of equal length.
- A 45° triangle will have a hypotenuse that is longer than either of the shorter sides by a factor of 1.414.

These are very important facts to remember as a pipe trades worker because of the frequency that 45° ells are used in industry.

Example 2:

Using the 60° offset shown in Figure 13, calculate the amount of pipe run and travel.

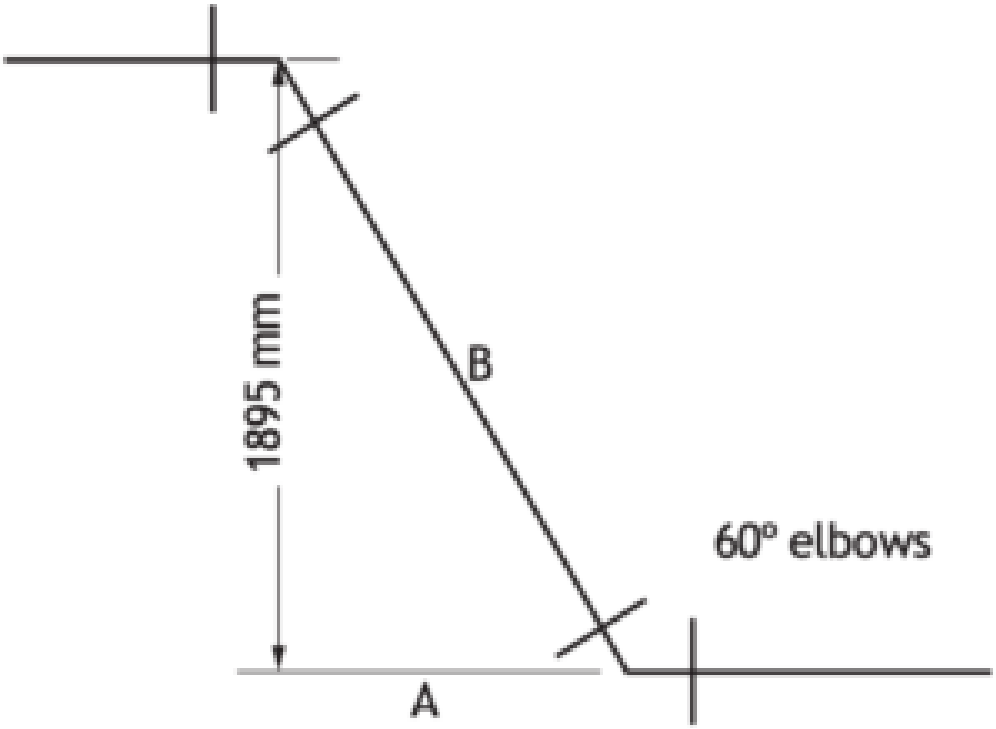

Figure 13 *Illustration for Example 2 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

Step 1: Solve for the A (run or adjacent). The known dimension is side opposite, so tangent would be the correct ratio triangle to use (Figure 14).

Figure 14 *Tan ratio triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The triangle shows that the length of side $\frac{\text{opposite}}{\tan(60)}$ would equal the adjacent side's length:

$$\frac{1,895}{\tan(60)} = 1,094.08 \text{ mm}$$

Step 2: Solve for B (travel or hypotenuse). The known dimension used is still side opposite, so sine would be the correct ratio triangle to use (Figure 15).

Figure 15 *Sine ratio triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The triangle shows that the length of side $\frac{\text{opposite}}{\sin(60)}$ would equal the length of the hypotenuse:

$$\frac{1,895}{\sin(60)} = 2,188.16 \text{ mm}$$

Self-Test C-1.9.2: Calculate Offsets Using the Applicable Trigonometric Function

Complete Self-Test C-1.9.2 and check your answers.

Using trigonometry, solve for the unknown lengths for the following 45° (questions 1-10), 60° (questions 11-20), and $22\frac{1}{2}$ ° (questions 21-30) piping offsets. Express your answers to the nearest $\frac{1}{8}$„ or 0.1 mm, as required.

If you are using a printed copy, please find Self-Test C-1.9.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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C-1.10 Calculate Required Measurements for Piping Offsets

Parallel Unequal Spread

Offsets are designed into piping systems when it is necessary for a piping run to avoid an obstacle or another component of the piping system.

When parallel piping runs are installed by a fitter, the pipes run at a certain ***spread***. Spread is the distance (centre-to-centre) between pipes. In many installations, the spread distance changes when we offset around an object. This type of offset is called an ***unequal spread offset***. This piping practice poses aesthetic problems when the piping is exposed, which is common in many industrial applications.

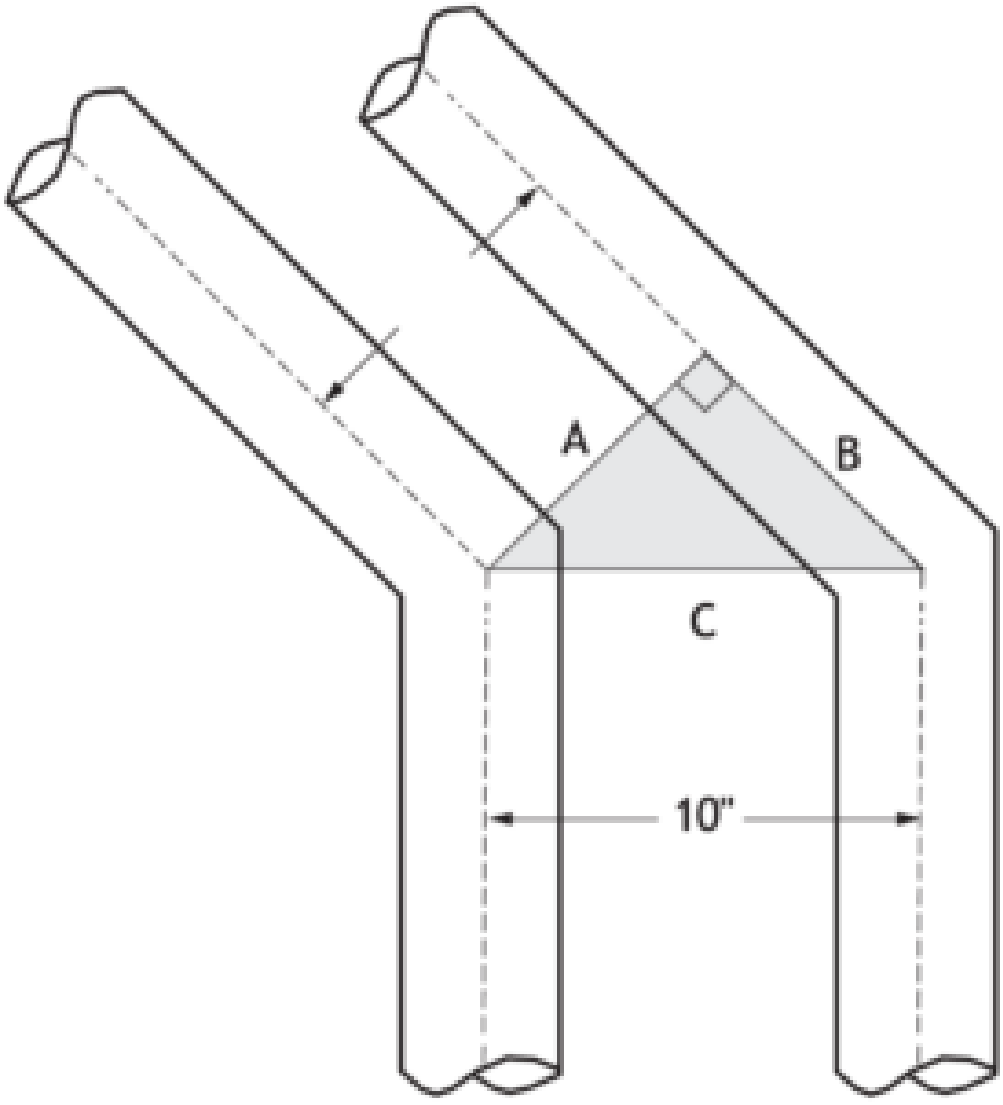

Figure 1 *Parallel unequal spread offset (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A close look at the start of a 45° offset (Figure 1), shows that the two parallel lines terminate at the same place. This is indicated by the line labelled C. It is also apparent that line C is the ***hypotenuse*** of a triangle formed by the shaded area. Once the offset is formed the spread has been reduced by almost 3″ (indicated by line A, which is the ***adjacent side*** of the triangle)

Given the original spread of 10″, we can calculate the new spread using ***trigonometry*** by solving for the adjacent side:

$$\cos(45) \times \text{hypotenuse} = \text{adjacent}$$

Example using 45° elbows:

Figure 2 shows a parallel piping run with an 8″ spread. The original route is obstructed by a building column and requires a 6″ offset to go around it using 45° elbows. The original spread (8″) is the hypotenuse of the triangle formed by the dashed lines. The reduced spread through the turn is the adjacent side of the triangle.

Solve for the length of the reduced spread.

Solution:

$$\cos(45) \times \text{hypotenuse} = \text{adjacent}$$

$$\cos(45) \times 8\text{”} = 5.66\text{”}$$

It is important to note that when the offset terminates, the pipe run returns to its original spread, as shown in Figure 2. The reduced spread (A) is still the adjacent side, and the 8″ spread (C) is the hypotenuse of the triangle.

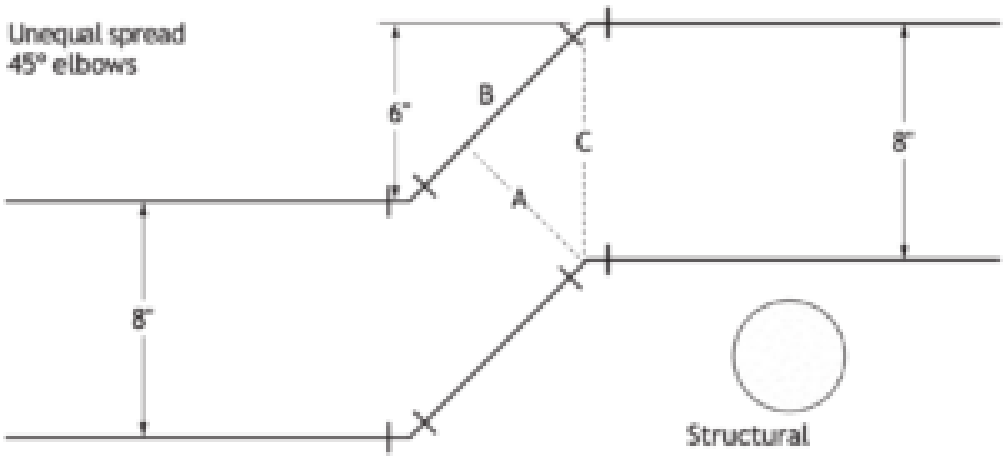

Figure 2 *Illustration for example using 45° elbows (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example using $22\frac{1}{2}^\circ$ **elbows:**

Figure 3 shows a parallel piping run with a 10″ spread. The pipe run has a 4″ offset using $22\frac{1}{2}^\circ$ elbows. The original spread (10″) is the hypotenuse of the triangle formed by the dashed lines. The reduced spread, through the turn, is the adjacent side of the triangle.

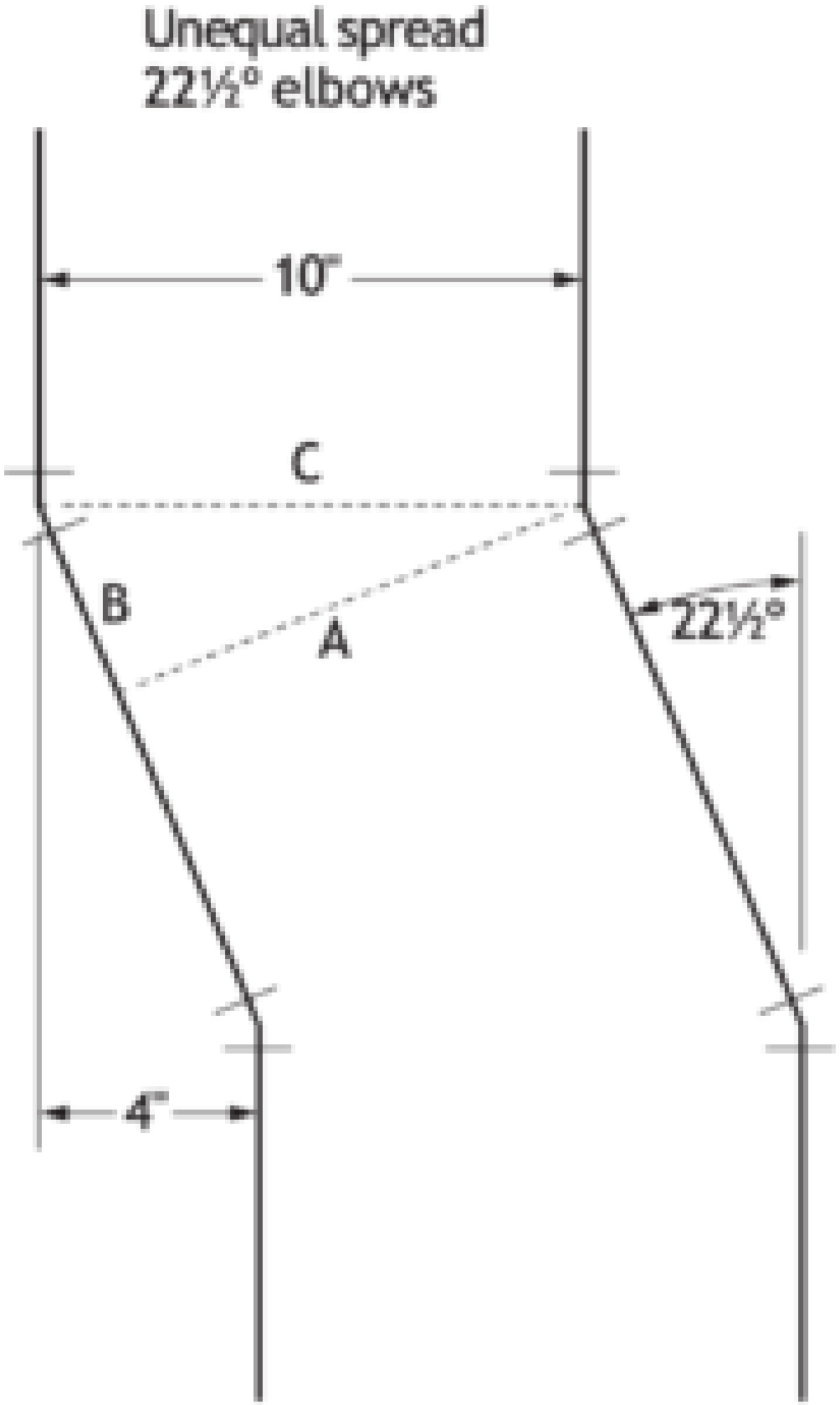

Figure 3 *Illustration for example using \(textit{22}\frac{\textit{1}}{\textit{2}}°\) elbows (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solve for the length of the reduced spread:

$$\cos(22\frac{1}{2}) \times \text{hypotenuse} = \text{adjacent}$$

$$\cos(22\frac{1}{2}) \times 10\text{”} = 9.24\text{”}$$

Example using 45° elbows:

Solve for dimensions A and B in Figure 4.

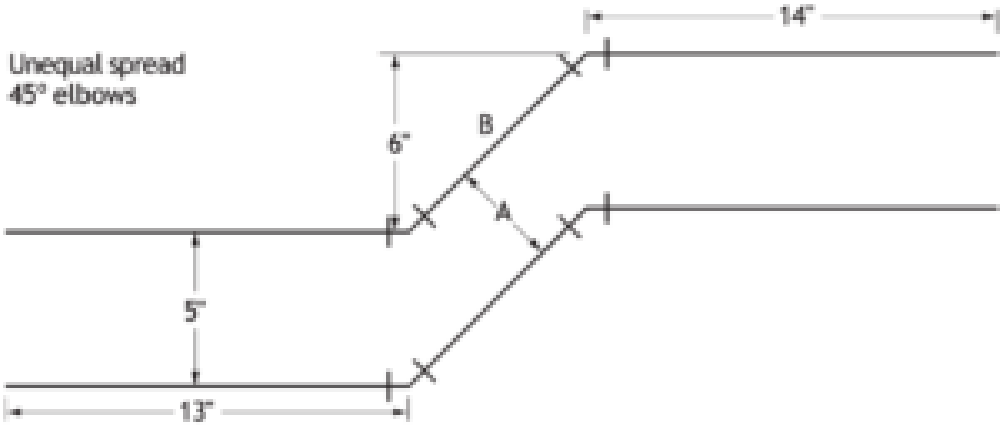

Figure 4 *Illustration for example using 45° elbows (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

Dimension A:

The original spread is the hypotenuse of the triangle formed by the offset. Dimension A is the reduced spread through the offset, which is the adjacent side of the triangle.

$$\cos(45) \times \text{hypotenuse} = \text{adjacent}$$

$$\cos(45) \times 5\text{”} = 3.535\text{”} \text{ or } 3\frac{1}{2}$$

Dimension B:

Dimension B is the travel piece length formed by a 6″ offset. Since we are using 45° elbows, the travel will be the hypotenuse of a 6″ triangle. We can solve for this in two ways. One method is to use trigonometry, where the lengths of both the adjacent and ***opposite sides*** are 6″, and the length of the hypotenuse is solved using the sin triangle (the *sine* function on your calculator) (Figure 5).

Figure 5 *Sin triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

$$\frac{6}{\sin(45)} = 8.485\text{” or } 8\frac{1}{2}\text{”}$$

As mentioned earlier, because we use 45° triangles so often in the piping trades, it is useful to remember the multiplier for a 45° offset. The centre-to-centre length of the travel piece (hypotenuse) will always be 1.414 × the length of either of the shorter sides:

$$6\text{” } \times 1.414 = 8.485\text{” or } 8\frac{1}{2}\text{”}$$

Parallel Equal Spread Offsets

Equal spread offsets are offsets in which the piping's centre-to-centre measurements remain the same through the offset. This consistent distance is achieved by increasing the length of the pipe on the outside of the offset to maintain equal spacing. This is the preferred way of installing parallel piping runs in our industry.

A close look at the 45° offset in Figure 6 shows that the pipes do not start the offset at the same point. The distance that one fitting extends past the next is indicated by the length of line B and is called the ***extension***. If we use the smaller angle as the reference angle, we can see that the known dimension (10″) is the adjacent side, and the *extension* is the opposite side of the triangle. **This reference angle is always half of the fitting angle**, in this case $22\frac{1}{2}^\circ$.

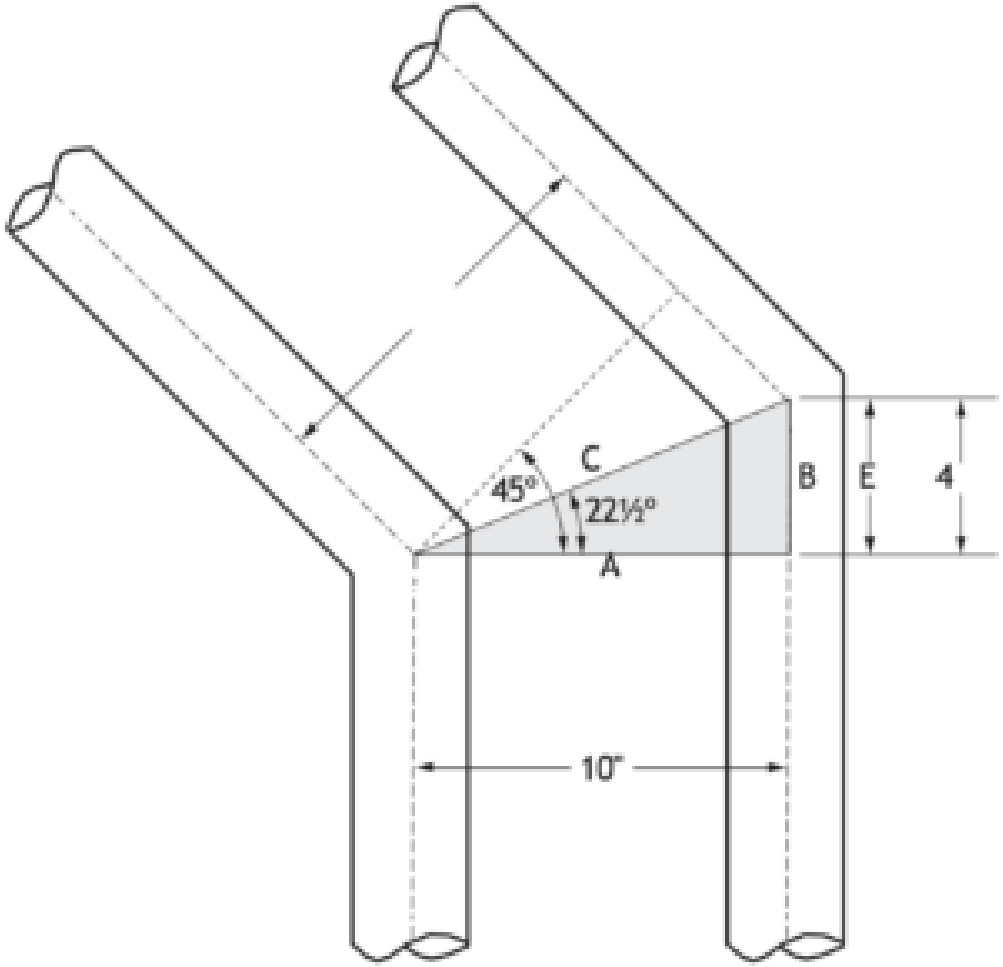

Figure 6 *Equal spread offset (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Calculating the Extension

As stated earlier, the angle used for calculating the extension for an equal spread offset is half of the fitting angle. This is because the extension is measured from the centre of the fitting, and at that point, only half of the fitting's deflection has occurred.

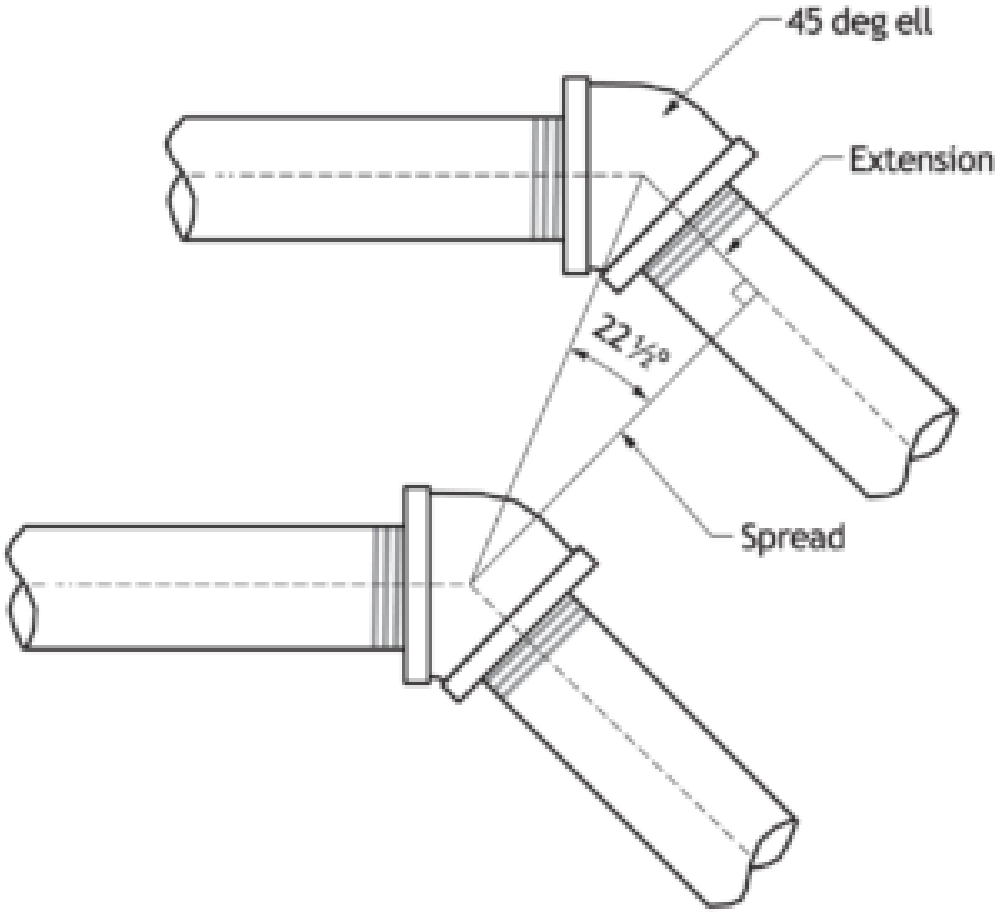

Figure 7 *Calculating the extension (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

It is important to note that because both the extension and the spread are two sides of the same triangle, when the spread increases, the length of the extension increases proportionally.

To find the length of the extension, we use the given spread (10″) as the adjacent side of the triangle. The length of the extension is the opposite side (B).

Figure 8 *Tan triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The solution therefore is:

$$\tan(22.5) \times 10” = 4.142” = 4\frac{1}{8}”$$

Example using 45° elbows:

Find the length of the extension for the piping offset in Figure 9, which has an 8″ spread.

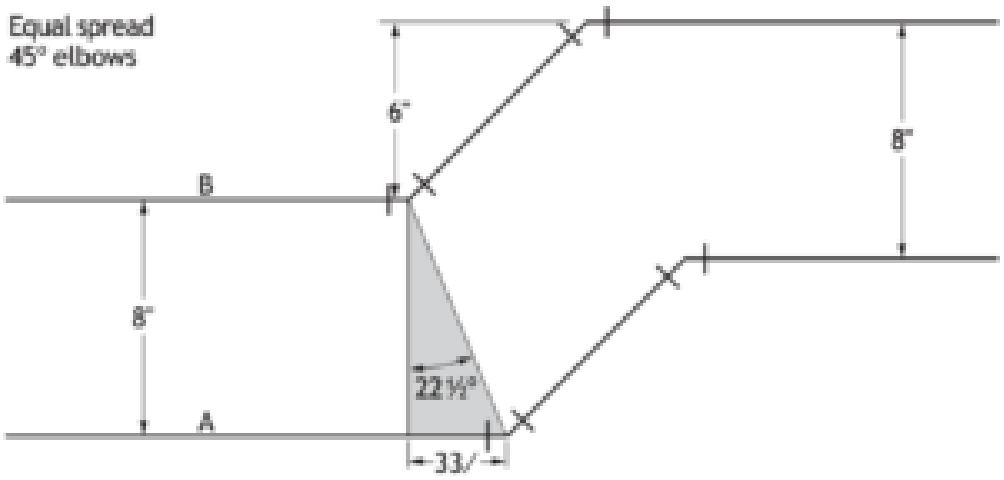

Figure 9 *Piping offset with 8″ spread (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

$$\tan(22.5) \times 8\text{”} = 3.314\text{”} = 3\frac{3}{8}\text{”}$$

Pipe A is longer than pipe B by the length of the extension, in this case, $3\frac{3}{8}$” .

Example using 60° elbows:

Solve for lengths A, B, C and D in Figure 10.

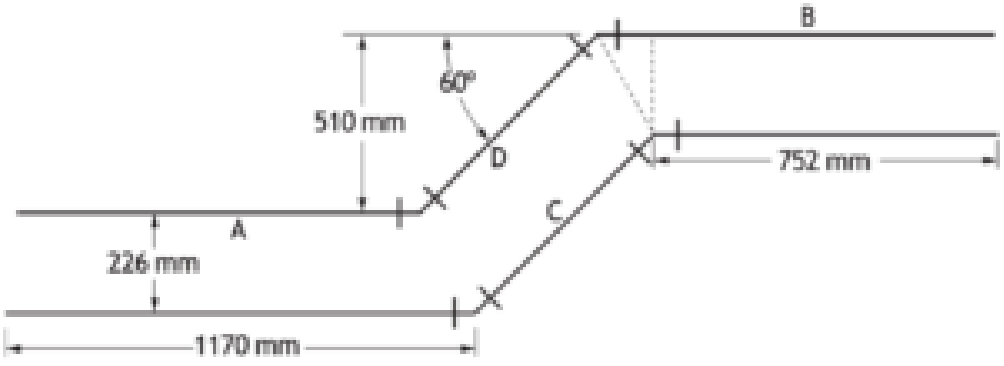

Figure 10 *Equal spread offset with 60° elbows (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

Length A:

Pipe A is shorter than the given dimension (1,170 mm) by the length of the extension formed by a 226-mm spread.

Calculate the extension:

$$\tan(30) \times 226 = 130.48 \text{ mm}$$

The length of pipe A is:

$$1,170 - 130.48 = 1,039.52$$

Length B:

Pipe B is longer than the given dimension (752 mm) by the length of the extension using the same 226-mm spread.

The length of pipe B is:

$$752 + 130.48 = 882.48 \text{ mm}$$

Lengths C and D:

Because these two pipes are parallel and maintain the equal spread, they are of identical length. They are really the hypotenuse of a 60° triangle. The given dimension of 510 mm is the opposite side of the triangle. With this information, sin is the trig function to use (Figure 11).

Figure 11 *Sin triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solution:

$$\frac{510}{\sin(60)} = 588.897 \text{ mm}$$

Self-Test C-1.10.1: Calculate Required Measurements for Piping Offsets

Complete Self-Test C-1.10.1 and check your answers.

Solve for the lengths indicated. Express your answers to the nearest $\frac{1}{8}$„ or 0.1 mm, as required.

If you are using a printed copy, please find Self-Test C-1.10.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2435#h5p-17

Rolling Offsets

When the travel section in an offset piping arrangement is neither parallel nor perpendicular to the horizontal or vertical planes, the arrangement is called a ***rolling offset***. There are times when both horizontal and vertical direction changes are required to route piping around an obstacle.

The pipe run in Figure 12 shows a typical rolling offset with vertical and horizontal offsets. To visualize the travel of the pipe, imagine a three-dimensional box with the pipe entering at one corner and exiting at the opposite diagonal corner.

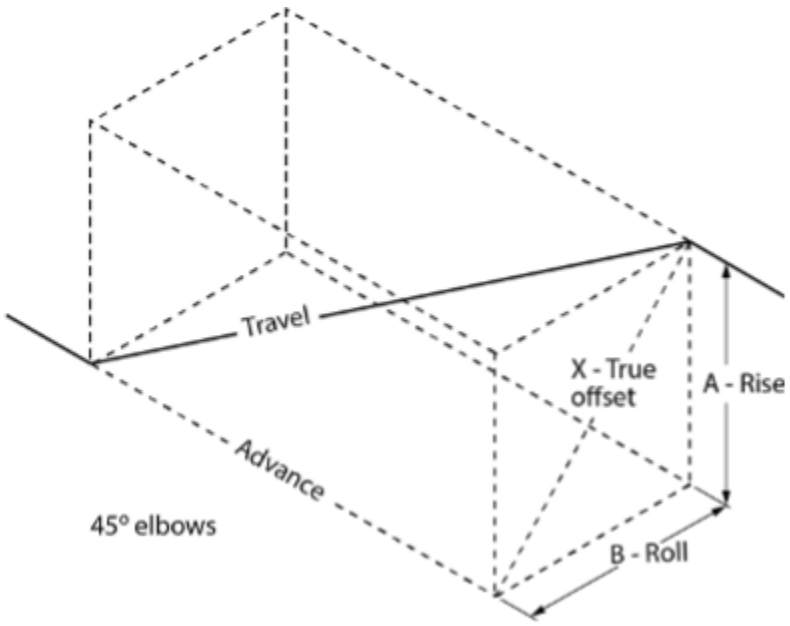

Figure 12 *Typical rolling offset (In Figure 12, A is the Rise, B is the Roll and X is the True Offset) (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

In order to solve for the length of pipe needed for the travel, we must add some dimensions to this imaginary box, starting with the vertical offset dimension, or ***rise*** (A), and the horizontal offset dimension, or ***roll*** (B). For our example we will use a 30″ vertical rise and 24″ horizontal roll for our offset.

The first step is to find the length of the ***true offset***, which is the diagonal line X in Figure 12.

In past exercises, we found the lengths of different sides of a triangle using trigonometry. When we did this, we knew the reference angle and the length of at least one side. By knowing these two values, we could calculate the lengths of the other two sides.

To solve for the true offset (X), we know the length of two sides, but we do not know the angles (other than one being a right angle). To find the length of the true offset, we must use the ***Pythagorean theorem***.

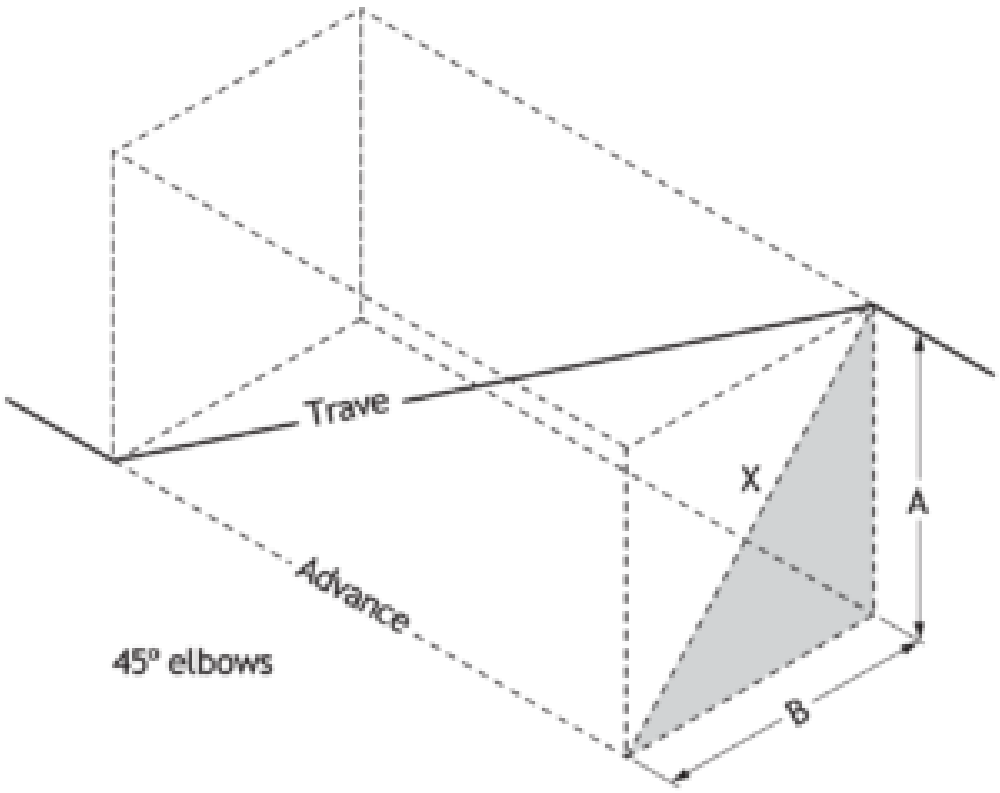

Figure 13 *Triangle for using Pythagorean theorem (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Remember that if we know the lengths of two of the short sides of the shaded triangle, we can solve for the hypotenuse (X) by using the following equation:

$$c = \sqrt{a^2 + b^2}$$

In our example, the equation would look like this:

$$\text{TO} = \sqrt{30^2 + 24^2} \quad \text{TO} = \sqrt{900 + 576} \quad \text{TO} = \sqrt{1,476} \quad \text{TO} = 38.42\text{” or } 38\frac{3}{8}\text{”}$$

Once the true offset has been determined, we can use this measurement to calculate:

- *advance* (horizontal component)
- *travel* (actual pipe length)

Referring to Figure 14, we see that the true offset (X) is actually part of two triangles. It serves as the hypotenuse of the dark shaded triangle we solved for earlier using our 30″ and 24″ dimensions. Also, and more importantly, it serves as the opposite side of the light-shaded 45° triangle. This triangle also contains the length of the offset travel (as the hypotenuse) and the length of the offset ***advance*** (as side adjacent).

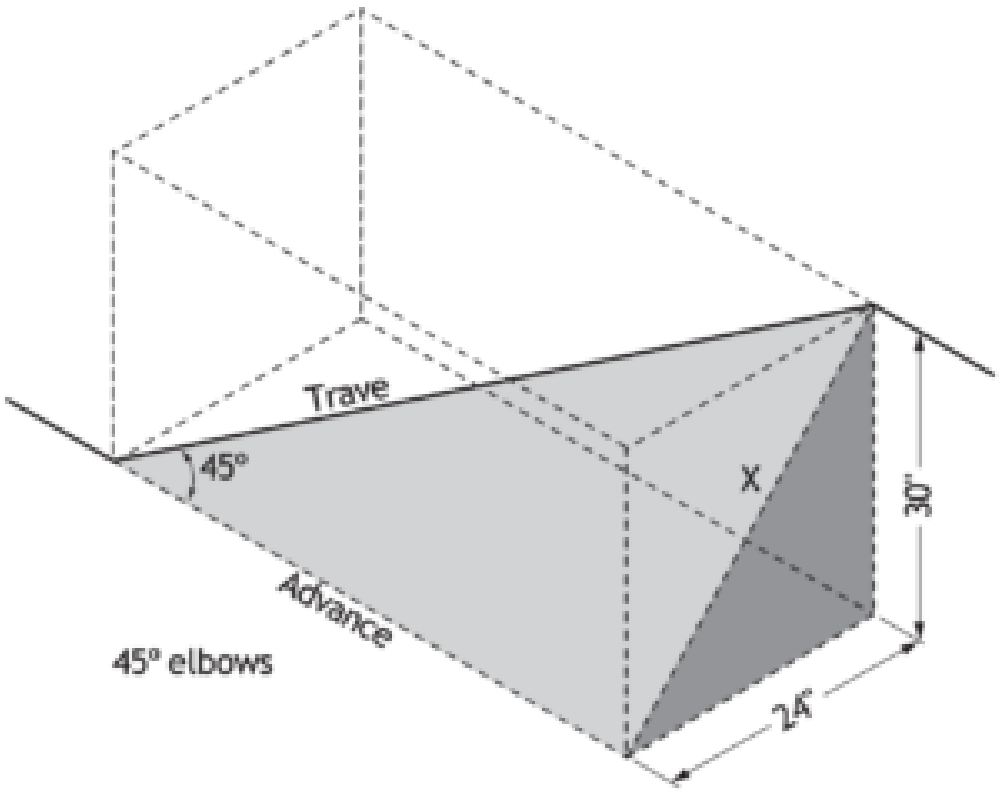

Figure 14 *True offset as part of two triangles (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Given the fitting angle, called the reference angle (45), and the length of one side, called side opposite (X), we can now use trigonometry to solve for the two unknown dimensions.

Solve for advance:

Tan is the trig function to use to solve for side adjacent (Figure 15). Using our triangle to solve for the adjacent, the equation should read:

$$\frac{\text{opposite}}{\tan(45)} = \text{adjacent}$$

Figure 15 *Tan triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Using the length of the opposite (true offset) as 38.42″, the length of the adjacent would be:

$$\frac{38.42}{\tan(45)} = 38.42$$

The lengths of the adjacent and opposite sides are the same in this case. As discussed earlier, this is true for the short sides of all 45° triangles. When solving for other fitting angles ($22\frac{1}{2}^\circ$ or 60°), this will not be the case, and additional trig calculations will need to be used.

Solve for travel:

The travel is the hypotenuse of the 45° triangle and can be found by using the sin function (Figure 16).

$$\frac{38.42}{\sin(45)} = 54.33$$

Figure 16 *Sin triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example:

The offset in Figure 17 uses 60° elbows. Solve for the lengths of the following:

a. True offset
b. Advance
c. Travel
d. Dimension A
e. Dimension B

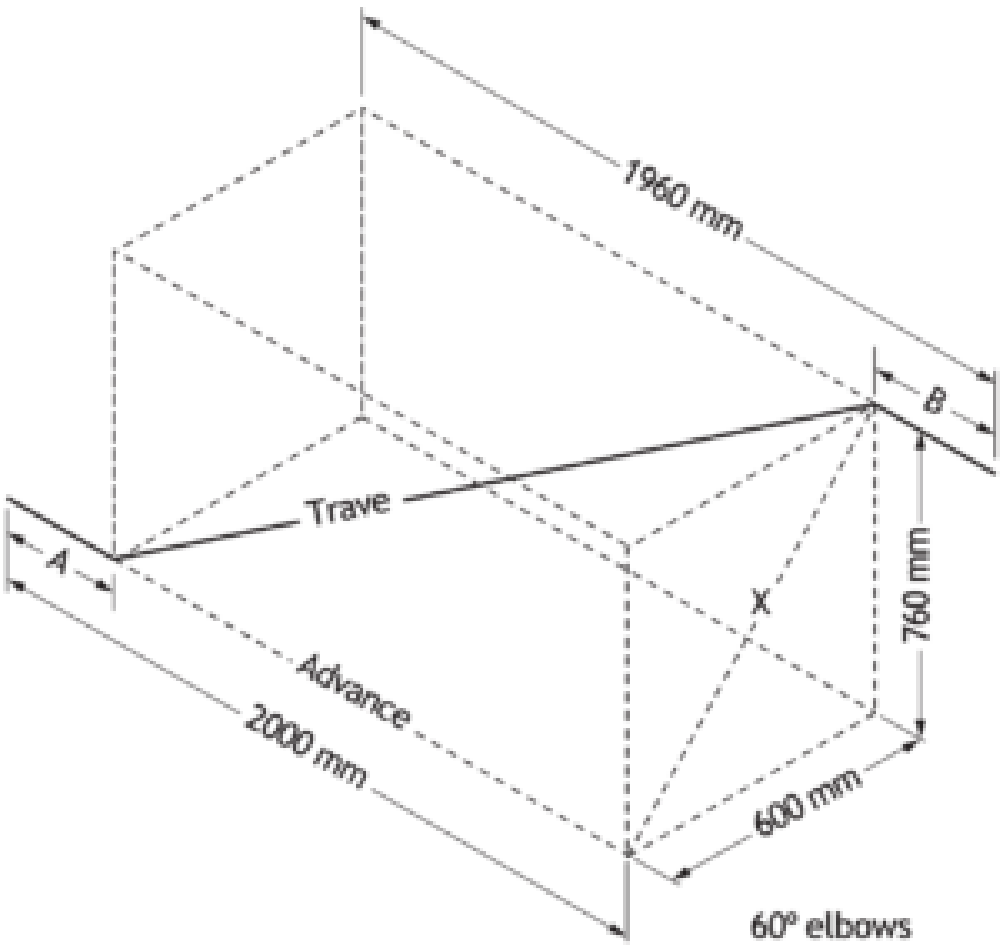

Figure 17 *Illustration for example (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

a. Solve for true offset:

$$\text{TO} = \sqrt{760^2 + 600^2} \quad \text{TO} = \sqrt{577,600 + 360,000} \quad \text{TO} = \sqrt{937,600} \quad \text{TO} = 968.3 \text{ mm}$$

b. Solve for advance (adjacent):

$$\frac{\text{opposite}}{\tan(60)} = \text{adjacent} \quad \frac{968.3}{\tan(60)} = 559 \text{ mm}$$

c. Solve for travel (hypotenuse):

$$\frac{\text{opposite}}{\sin(60)} = \text{hypotenuse} \quad \frac{968.3}{\sin(60)} = 1,118.1 \text{ mm}$$

d. Solve for dimension A:

$$\text{Given Dimension - Advance} = \text{A} \quad 2,000 - 559 = 1,441 \text{ mm}$$

e. Solve for dimension B:

$$\text{Given Dimension - Advance} = \text{B} \quad 1,960 - 559 = 1,401 \text{ mm}$$

Jumper Offsets

A *jumper offset* in a piping system uses a combination of fittings to route piping around or over an obstacle such as a duct, column, or other object. Unlike a rolling offset, a jumper offset changes direction in only one plane. There are two common configurations for jumper offsets, both of which contain 45° fittings:

- two 45° elbows and one 90° elbow
- four 45° elbows

This approach provides a more streamlined flow path compared to the installation of four 90° fittings.

The key to solving jumper offsets is recognizing where the 45° triangles occur in the layout.

- Multiply a short side by 1.414 to find the hypotenuse
- Divide the hypotenuse by 1.414 to find a short side

The key to solving for the lengths of a piping arrangement is the ability to recognize where the 45° triangles are located in the offset.

Example 1:

Figure 18 shows a jumper piping offset containing two 45° fittings and one 90° fitting. The piping is installed to "jump" over a run of circular ductwork.

Solve for the centre-to-centre lengths of the lettered pipe sections indicated using the following information:

- Duct diameter = 8″
- Space between outside of duct and pipe's centreline = 1″

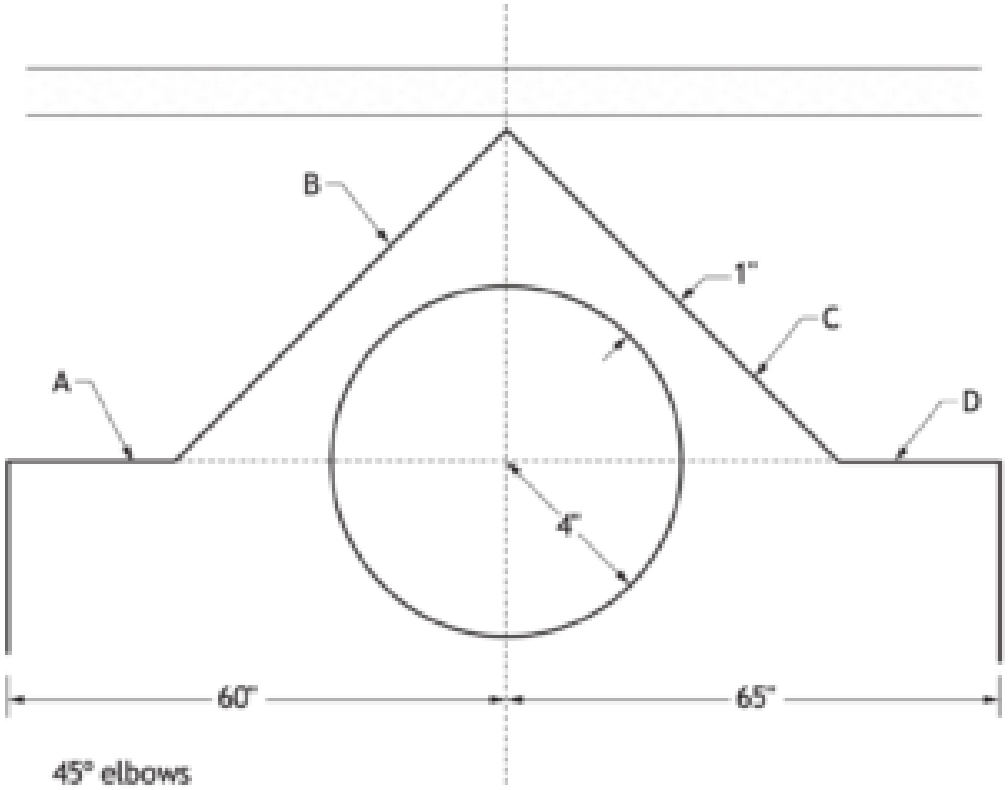

Figure 18 *Jumper offset (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: First, find the side of the secondary square or right angle triangle. (Figure 19). Scribe a line from centre of the duct rising at 45° until it intersects the centreline of the diagonal pipe B. Once the side of the secondary square is established, you can now find its length:

$$\text{duct radius} + \text{space} = \text{length of secondary square}$$

$$4” + 1” = 5”$$

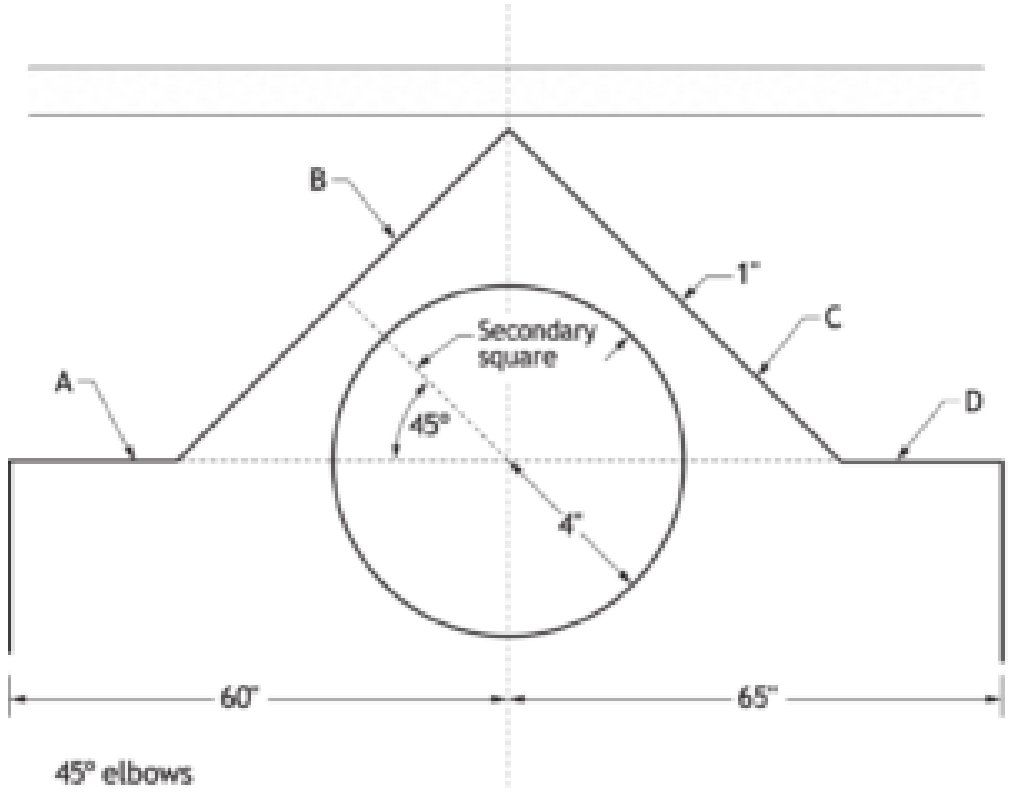

Figure 19 *Secondary square (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 2: Multiplying the secondary square by 2 will give you the lengths of pipes B and C, as both start and end at the centreline of the duct.

Step 3: Finding the length of pipe A will require two steps: first, multiply the length of the secondary square dimension by 1.414 to find the length of the hypotenuse (Figure 20) (this will be the horizontal distance from the centreline of the duct to the centre of the 45° elbow).

$$\text{Hypotenuse} = 5\text{”} \times 1.414 = 7.07\text{”}$$

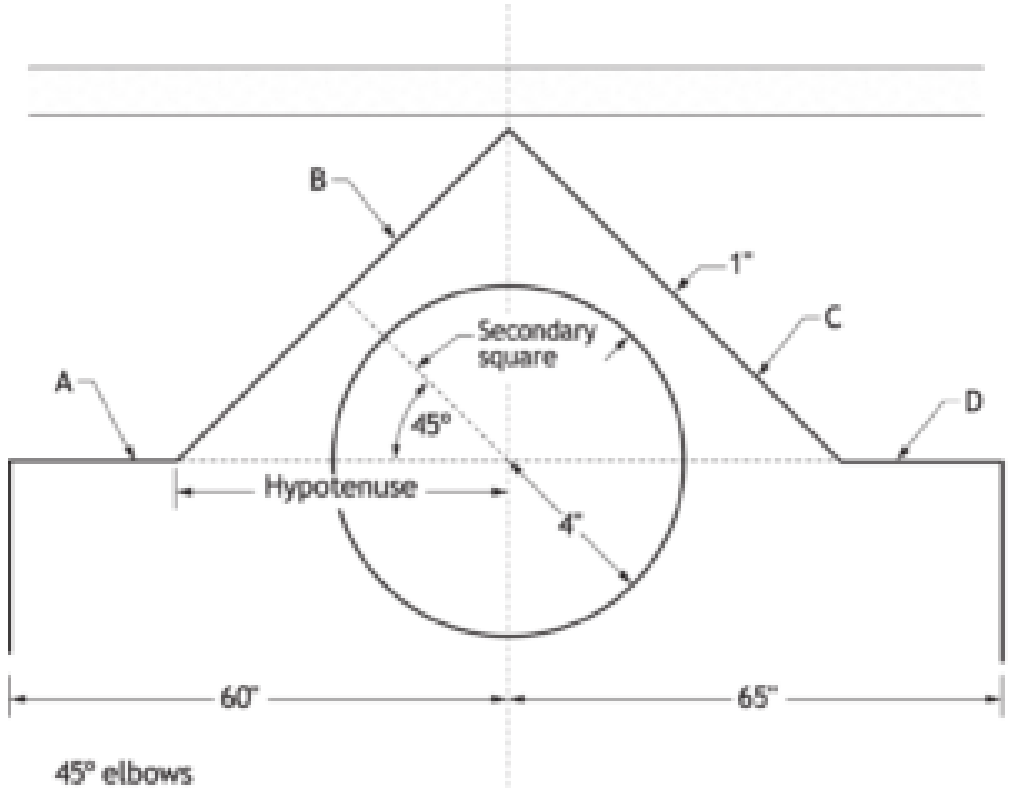

Figure 20 *Hypotenuse—pipe A (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Next, subtract the length of the hypotenuse from the given dimension of 60″:

$$\text{A} = (60 - 7.07) = 52.93\text{”}$$

Step 4: The length of pipe D is found using the same procedure used to find the length of pipe A. Multiply the length of secondary square dimension by 1.414 to find the length of the hypotenuse (Figure 21) (this will be the horizontal distance from the centreline of the duct to the centre of the 45° elbow).

$$\text{Hypotenuse} = 5\text{”} \times 1.414 = 7.07\text{”}$$

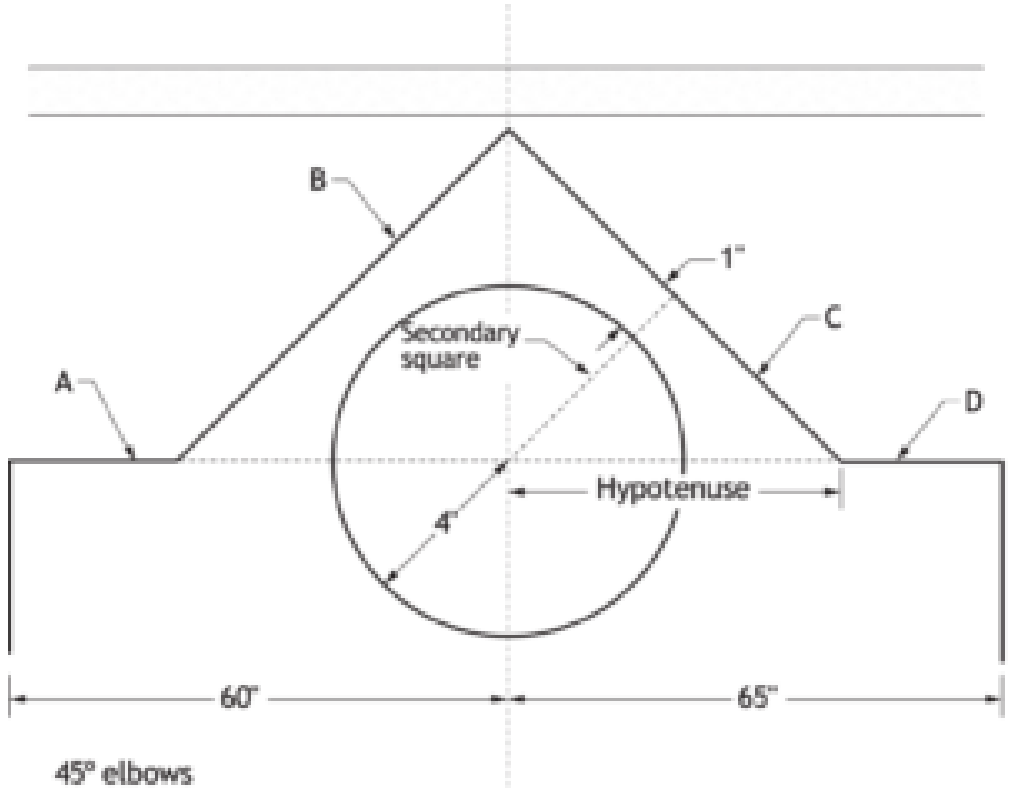

Figure 21 *Hypotenuse—Pipe D (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Subtract the length of the hypotenuse from the given dimension of 65″:

$$\mathrm{D} = 65 - 7.07 = 57.93\text{”}$$

Example 2:

Solve for the centre-to-centre lengths of the lettered pipe sections indicated in Figure 22 using the following information:

- Duct diameter = 20″
- Space between duct and pipe centre = 2″

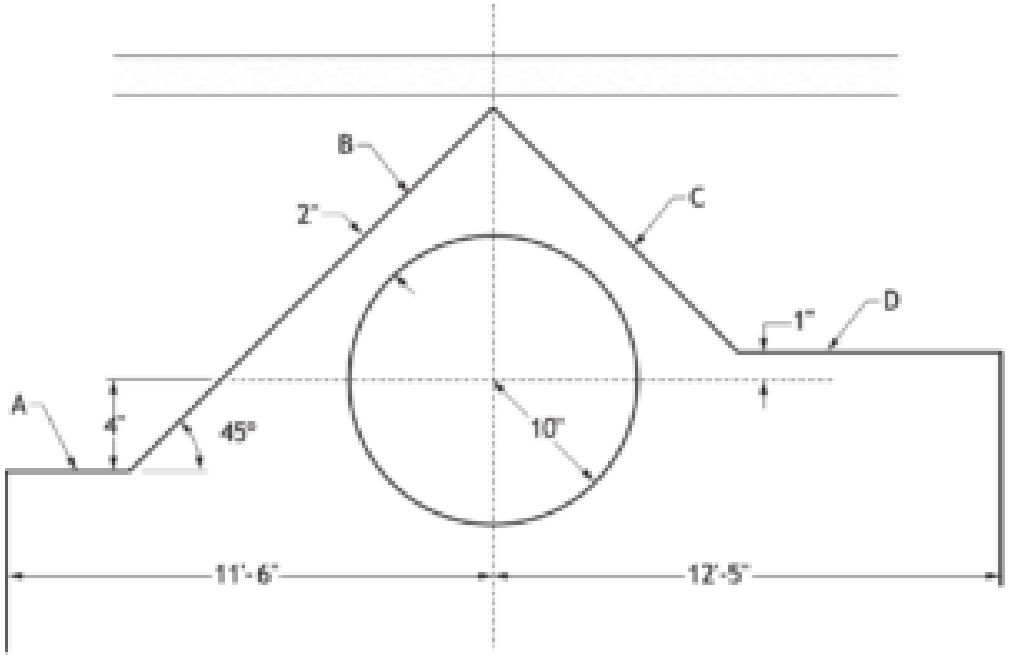

Figure 22 *Illustration for Example 2 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

This example is more complex than the previous example, as the horizontal sections of the piping system differ in elevations. The pipe enters the offset 4″ below the centreline of the duct and exits the offset 1″ above the centreline of the duct.

It is important to always use the centreline of the duct as a reference point when establishing triangles used in solving pipe lengths.

Step 1: Find the length of the *secondary square* side:

$$\text{duct radius} + \text{space} = \text{length of secondary square (L)}$$

$$10” + 2” = 12”$$

Step 2: Multiply the secondary square by 2 to give you the partial length of pipe B, measured from the peak of the offset to where pipe B intersects the centreline of the duct ($2 \times \text{L}$).

Pipe B is longer than ($2 \times \text{L}$) by the length of the hypotenuse formed by the 4″ triangle (seen at H in Figure 23).

$$4” \times 1.414 = 5.656”$$

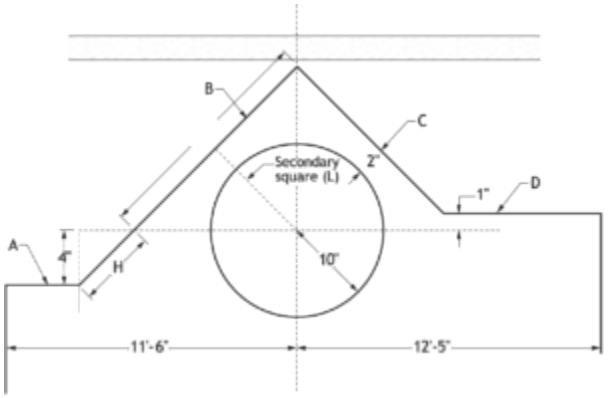

Figure 23 *Partial length of pipe B (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Solve for the length of pipe B:

$$\mathrm{B} = (2 \times \mathrm{L}) + \mathrm{H} \quad = (2 \times 12) + 5.656 \quad = 24 + 5.656 \quad = 29.656\text{” or } 29\frac{5}{8}\text{”}$$

Step 3: To find the length of A, first determine how far the 45° elbow is away from the vertical centreline of the duct.

In Step 1, we determined the length of pipe B, which is really the hypotenuse formed by the dashed lines shown in Figure 24. The distance from the vertical centreline of the duct and the 45° elbow is the short side of that same triangle. To find this dimension, divide the length of pipe B (hypotenuse) by 1.414, which will give us the length of one of the shorter sides:

$$\frac{29.656}{1.414} = 20.97\text{”}$$

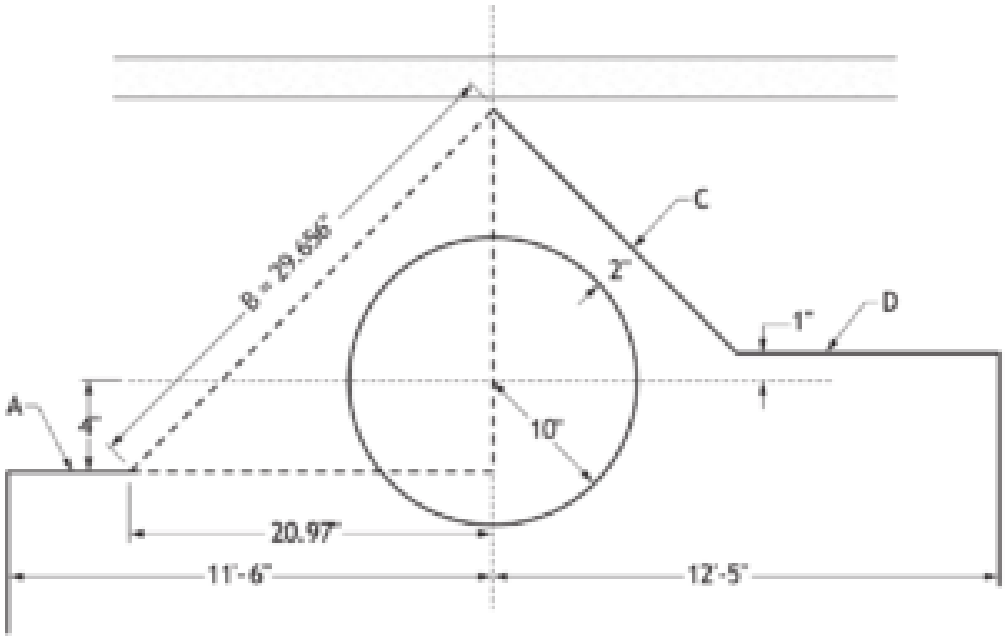

Figure 24 *Illustration for Step 3 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The given dimension of 11′ 6″ is measured from the vertical centreline of the duct to the start of pipe A. Pipe A is measured from the riser to the centre of the 45° elbow. The difference between the given dimension and pipe A would be the short side of the triangle, or 20.97.

$$\text{Pipe A} = 11\text{'}6\text{"} - 20.97\text{"} \quad = 138\text{"} - 20.97\text{"} \quad = 117.03\text{"} \text{ or } 117\text{"}$$

Step 4: To find the length of pipe C, first multiply the secondary square by 2; which will give you the length from the peak of the offset to where pipe C would intersect the centreline of the duct ($2 \times \text{L}$). However, pipe C does not travel to this point but instead levels out 1″ above the horizontal centreline of the duct.

Pipe C is shorter than 2L by the length of the hypotenuse formed by the 1″ triangle (seen at H in Figure 25).

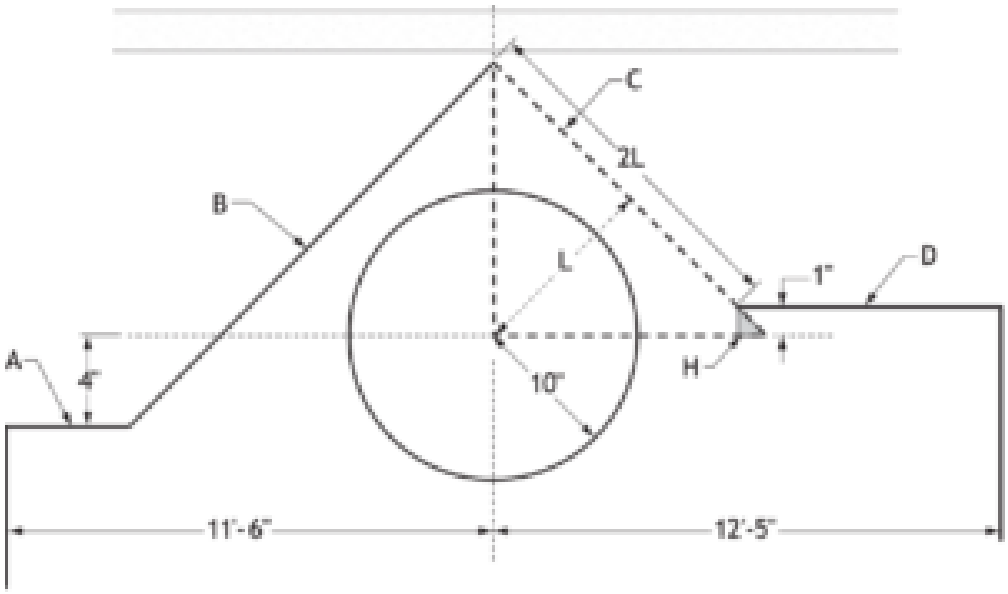

Figure 25 *Illustration for Step 4 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

$$\text{H} = 1\text{"} \times 1.141 = 1.414\text{"}$$

The length of pipe C is then:

$$\text{Pipe C} = 2\text{L} - \text{H} \quad = 24 - 1.414 \quad = 22.586\text{" or } 22\frac{5}{8}\text{"}$$

Step 5: To find the length of D, we must determine how far the 45° elbow is away from the vertical centreline of the duct (Figure 26).

In Step 1, we determined the length of the secondary square to be 12″. If we solved for the hypotenuse of this triangle, it would be 12 × 1.414 = 16.97″. Because the 45° elbow in this question is 1″ closer to the vertical centreline of the duct, the distance from the centreline of the duct to the 45° elbow is now as follows:

$$16.97 - 1 = 15.97\text{"}$$

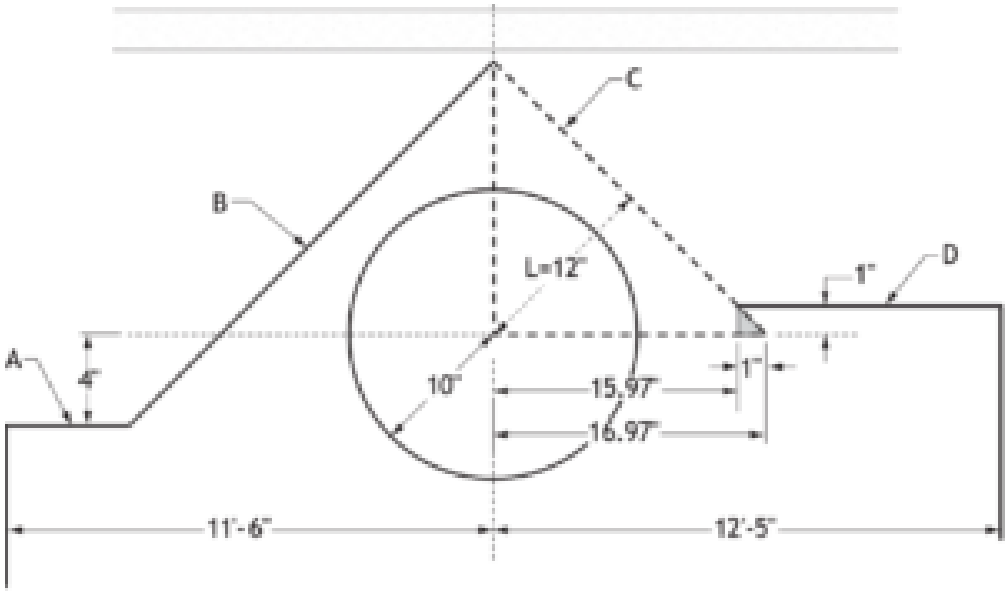

Figure 26 *Illustration for Step 5 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The given dimension of 12′ 5″ is measured from the vertical centreline of the duct to the start of the turn at pipe D. Pipe D is measured from the centre of the riser at the turn to the centre of the 45° elbow. The difference between the given dimension and pipe D would be the hypotenuse of the triangle minus 1″, or 15.97″.

Then:

$$\text{Pipe D} = 12\text{'}5\text{''} - 15.97\text{''} \quad = 149\text{''} - 15.97\text{''} \quad = 125.03\text{''} \text{ or } 125\text{''}$$

Example 3:

Solve for the centre-to-centre lengths of the lettered pipe sections indicated in Figure 27 using the following information:

- Duct diameter = 10″
- Space between duct and pipe centre = 4″

This pattern of jumper offset uses two 45° elbows at the peak instead of one 90° elbow.

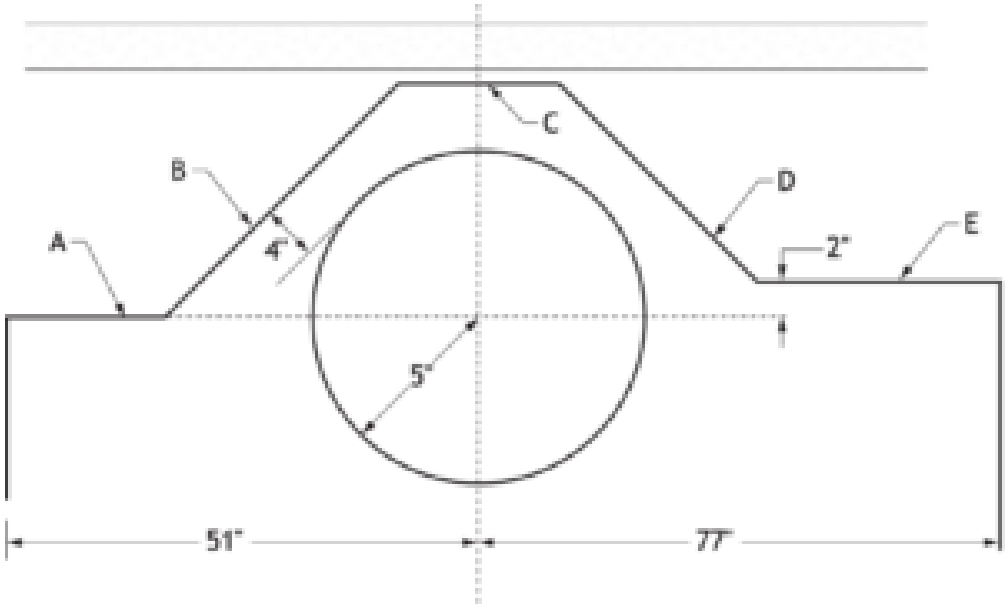

Figure 27 *Illustration for Example 3 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Step 1: As with all jumper offsets, the first thing to find is the side of the secondary square. Scribe a line from the centre of the duct rising at 45° until it intersects the centreline of the diagonal pipe B (Figure 28). Once the side of the secondary square is established, you can find its length:

$$\text{Duct radius} + \text{space} = \text{length of secondary square}$$

$$5” + 4” = 9”$$

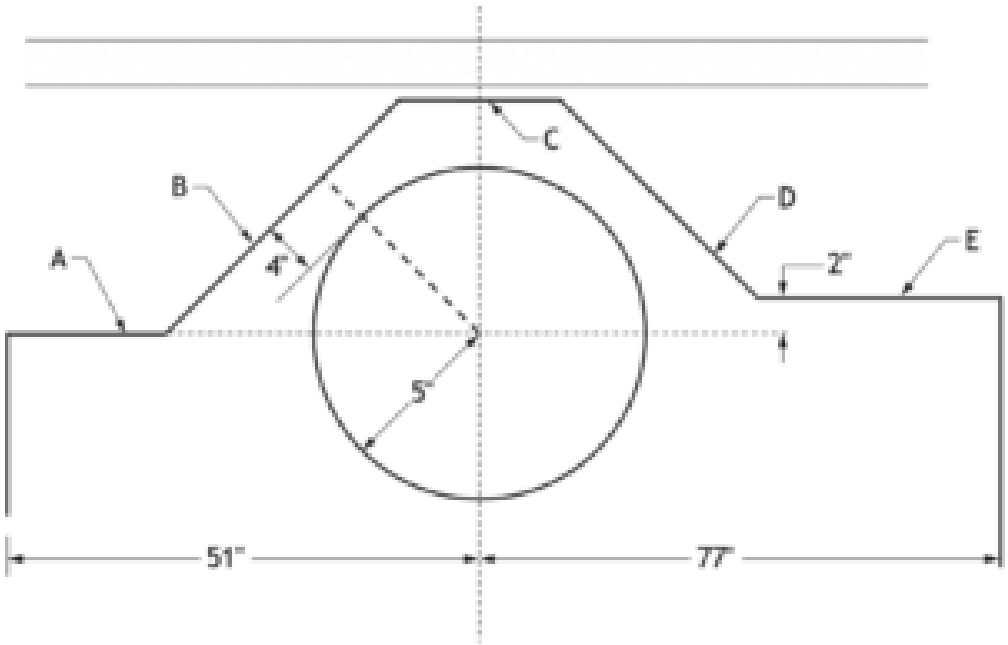

Figure 28 *Illustration for Step 1 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Once you have determined the length of the secondary square, that length will also be the portion of pipe B indicated by the dashed line. This is because the lengths of the short sides of a 45° triangle are always equal.

Step 2: To solve for the length of the short section of pipe B, scribe a line from the centre of the duct to the centre of the upper 45° elbow, as shown in Figure 29. This new line in combination with the secondary square line forms a $22\frac{1}{2}^\circ$ triangle, with the secondary square line becoming the adjacent side and the portion of pipe B in question becoming the opposite side.

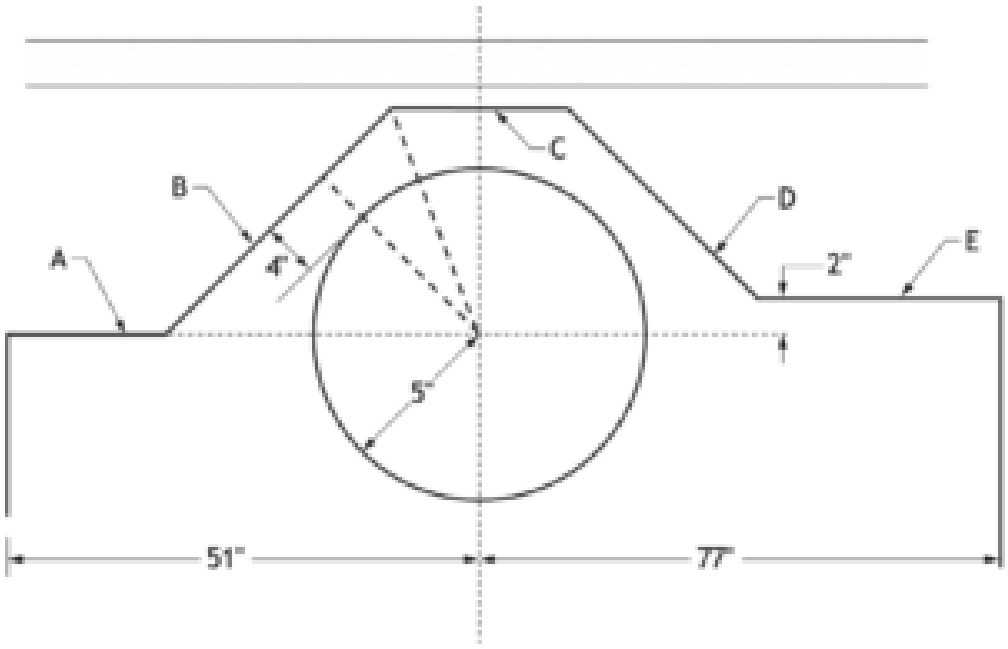

Figure 29 *Illustration for Step 2 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

To solve for this portion of pipe B, we will use a trig function that compares the opposite side and the adjacent side. The trig function tan (Figure 30) will be used to solve for the length of the opposite side.

Figure 30 *tan triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Remember that the adjacent side is the length of the secondary square = 9″:

$$\text{opposite} = \tan(22.5) \times \text{adjacent} \quad \text{opposite} = \tan(22.5) \times 9\text{”} \quad \text{opposite} = 3.73\text{”}$$

Therefore, the length of pipe B is the opposite side of the $22\frac{1}{2}^\circ$ triangle plus the length of the secondary square:

$$\text{Pipe B} = 9 + 3.73 = 12.73\text{”}$$

Step 3: As before, in order to find the length of A, we must determine how far the lower 45° elbow is away from the vertical centreline of the duct.

In Step 1, we determined the length of the secondary square, which is the length of a short side of the triangle, represented by dashed lines in Figure 31. The distance from the vertical centreline of the duct to the 45° elbow is the hypotenuse of that same triangle. To find this dimension, we simply multiply the length of the secondary square by 1.414, which will give us the length of the hypotenuse.

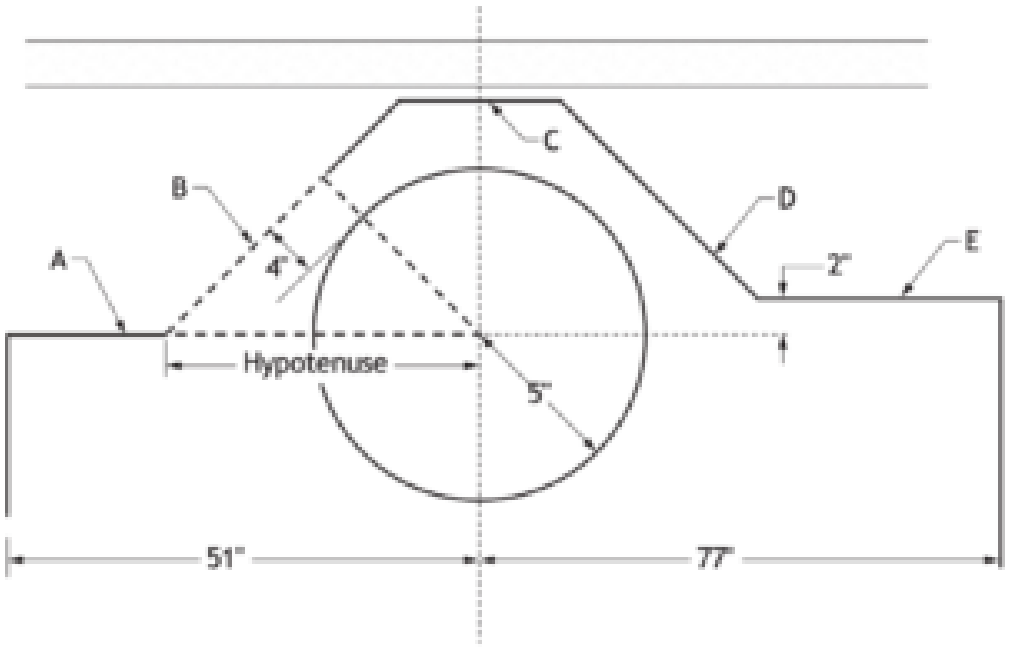

Figure 31 *Illustration for Step 3 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The length of the hypotenuse is then:

$$9\text{”} \times 1.414 = 12.73\text{”}$$

The given dimension of 51″ is measured from the vertical centreline of the duct to the start of pipe A. Pipe A is measured from the riser to the centre of the 45° elbow. The difference between the given dimension and pipe A would be the hypotenuse of the triangle, or 12.37. The length of pipe A is therefore:

$$\text{Pipe A} = 51 - 12.37 \quad = 38.63\text{”} \text{ or } 38\frac{5}{8}\text{”}$$

Step 4: Recall a calculation in Step 2, where trig was used to solve for the opposite side of a $22\frac{1}{2}^\circ$ triangle that made

up a portion of pipe B. The resulting length of this portion was 3.73″. If lines are scribed as shown in Figure 32, you can see that four identical $22\frac{1}{2}^\circ$ triangles are formed.

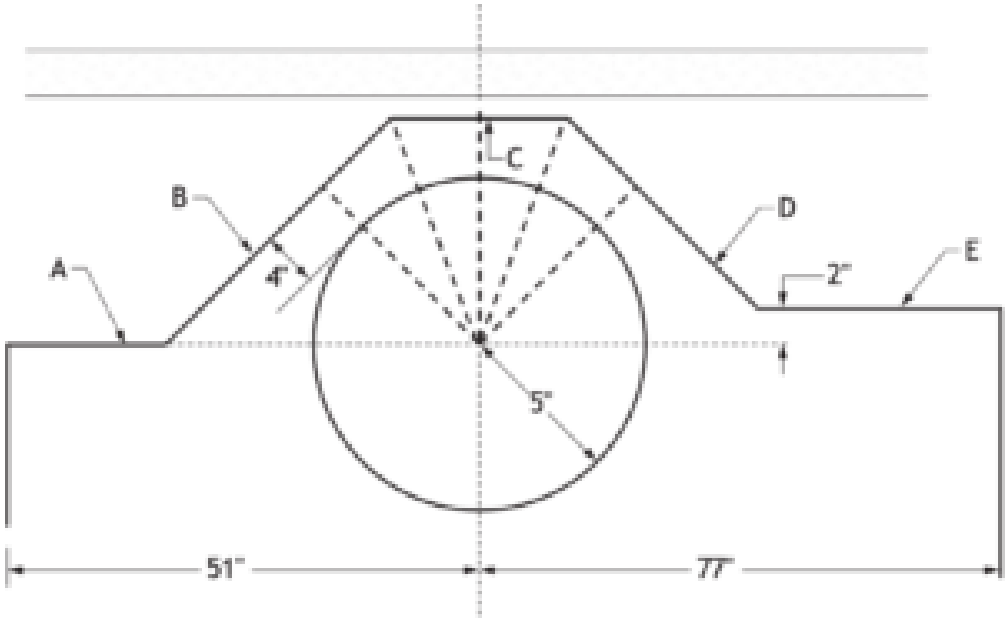

Figure 32 *Illustration for Step 4 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The length of line C is the sum of two of these opposite sides, and thus:

$$\text{Pipe C} = 2 \times 3.73 \quad = 7.46\text{”}$$

Step 5: To solve for the length of pipe D, you can see from Figure 33 that there are three component lengths to consider, indicated by the dashed lines:

1. The opposite side of a $22\frac{1}{2}^\circ$ triangle, previously calculated to equal 3.73″
2. The short side of a secondary square 45° triangle, previously calculated to be 9″
3. The hypotenuse of a 2″ triangle created when the pipe offset exited before reaching the duct centreline:

$$2 \times 1.414 = 2.828\text{”}$$

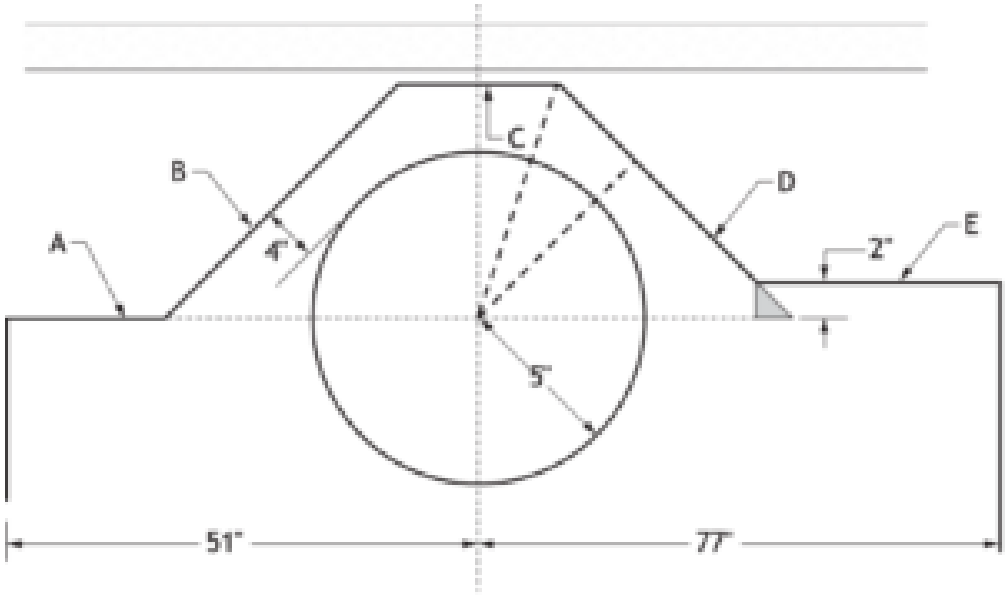

Figure 33 *Illustration for Step 5 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The length of pipe D is then:

$$\text{Pipe D} = 3.73 + 9 - 2.828\text{”} \quad = 9.9\text{”}$$

Step 5: Similar to the previous example, to find the length of E, we must determine how far the 45° elbow is away from the vertical centreline of the duct (Figure 34).

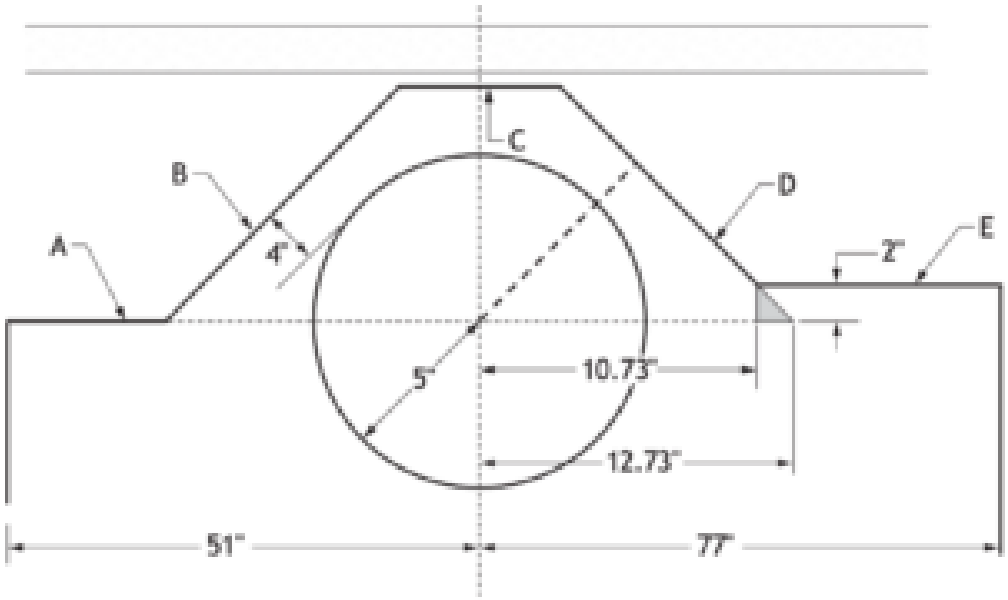

Figure 34 *Illustration for Step 5 (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

To find the length of E, we must determine how far the 45° elbow is away from the vertical centreline of the duct. In Step 1 we determined the length of the secondary square to be 9″. If we solved for the hypotenuse of this triangle, it would

be $9” \times 1.414 = 12.73”$. Because the 45° elbow in question is 2″ closer to the vertical centreline of the duct, the distance from the centreline of the duct to the 45° elbow is now:

$$12.73 - 2 = 10.73”$$

The given dimension of 77″ is measured from the vertical centreline of the duct to the start of pipe E. Pipe E is measured from the riser to the centre of the 45° elbow. The difference between the given dimension and pipe E would be the hypotenuse of the triangle minus 2″, or 10.73″.

Then:

$$\text{Pipe E} = 77” - 10.73” \quad = 77” - 10.73” \quad = 66.27, \text{ or } 66\frac{1}{4}”$$

Self-Test C-1.10.2: Calculate Required Measurements for Piping Offsets

Complete Self-Test C-1.10.2 and check your answers.

Solve for the lengths indicated. Express your answers to the nearest $\frac{1}{8}$„ or $\frac{1}{10}$ mm, as required.

If you are using a printed copy, please find Self-Test C-1.10.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2435#h5p-18

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Note: these videos align with the open textbooks *Math for Trades: Volume 1* and *Math for Trades: Volume 2*. All videos are by Chad Flinn and available under a Creative Commons Attribution 4.0 Licence.:

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C-1.11 Define the Properties of Matter

Describe the Structure of Matter

Matter is generally defined as anything that occupies space and has a measurable ***weight*** or ***mass***. You can think of matter as all the materials or substances existing on Earth (Figure 1).

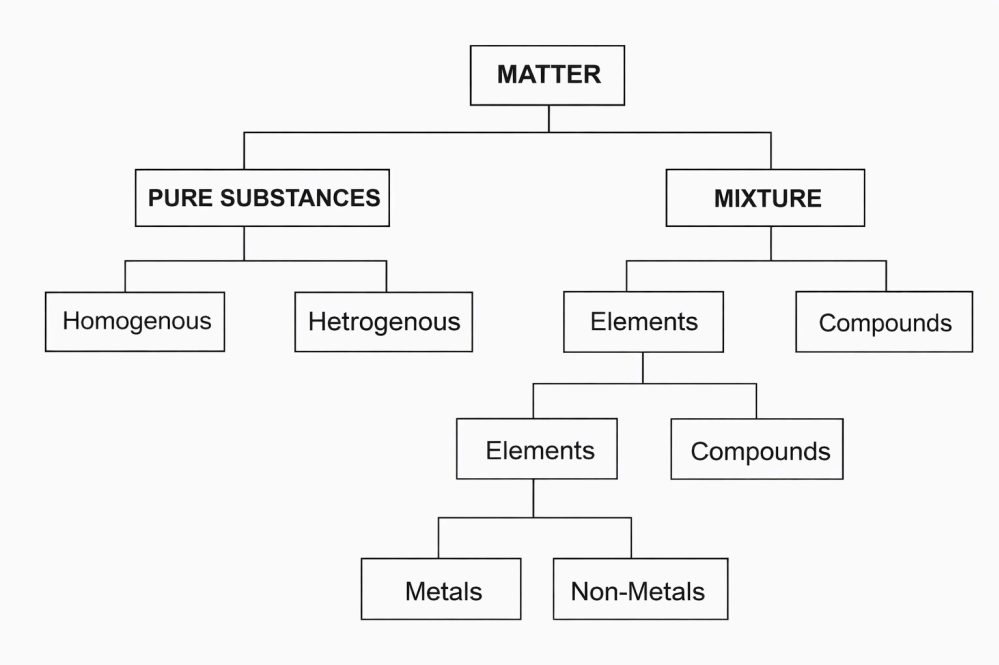

Figure 1 *Categories of matter (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

All matter is composed of ***submicroscopic particles***. When combined with one another, these particles assume one of two different forms: either they are ***pure substances***, or they are ***mixtures***.

Pure Substances

Pure substances are a form of matter containing only one type of particle. The particles in pure substances are made of either unique *elements* or ***molecules*** that are present in ***fixed definite proportions***.

Some examples of pure substances are water, oxygen gas, carbon dioxide, and sodium chloride (table salt).

Elements

Elements are unique in that they cannot be broken down or decomposed into other materials by ordinary means. For

example, pure gold contains only gold particles. Gold is an example of an element. The smallest particle of an element is called an ***atom***.

There are currently 118 confirmed elements, including hydrogen, oxygen, carbon, copper, lead, silver, and gold.

Note: An element is considered a pure substance. All elements are pure substances, but not all pure substances are elements. For example, water is a pure substance but not an element because it is made of hydrogen and oxygen.

Molecules

Atoms of elements can unite to form more complex structures called ***molecules***. Molecules are made up of atoms arranged in fixed proportions, either of the same element, or of two or more different elements. When two or more different elements are present in a molecule, it is classified as a ***compound***. When two or more pure substances are combined without a chemical change, the result is called a *mixture*.

Thousands of substances can be produced by chemically or physically combining different proportions of the 118 basic elements. For example, two atoms of the element hydrogen can combine with a single element of oxygen to produce water. Or atoms of oxygen and hydrogen can combine with atoms of iron to produce ferric hydroxide (common rust).

Aside from some elements that can exist as single atoms (for example, helium), most matter is composed of molecules that contain two or more atoms. This means that although the number of different atoms is limited, the number of different molecules is almost infinite.

The arrangement and structure of the molecules in a substance are unique and determine the characteristics of a material. For example, iron is harder than copper because of differences in the arrangement and structure of their molecules (molecular structure). The colour of gold is determined by its molecular structure.

The choice of the tools used to work a material depends on the molecular structure of both the tool and the material. For example, if a tool designed for use on wood is used on a block of iron, it will quickly become dull. Conversely, a hacksaw blade that is designed to cut metal is inappropriate for cutting wood. Because wood is softer than metal, a hacksaw blade will easily become clogged with fibres, limiting its effectiveness. When a hacksaw is used to cut metal, metal filings fall off of the blade, making it more effective.

Compounds

A ***compound*** is formed when two or more elements chemically combine to create a pure substance. The elements in a compound are always present in definite or fixed proportions. For example, the ratio of sodium to chlorine in sodium chloride (table salt) is always 0.65:1. If extra sodium or chlorine is present, the extra atoms will not combine.

There are many examples of compounds. Water is a compound of hydrogen and oxygen. Sugar and alcohol are both compounds of carbon, hydrogen and oxygen, although the number and arrangement of the atoms in the sugar and the alcohol molecules are different. Water, sugar, and alcohol are all compounds made of different combinations of elements.

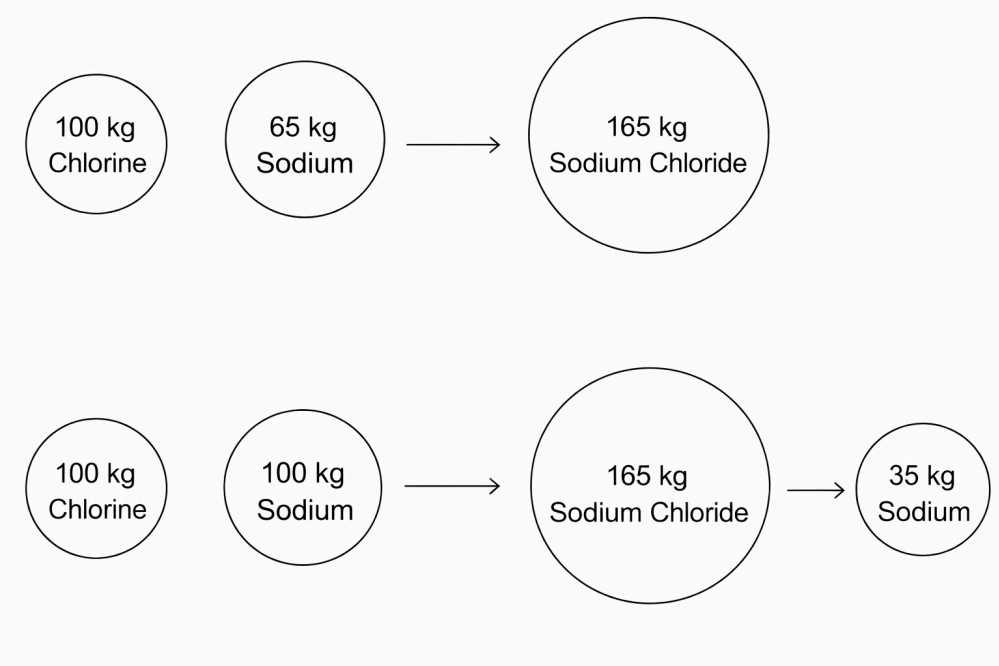

Figure 2 *Ratio of elements in sodium chloride (table salt) (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Molecules of compounds have all the properties of the compound and represent the smallest unit of that substance.

Mixtures

A ***mixture*** is formed when two or more elements or compounds are combined, but the substances retain their original properties.

Unlike compounds, mixtures can be made using different proportions of each ingredient. For example, concrete is a mixture of cement, water, and aggregate. The proportion of cement, water, and rock can vary, but the mixture will still be concrete. Changing the proportions changes the properties of the concrete—the physical characteristics of the concrete will be determined by the ratio of the ingredients.

Alloys are mixtures of a metal with other metals or non-metals. Like concrete, the final properties of the alloy mixture depend on the proportion of its constituent parts. Brass, for example, is essentially a mixture of copper and zinc. The proportion of copper and zinc varies widely, producing different types of brass with different properties. For example, if you wish to produce a bronze-coloured alloy, you would use 90% copper and 10% zinc. To produce silvery-white metal, use a mixture of 55% copper and 45% zinc. Brass is produced in about a dozen formulations, each with its own distinct characteristics, yet all are brass!

There are numerous examples of alloys used in the trades. ***Babbitt*** is used in bearings, stainless steel in construction, copper and silver in brazing rods, and aluminum/magnesium alloy in aircraft. Figure 3 shows the relationship between elements, compounds, and mixtures.

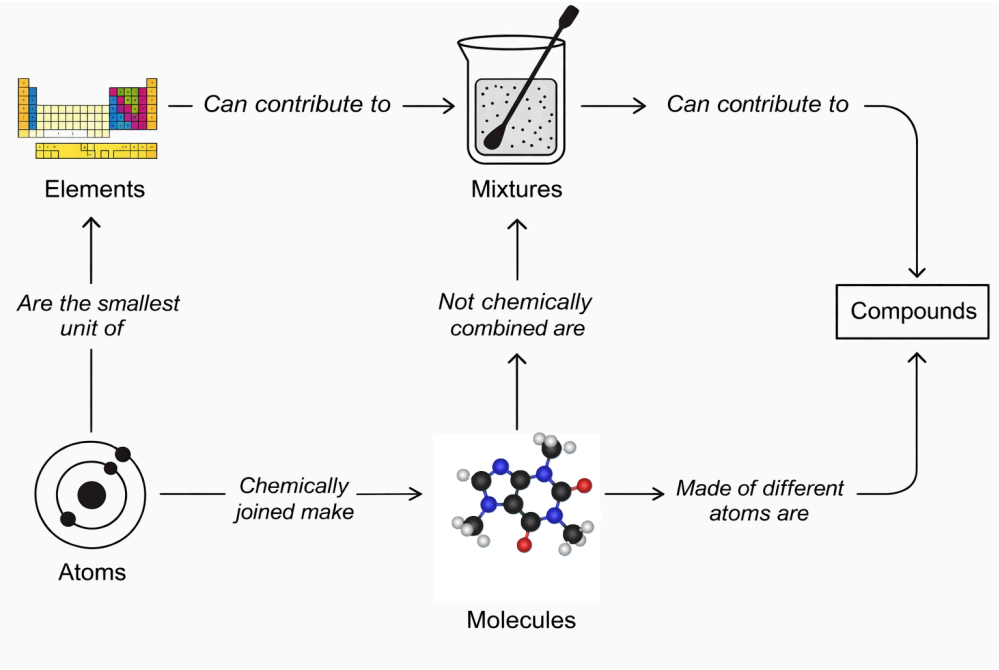

Figure 3 *Composition and relationship of elements, compounds, and mixtures ([adapted by TRU Open Press, from] BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Describe Matter

Matter is defined as anything that occupies space and has a measurable weight or mass. Matter commonly exists in one of three forms or states:

- solid
- liquid
- gas

Solids have particles (ions, atoms, or molecules) that are closely packed together. The forces between particles are strong so that the particles cannot move freely but can only vibrate. As a result, solids have a stable, definite shape and definite volume. Solids can only change their shape by force, as when being broken or cut.

A ***liquid*** is a nearly incompressible fluid that conforms to the shape of its container but retains a (nearly) constant volume independent of pressure. The volume is definite if the temperature and pressure are constant.

Gases are compressible fluids. Not only will a gas conform to the shape of its container, but it will also expand to fill the container.

In this context, the term ***fluid*** means any substance—liquid or gas—that can flow and has no fixed shape, taking the shape of its container.

Density

Density is the ratio of a mass to a volume, or the ratio of a weight to a volume. Density compares the masses of equal volumes of different kinds of matter. In the metric system, mass density is found by using the following equation:

Metric formula:

$$\text{(Metric) Density} = \frac{\text{mass}}{\text{volume}} \quad \text{D} = \frac{\text{m}}{\text{v}}$$

The most common units of mass density are kilograms per cubic metre ($\frac{\text{kg}}{\text{m}^3}$) and grams per cubic centimetre ($\frac{\text{g}}{\text{cm}^3}$).

In the imperial system of measurements, we find weight density using the following equation:

Imperial formula:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

The most common weight density units are pound per cubic foot ($\frac{\text{lb.}}{\text{ft.}^3}$) and pounds per cubic inch ($\frac{\text{lb.}}{\text{in.}^3}$). The density values for a variety of materials are shown in Table 1.

Table 1: Densities of Various Materials

Substance	**Mass Density** $\frac{\text{kg}}{\text{m}^3}$	**Unit** $\frac{\text{lb.}}{\text{ft.}^3}$
Air	1.3	0.08
Aluminum	2,700	170
Concrete	2,300	140
Ice @ 0°C	920	58
Iron and steel	7,800	480
Mercury	13,600	830
Water (pure) @ 4°C	1,000	62.4
Water (sea)	1,030	64.3

Comparing densities demonstrates that some substances weigh more than others do, even though they all take up the same amount of space.

Example 1:

Calculate the density of a 700-g rectangular block with the following dimensions: length = 9 cm, width = 10 cm, height = 7 cm.

Solution:

$$\text{Mass} = 700 \text{ g} \quad \text{Volume} = 9 \text{ cm} \times 10 \text{ cm} \times 7 \text{ cm} = 630 \text{ cm}^3 \quad \text{D} = \frac{700 \text{ g}}{630 \text{ cm}^3} = 1.11 \frac{\text{g}}{\text{cm}^3}$$

Answer:

$$1.11 \frac{\text{g}}{\text{cm}^3}$$

Example 2:

Calculate the density of a mixture of water and glycol when a 77-ft.^{3} tank contains 4,375 lb. of liquid.

Solution:

$$\text{Weight} = 4,375 \text{ lb.} \quad \text{Volume} = 77 \text{ ft.}^3 \quad \text{D} = \frac{4,375 \text{ lb.}}{77 \text{ ft.}^3} = 56.818 \frac{\text{lb.}}{\text{ft.}^3}$$

Answer:

$$56.818 \frac{\text{lb.}}{\text{ft.}^3}$$

Specific Gravity (Weight)

Specific gravity (SG), sometimes called *relative density* particularly when referring to gases, is closely related to density. Specific gravity is considered to be the ratio of the density of a substance to the density of water (for liquids/solids) or air (for gases). Therefore, water and air have both been assigned a specific gravity of 1.0. Therefore, water has been assigned a specific gravity of 1.0 and air assigned a relative density of 1.0. Specific gravities are used in industry as a means of obtaining information about the concentration of solutions of various materials such as brines, hydrocarbons and glycol solutions.

The specific gravity of a solid or liquid tells you how heavy the object is compared to an equal volume of water. A material with a specific gravity less than 1.0 will float on water, while a material with a specific gravity more than 1.0 will sink in water. As well, a gas with a relative density less than 1.0 will rise in the atmosphere, while a gas with a relative density of more than 1.0 will sink.

For example, the specific gravity of aluminum is found by dividing either the mass density of aluminum by the mass density of water, or by dividing the weight density of aluminum by the weight density of water. The answers are the same in both cases, as the specific “number” is merely a ratio comparing densities.

Metric calculation:

$$\text{Specific gravity} = \frac{\text{mass density of a substance}}{\text{mass density of water}} \quad \text{Specific gravity aluminum} = \frac{2,700 \frac{\text{kg}}{\text{m}^3}}{1,000 \frac{\text{kg}}{\text{m}^3}} \quad \text{Specific gravity aluminum} = 2.7$$

Imperial calculation:

$$\text{Specific gravity} = \frac{\text{mass density of a substance}}{\text{mass density of water}} \quad \text{Specific gravity aluminum} = \frac{170 \frac{\text{lb}}{\text{ft}^3}}{62.4 \frac{\text{lb}}{\text{ft}^3}} \quad \text{Specific gravity aluminum} = 2.7$$

Specific gravity is a unitless number, or ratio, comparing same units. When divided as above, the units cancel out.

It is interesting to note that the specific gravity of any material that will float in water tells you what percentage of the volume will be submerged below the water line. For example, if a pine log (specific gravity of pine = 0.37) is floating on a body of water, it will have only 37% of its volume submerged.

If the specific gravity (SG) of a substance is known, it can be used to find the density of a solid or liquid by multiplying the SG times the density of an equal volume of water.

Example:

Calculate the density of mercury (SG 13.6) in $\frac{\text{lb.}}{\text{ft.}^3}$

$$\text{Density of a substance} = \text{SG of a substance} \times \text{density of water} \quad \text{Density of mercury} = 13.6 \times 62.4 \frac{\text{lb.}}{\text{ft.}^3} \quad \text{Density of mercury} = 848.64 \frac{\text{lb.}}{\text{ft.}^3}$$

Specific gravity will be covered more closely in C-1.13 Use Archimedes' Principles of Displacement and Floatation when we will explore Archimedes' principle of ***buoyancy***.

It is a **unitless value**.

- SG < 1 → floats
- SG > 1 → sinks

Adhesion and Cohesion

The state a substance is in (solid, liquid or gas) is determined by the spacing and motion of the individual molecules. The spacing among the molecules is determined by several attracting forces.

- *Cohesion* is the attraction between similar molecules.
- *Adhesion* is the attraction between different molecules.

These forces affect how fluids behave in pipes.

Cohesive Forces

Solids consist of molecules that are strongly attracted to one another. This mutual molecular attraction, called ***cohesive***

force, limits the space around individual molecules and creates a closely packed situation that allows solids to hold definite shapes.

Cohesive forces in solids can be extremely strong. For example, a mass of several thousand kilograms can be suspended from a steel rod one centimetre in diameter without causing the molecules in the rod to separate. This is due to steel's high rate of ***cohesion***.

Gas molecules exhibit little cohesion. Individual molecules are, relatively speaking, widely separate. Indeed, under certain standard conditions, the distance between molecules in a gas can be more than 10 times greater than the diameter of a single molecule. The lack of cohesion allows a gas to ***diffuse (expand)*** quickly and broadly.

If not confined, a gas has almost unlimited expandability. For example, a cubic centimetre of water has a mass of one gram. When the single gram of water is vaporized, the resulting steam contains the same number of water molecules as were present in the liquid form but can occupy a space of several thousand cubic centimetres.

Liquids are also composed of tightly packed molecules, but the cohesive force is not as great as that found in solids. This reduction in ***intermolecular force*** allows some molecules to slip over other molecules. Molecular slippage allows liquids to flow.

Adhesive Forces

Dissimilar molecules often exhibit a force of attraction similar to cohesion. The intermolecular force acting between dissimilar molecules is called the ***adhesive force***. The adhesive force between unlike molecules allows water to cling to the walls of glass, allows paint to stick to wood, oil to lubricate bearings, etc.

Sometimes a substance has an adhesive capability that exceeds its cohesiveness. This is true of many types of glue used in the furniture industry. A thin layer of glue creates a stronger bond between two pieces of wood than a thick layer of glue because the cohesive force between glue molecules is less than the adhesive force between glue molecules and wood molecules.

The vast majority of work done by individuals employed in the pipe trades involves the transportation of fluids through pipelines. It is important that a pipe tradesman have a good understanding of how fluids react with each other in addition to a good knowledge of the piping system they are being conveyed in.

The behaviour of fluids within a piping system demonstrates these characteristics. ***Adhesion*** is the force that occurs between a liquid and the piping material that contains it. This adhesion causes a layer of molecules to bond tightly to the pipe's inner surface. Cohesion is the attractive force that occurs between the fluid molecules and causes them to hold together.

To illustrate these forces in a pipe, Figure 5 shows a water column flow profile viewed from the side. The water column moves as a series of concentric layers, some of which may be just a few molecules thick. The outer layer, which is in contact with the surface of the pipe, does not move at all, while the one in the very centre of the pipe moves at the highest velocity. This illustrates that the adhesive forces between the water and the pipe are stronger than the cohesive forces between the water molecules.

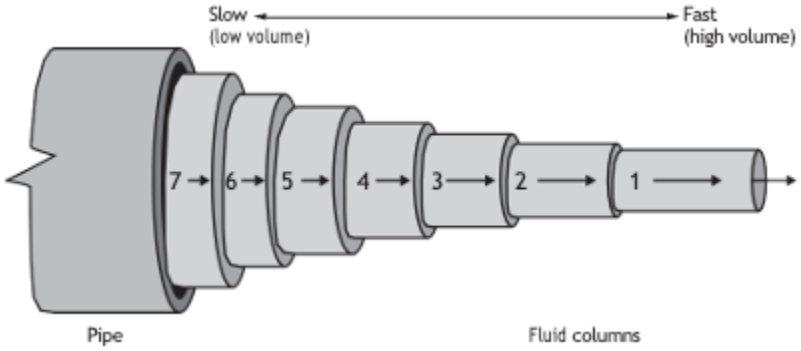

Figure 5 *Fluid velocity profile of water in a pipe (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Mechanical Properties

- *Tensile strength* — resistance to breaking when pulled
- *Ductility* — ability to stretch into wires
- *Malleability* — ability to be shaped under compression
- *Elasticity* — ability to return to original shape

Tensile Strength

Several properties of solids depend on the cohesive force between molecules. One of these properties is ***tensile strength***. Tensile strength measures the force required to pull something (such as a rope, wire or structural beam) to the point where it breaks. The tensile strength of a material is the maximum amount of tensile stress that can be applied before failure occurs.

If two metal rods of the same diameter, one copper and one steel, are placed in the tensile testing machine shown in Figure 6, it will be found that a greater force must be exerted to break or pull apart the steel rod than that required to break or pull apart copper. Steel, therefore, has a higher tensile strength.

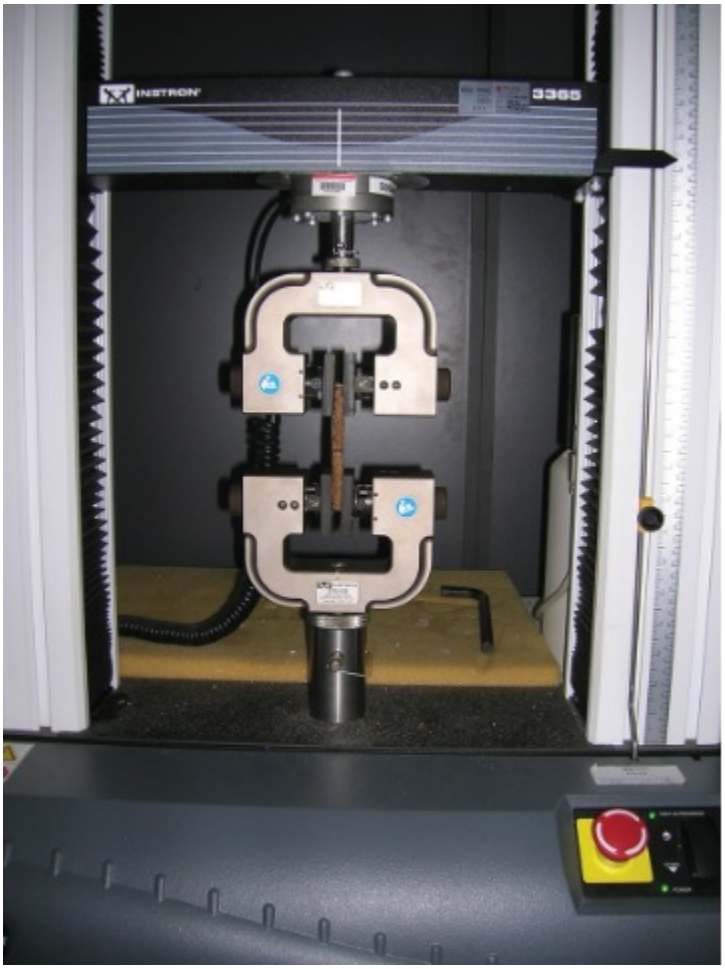

Figure 6 *Tool for testing pipe tensile strength (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The tensile strength of a material is defined as the force needed to break a rod or wire of that material having a unit cross-sectional area of either one square inch or one square centimetre. The tensile strength of mild steel pipe, for example, is 60 000 psi.

Tensile strength tests are performed for several reasons. The results of tensile strength tests are useful in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials, so that different materials can be compared under different forms of loading.

Ductility

Ductility is the ability of material to be drawn out into thin wires or flat sheets without pulling apart or breaking. Ductility allows a material to maintain its formed shape while under tensile stress. The finer the wire produced, the more ductile the material is. This is a desirable quality, especially in metals.

Many manufacturers want materials that will not break even when thin pieces are required.

When the ductility of a material needs to be determined, a commonly used method is the ***bend test*** (Figure 7). The ductility test or bend test is a very common test for welded joints, piping products, and reinforcing (rebar) materials.

Figure 7 *Bend test for ductility (BC Industry Training Authority, 2019).*
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Malleability

While ductility is the property of a material to strain without rupturing under tension, ***malleability*** describes the ability to do so under compression. The most typical example given is that a malleable material can be hammered or rolled into thin and flat sheets without tearing. Most malleable materials are also ductile, though lead is one exception. Gold leaf and aluminum foil are common products demonstrating high malleability.

Elasticity

Elasticity is the ability of a material to return to its original dimensions after it has been subjected to a force. All solids have some elasticity. However, the term *elastic* is used to describe a substance that quickly resumes its original shape when the deforming force is removed.

The maximum force or stress that a solid can withstand and still "snap" back to its original shape and so not be permanently deformed is called the ***elastic limit***. The elastic limit is not the material's breaking point, although the object may or may not be far from breaking. Brittle materials (such as glass and cast iron) break at or close to their elastic limit. Other materials, notably most metals, can be flatted or shaped long after the elastic limit is reached, particularly if they are heated.

Conductivity

Conductivity refers to the ability of a material to transfer energy from one place to another. ***Thermal conductivity*** describes a substance's ability to transmit heat, while ***electrical conductivity*** describes a substance's ability to transmit electrical current.

- *Thermal conductivity* — heat transfer
- *Electrical conductivity* — current flow

Thermal Conductivity

Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. The reciprocal of thermal conductivity is ***thermal resistance***. Thermal resistance is a measure of a material's ability to resist heat transfer. The more a material is able to block heat transfer through its surface, the greater its thermal resistance. This concept is often applied to the building industry as a measure of insulation effectiveness and energy efficiency. As ***thermal insulation*** is added to the building to improve efficiency levels, the thermal resistance of the structure increases.

Throughout most of the world, ***R-value*** is used to measure thermal resistance. The higher the R-value of a material, the better it is able to resist heat transfer. The lower the R-value, the easier it is for heat to pass through the material's surface.

Electrical Conductivity

Electrical conductivity is a property that describes how well a material allows electrical current to flow through it. Examples of metals that have a high electrical conductivity include gold, silver, copper, aluminum and steel. Copper and aluminum are the most common materials used in electrical wires. Interestingly, most thermal conductors are good electrical conductors.

Another important property that is measured in electrical systems is ***electrical resistance***, which is measured in units called ohms (Ω). Resistance, in electrical terms, describes the forces that oppose the flow of electrical current in a conductor. Certain materials that are low in electrical conductivity are termed ***electrical insulators***. Good insulators have high resistance.

Ohm's law describes the relationship of current flowing through a resistance when a different electric potential (voltage) is applied at each end of the resistance. A comparison would be to imagine water flowing through a pipe. Voltage would be the water's pressure, current (or amps) would be the amount of water flowing through the pipe, and resistance is similar to the friction incurred due to the size of the pipe. More water will flow through the pipe (current) as more pressure is applied (voltage). Resistance would also change as the pipe size changes, thereby increasing or decreasing flow accordingly.

Self-Test C-1.11: Define the Properties of Matter

Complete Self-Test C-1.11 and check your answers.

If you are using a printed copy, please find Self-Test C-1.11 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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Note: these videos align with the open textbooks *Math for Trades: Volume 1* and *Math for Trades: Volume 2*. All videos are by Chad Flinn and available under a Creative Commons Attribution 4.0 Licence.:

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C-1.12 Use Pascal's Theory of Pressure and Force

Blaise Pascal and Pascal's Law

Blaise Pascal was a noted French mathematician who discovered that a closed container of fluid could be used to transfer force from one place to another, or to multiply force by its transmission through a fluid. This seemingly innocuous principle led to the development of the ***hydraulic press*** and the science of modern ***hydraulics***, which studies the mechanical properties and uses of liquids. In honour of his discovery, the unit of pressure in the metric system is called the pascal (Pa), and hydraulics is described using Pascal's law.

According to ***Pascal's law***, any force applied to a ***confined fluid*** is transmitted in all directions throughout the fluid, regardless of the shape of the container. To understand how Pascal's law applies to hydraulics, imagine an enclosed fluid as shown in Figure 1.

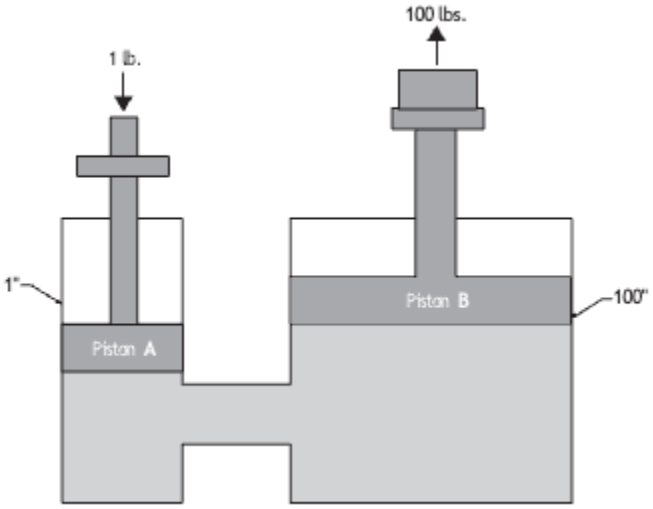

Figure 1 *The hydraulic press, an example of Pascal's law (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

The enclosure has two movable *pistons*. Now imagine that piston A has a cross-sectional area of 1 in² and piston B has a cross-sectional area of 100 in². If a 1 lb **force** pushes piston A into the fluid, this produces a pressure of 1 $\frac{\text{lb}}{\text{in}^2}$, or 1 psi. This pressure is transmitted through the enclosure to piston B. This 1 psi pressure acts on piston B, which has an area of 100 in². As a result, a force of 100 lb is produced, which can support a 100 lb load at the same height.

As stated earlier, Pascal's law is independent of the shape of the container. The connecting tube does not need to match the size of the pistons. A connection of any size, shape, or length will work, as long as there is an unobstructed passage for the fluid.

This principle allows large forces to be generated with relatively little effort. Large pieces of earth-moving equipment,

for example, use hydraulics to exert large forces on soil or boulders. Hydraulic devices all depend on Pascal's law and the relationship among *pressure*, *force*, and *area*.

Pressure, Force, and Area

There is a mathematical relationship between *pressure*, *force*, and *area*. To understand this relationship, study the formulas below:

$$F = P \times A \quad P = \frac{F}{A} \quad A = \frac{F}{P}$$

$$\mathrm{F(force)} = \mathrm{P(pressure)} \times \mathrm{A(area)} \quad \mathrm{P(pressure)} = \frac{\mathrm{F(force)}}{\mathrm{A(area)}} \quad \mathrm{A(area)} = \frac{\mathrm{F(force)}}{\mathrm{P(pressure)}}$$

The triangle shown in Figure 2 is a convenient memory device for these formulas. Because force is above the line, it reminds you that in division formulas, force is divided by one of the other two factors.

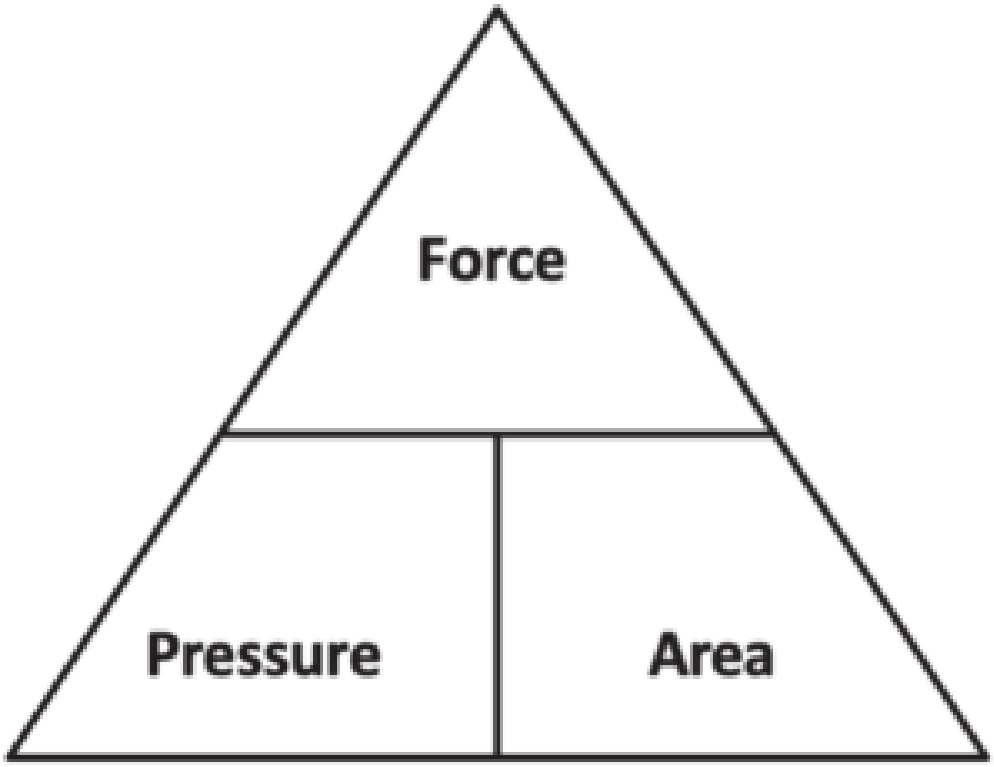

Figure 2 *Memory device for force-area-pressure formulas* (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

Force is measured using the standard metric unit, *newton* (N). The term *newton* is abbreviated as the letter N in most

formulas; “10.0 N” would represent 10.0 newtons of force. One newton is the amount of force required to give a 1 kg mass an acceleration of $1\frac{\text{metre}}{\text{second}^2}$.

In the imperial system, the term ***pound (lb)*** is used as a unit of force.

The Units of Pressure

Pressure is defined as force divided by the area over which the force is evenly distributed. Since liquids and gases are fluids, they exert pressure on their containers evenly.

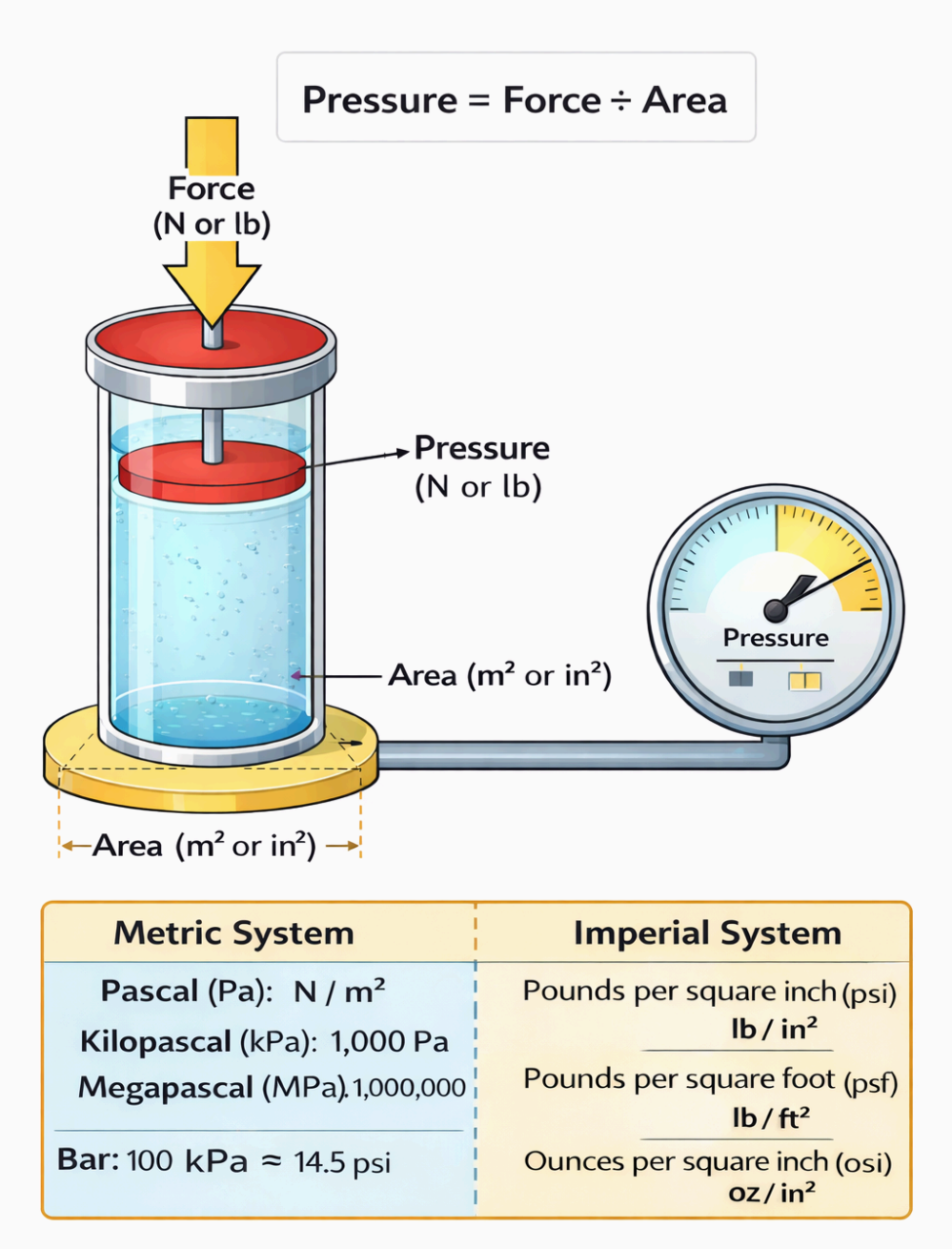

Figure 3 *Pressure and measurement systems comparison (TRU Open Press/OpenAI) CC BY-NC-SA*

The metric system measures pressure in *newtons* (force) per square metre (area); these pressure units are called *pascals* (Pa). Pascals are such small units of pressure that it is more common to actually use units like ***kilopascals*** or ***megapascals*** (kPa or MPa), which are 1,000 and 1,000,000 pascals, respectively.

Also found in the metric system is the ***bar***. This unit is not approved by the International System of Units (SI) but is recognized in the European Union, and is equal to 100 kPa, or approximately 14.5 psig.

In the imperial system, pressure is commonly measured in units of pounds per square inch (psi), or *pounds per square foot (psf)* pounds per square inch (psi), *pounds per square foot (psf)*, or *ounces per square inch (osi)*.

Remember that there are three distinct types of pressure, each described by specific units, as follows:

- ***Absolute pressure*** is the actual pressure of a fluid with respect to a perfect vacuum. Absolute pressure is gauge pressure plus atmospheric pressure.
- ***Gauge pressure*** is the fluid pressure with respect to the atmospheric pressure outside its container. Gauge pressure does not include ***atmospheric pressure***.
- ***Differential pressure*** is the difference between any two pressures. Notice that gauge pressure is actually a differential pressure between absolute pressure and atmospheric pressure.

The metric system does not distinguish between absolute and gauge pressure; therefore, it is always necessary to spell it out as *kPa abs*, *kPa gauge* and perhaps *kPa diff*. In the imperial system, the abbreviations psig, psia, and psid clearly describe the pressure type intended.

The Units of Area

Depending on what system you are working in, area is measured in units of:

- square inch (in^2)
- square foot (ft^2)
- square centimetre (cm^2)
- square metre (m^2)

Example 1:

A box weighs 170 N, and its base has an area of 2.2 m^2. What pressure does it exert on the floor?

Solution:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{Pressure} = \frac{170\ \text{N}}{2.2\ \text{m}^2} = \frac{77.27\ \text{N}}{1\ \text{m}^2} \quad \text{Pressure} = 77.27\ \text{Pa}$$

Answer:

$77.27\ \text{Pa}$

Example 2:

What is the area of a surface when the pressure is 15 Pa and the force applied on it is 300 N?

Solution:

$$\text{Area} = \frac{\text{Force}}{\text{Pressure}} \quad \text{Area} = \frac{300\ \text{N}}{15\ \text{Pa}} \quad \text{Area} = 20\ \text{m}^2$$

Answer:

$20\ \text{m}^2$

Example 3:

What is the force when 82 kPa of pressure is applied to a surface area of 1.3 m^2?

Solution:

$$\text{Force} = \text{Pressure} \times \text{Area} \quad \text{Force} = 82,000 \text{ Pa} \times 1.3 \text{ m}^2$$

Answer:

$106,600$ N force

Example 4:

A boiler weighs 850 lb, and its base has an area of 420 in^2 What pressure does it exert on the floor?

Solution:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{Pressure} = \frac{850 \text{ lb}}{420 \text{ in}^2} \quad \text{Pressure} = 2.02 \frac{\text{lb}}{\text{in}^2}$$

Answer:

2.02 psi

Example 5:

What is the area of the bottom of a tank when the pressure at the bottom is 17 psi and the weight of the fluid is 9,450 lb?

Solution:

$$\text{Area} = \frac{\text{Force}}{\text{Pressure}} \quad \text{Area} = \frac{9,450 \text{ lb}}{17 \text{ psi}} \quad \text{Area} = 555.88 \text{ in}^2$$

Answer:

555.88 in^2

Example 6:

What is the force exerted on an expansion tank diaphragm with an area of 1.25 ft^2 when 15 psi of system pressure is applied to it? (Note: 1 ft^2 = 144 in^2)

Solution:

$$\text{Force} = \text{Pressure} \times \text{Area} \quad \text{Force} = 15 \frac{\text{lb}}{\text{in}^2} \times 1.25 \text{ ft.}^2 \quad \text{Force} = 15 \frac{\text{lb}}{\text{in}^2} \times 180 \text{ in}^2 \quad \text{Force} = 2,700 \text{ lb}$$

Answer:

$2,700$ lb force

Elements of Hydrostatics

Pressure in a Liquid

As the name suggests, ***hydrostatics*** is that branch of physics concerned with the properties of water at rest. It is particularly concerned with how pressure is transmitted through fluids in closed and open containers.

The key principles of hydrostatics are as follows:

- Fluid pressure is exerted in all directions.
- The shape of the container does not affect fluid pressure.
- Fluid pressure is proportional to the depth below the surface; pressure increases with depth
- Fluid pressure is proportional to density; pressure depends on density
- Horizontal runs do not increase pressure.
- The volume of fluid does not affect pressure.

Let us examine each of these principles in more detail.

Fluid Pressure is Exerted in all Directions

The pressure a fluid exerts on an object is applied in all directions. That is because the particles that make up the fluid can move in any direction. These particles exert forces as they bump into objects in the fluid. Figure 4 shows how water exerts pressure on a swimmer who is underwater. Notice that the arrows point in different directions. That is because the water is pressing all around the swimmer, not just from above.

Figure 4 *Swimmer subject to pressure from all directions (TRU Open Press/Open AI, adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The Shape of the Vessel Does Not Affect Fluid Pressure

Fluids will conform to the shape of the container that they are placed into, and because of that, they will exert pressure outward against the container (Figure 5). The pressure increases as more fluid is added and is greater toward the bottom of the container, where the weight of the liquid has the most effect. In terms of fluid dynamics, gases can also be considered fluids in terms of their effects on containers, since they also conform to the container and exert pressure in the same way as liquids.

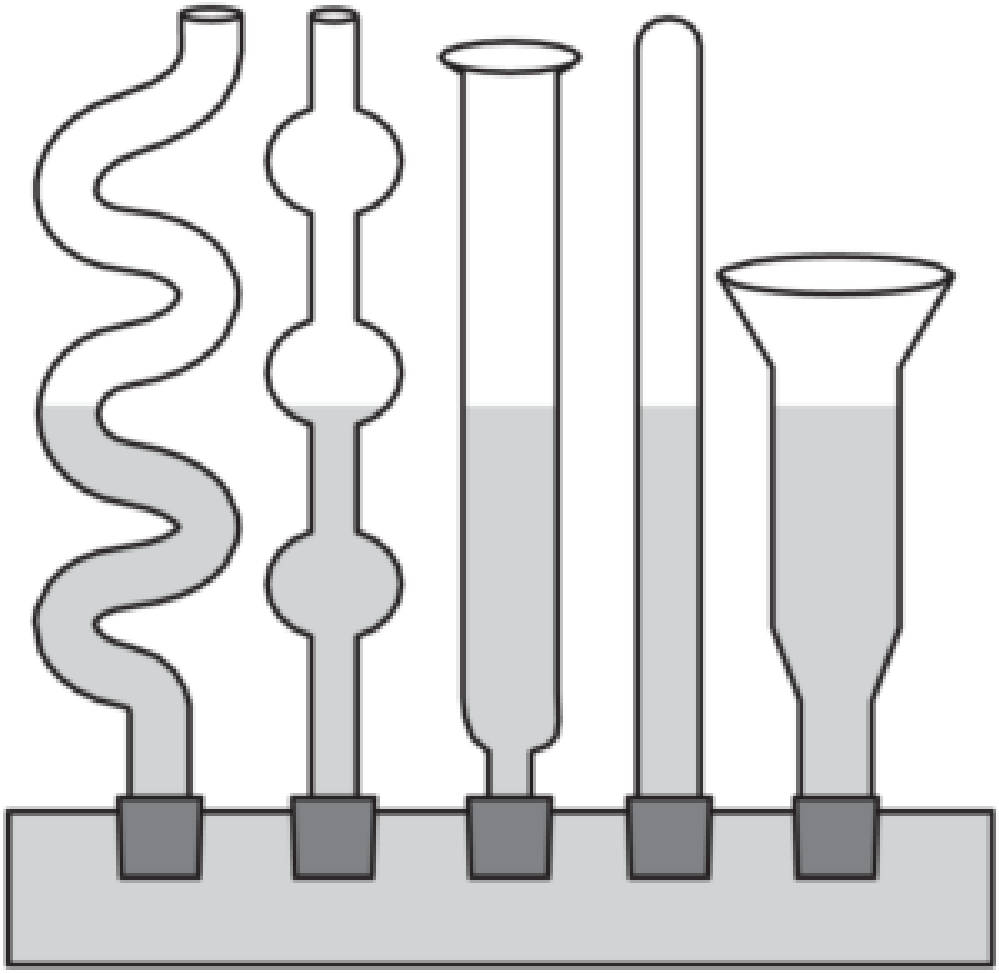

Figure 5 *Pascal's vases, showing equal pressure in containers of different shapes (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Fluid Pressure is Proportional to Depth Below the Surface

The force of gravity pulls fluids downward. Because any given volume has a certain weight, this weight pushes downward on whatever is below it. Fluid pressure is the result of the weight of all the fluid above pushing down on the fluid below. As you go deeper, there is a greater weight pushing down (Figure 6). This is the reason water pressure increases with depth. The pressure depends only upon the depth and is the same anywhere at a given depth and in every direction.

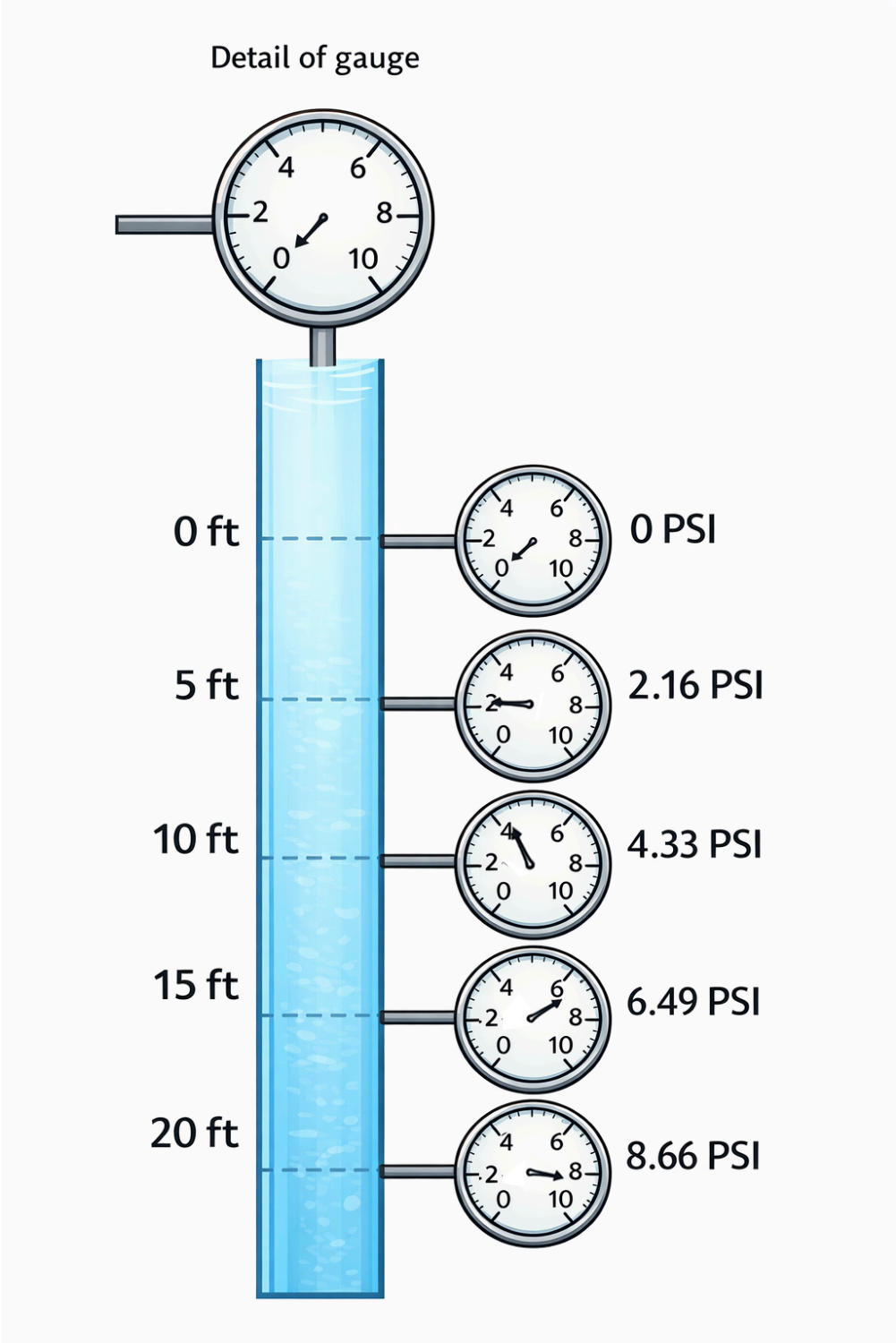

Figure 6 *Fluid pressure increases in proportion to depth (TRU Open Press/Open AI, adapted from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Water has a density of $62.4\frac{\text{lb}}{\text{ft}^3}$ As the depth increases, the pressure exerted on the sides of the vessel increases by approximately 0.433 psi per foot of depth.

Fluid Pressure is Proportional to Density

Another factor that changes pressure is the ***density*** of the liquid. This can be expressed as follows:

$$\text{Pressure} = \text{Height (in feet)} \times \text{density (per foot depth)}$$

Example:

Two vessels are filled to the same height with different fluids. One contains a liquid having a density of $124.8\frac{\text{lb}}{\text{ft.}^3}$ and the other contains water, which has a density of $62.4\frac{\text{lb}}{\text{ft.}^3}$.

The pressure at the bottom of the vessel containing the more dense fluid would be double the pressure at the bottom of the one containing water. This is because, due to its density, the fluid in the one column weighs twice as much as the water. Therefore the pressure is also double.

Because the heavier fluid has a density exactly twice that of water, it would be described as having a specific gravity (SG) of 2. (Remember: the SG of a liquid or solid is compared to an equal volume of water.)

You can calculate the pressure exerted by any fluid if you know its specific gravity. Then multiply the SG by the pressure that water would exert for any specific depth.

Example:

Find the pressure exerted by a column of mercury 10 ft in depth.

Solution:

Because the specific gravity of mercury is 13.6, mercury exerts a pressure 13.6 times greater than that exerted by a column of water 10 ft in depth.

Water 10 ft in depth would exert:

$$0.433\frac{\text{psi}}{\text{ft.}} \times 10 \text{ ft.} = 4.33 \text{ psi}$$

Therefore mercury 10 ft in depth would exert:

$$4.33 \text{ psi} \times 13.6 = 58.88 \text{ psi}$$

Horizontal Runs Do Not Increase Pressure

As pressure is exerted equally in all directions, horizontal ***runs*** cannot affect pressure. Only a change in the vertical component will change the pressure at the base of a liquid-filled piping arrangement.

The Volume of Fluid Does Not Affect Pressure

So far, we have discussed that the only two factors that affect pressure are the height and density of the fluid. Therefore, the total volume of the fluid does not affect pressure, as pressure always references a specific area. In Figure 7, storage tank No. 1 contains a greater volume of fluid than tank No. 2, but the pressure at the base is identical in both tanks (both gauges read pressure in pounds over 1 square inch). If the valve that joins the two tanks at the bottom was opened, the fluid from tank No. 1 would not enter into tank No. 2. Because fluids always seek their own level, the level in tank No. 1 cannot be different from the level in tank No. 2.

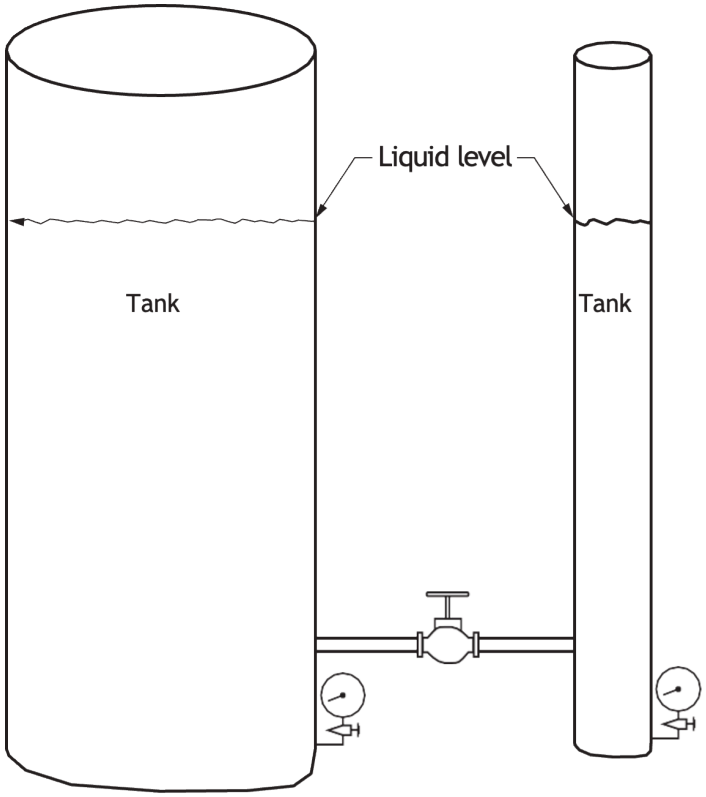

Figure 7 *Equal pressure exerted at the bottom of the containers due to equal fluid depth (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Hydrostatic Pressure Test

Hydrostatics is the study of fluids under pressure and at rest. When a ***hydrostatic pressure test*** is applied on a piping system, the piping is filled with water or other compatible liquid and then pressurized with a pump. To be proficient at this procedure, you must be able to calculate a pressure or to calculate the height of a water column needed to produce a certain pressure (known as ***feet of head***).

As stated previously, water has a density of $62.4\frac{\text{lb}}{\text{ft.}^3}$ This means that 1 cubic foot of water exerts a force of 62.4 lb

on its 1 ft² base. Because each side of a cubic foot is equal to 144 in^2, the force of the water is spread equally over all 144 square inches. The result would be 0.433 pounds of water exerting a force on each square inch of bottom surface:

$$\frac{62.4 \text{ lb}}{144 \text{ in}^2} = 0.433 \frac{\text{lb}}{\text{in}^2} \text{ (psi)}$$

Or:

$$0.0361 \frac{\text{lb}}{\text{in}^3} \times 12 \text{ in} = 0.433 \frac{\text{lb}}{\text{in}^2} \text{ (psi)}$$

The base area of the 1-foot-high column of water in Figure 8 is exactly 1 square inch. Thus, the pressure on the base of the column would be 0.433 psi. This is referred to as 1 foot of head pressure.

$$\text{Water pressure (psi)} = 0.433 \frac{\text{psi}}{\text{ft.}} \times \text{height in feet}$$

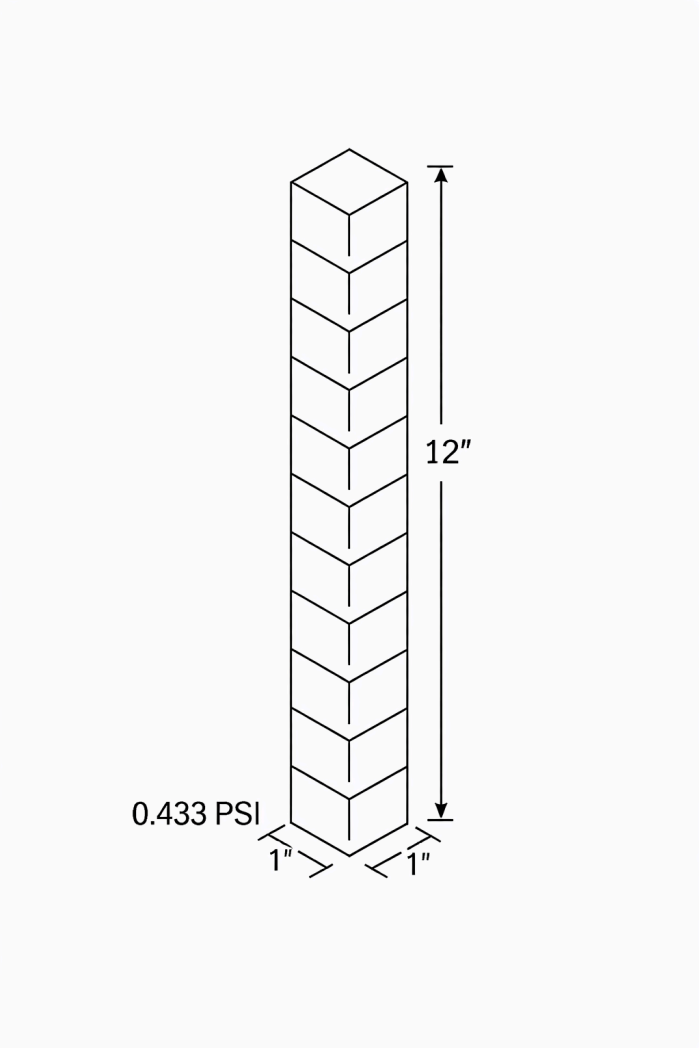

Figure 8 *Illustration of one foot of head pressure (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Example 1:

What is the pressure in psi exerted by a column of water 15 ft high?

Solution:

If each foot of water column (foot of head) exerts a pressure of 0.433 psi, then 15 ft of head would exert a pressure of:

$$15 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 6.495 \text{ psi}$$

Example 2:

What is the pressure in psi exerted by a column of mercury 4 ft high?

Solution:

We know that mercury weighs 13.6 times as much as water, so it would produce a pressure 13.6 times greater than an equal column of water. If each foot of head of water exerts a pressure of 0.433 psi, then 4 ft of water head would be:

$$4 \text{ ft.} \times 0.433 \frac{\text{psi}}{\text{ft.}} = 1.735 \text{ psi}$$

However, a 4-ft.-high column of mercury would exert a pressure of:

$$1.735 \text{ psi} \times 13.6 = 23.555 \text{ psi}$$

Table 1: Summary of Hydrostatic Pressure

Commonly Used Values	Number to Remember	Origin
One inch water column	0.0361 psi	$0.433 \frac{\text{psi}}{\text{ft.}} \div 12 \text{ in} = 0.0361 \frac{\text{psi}}{\text{in}}$
One foot head (water)	0.433 psi	$62.4 \frac{\text{lb}}{\text{ft.}^3} \div 144 \frac{\text{in}^2}{\text{ft.}^2} = 0.433 \text{ psi}$
One metre head (water)	9.81 kPa	Piping trades workers often use a close approximation of 10 $\frac{\text{kPa}}{\text{m}}$
One inch mercury column	0.491 psi	$0.0361 \text{ lb} \times 13.6$

Calculating Total Force

Force is defined as any interaction that tends to change or influence the motion of an object. Previously, we were

calculating the pressure on a single unit of area: in^2, ft^2, or cm^2. This was the force pushing down on a defined unit's area. The ***total force*** the liquid is exerting is equal to the pressure times the total area:

$$\text{Force} = \text{Pressure} \times \text{Area}$$

Example 1:

Calculate the total force on a surface when the pressure exerted is 40 psi and the surface has an area of 50 in^2

Solution:

$$\text{Force} = \text{Pressure} \times \text{Area} \quad \text{Force} = 40\frac{\text{lb}}{\text{in}^2} \times 50\ \text{in}^2 \quad \text{Force} = 2,000\ \text{lb}$$

Example 2:

Calculate the total force on the bottom of a storage tank when the depth of water is 20 ft and the diameter of the tank is 8 ft.

Solution:

In this example, we were not given the value for pressure or the area, but we were given enough information to calculate both of them. Once we establish the unknown values, we will use the following formula to calculate force:

$$\text{Force} = \text{Pressure} \times \text{Area}$$

First, calculate the pressure at the bottom of the storage tank due to 20 ft of head:

$$\text{Pressure} = 0.433\frac{\text{psi}}{\text{ft.}} \times 20\ \text{ft.} \quad \text{Pressure} = 8.66\ \text{psi}$$

Next, calculate the area of the bottom of the storage tank in square inches:

$$\text{Area} = \text{D}^2 \times 0.7854 \quad \text{Area} = 8^2 \times 0.7854 \quad \text{Area} = 50.27\ \text{ft.}^2 \quad \text{Area} = 50.27\ \text{ft.}^2 \times 144\frac{\text{in.}^2}{\text{ft.}^2} = 7,238.88\ \text{in.}^2$$

Notice that in this example, the area is required to be stated in square inches to match the pressure's expression in pounds *per square inch*.

Now calculate the force at the bottom of the storage tank:

$$\text{Force} = \text{Pressure} \times \text{Area} \quad \text{Force} = 8.66\frac{\text{lb}}{\text{in.}^2} \times 7,238.88\ \text{in.}^2 \quad \text{Force} = 62,688.7\ \text{lb}$$

Additional Resources

These open resources support essential math skills used in the plumbing trades (Overgaard & Flinn, 2022).

- *Math for Trades: Volume 1* (Overgaard & Flinn, 2022)
- *Math for Trades: Volume 2* (Overgaard & Flinn, 2022)
- *Math for Trades: Volume 3* (Overgaard & Flinn, 2022)
- *OER for Trades: Math for Trades* (Video collection) (Flinn, 2022)

Self-Test C-1.12: Use Pascal's Theory of Pressure and Force

Complete Self-Test C-1.12 and check your answers.

If you are using a printed copy, please find Self-Test C-1.12 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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- **Figure 3** Pressure and measurement systems comparison was created by TRU Open Press using OpenAI (2026), subject to the CC BY-NC-SA license.
- **Figure 4** Swimmer subject to pressure from all directions was created by TRU Open Press using OpenAI (2026), adapted from *BC Industry Training Authority*, 2019; subject to the CC BY-NC-SA license.
- **Figure 6** Fluid pressure increases in proportion to depth was created by TRU Open Press using OpenAI (2026), adapted from *BC Industry Training Authority*, 2019; subject to the CC BY-NC-SA license.

C-1.13 Use Archimedes' Principles of Displacement and Floatation

Archimedes' Principle of Displacement

Archimedes is best known for his work in ***hydrostatics***. One of his most important discoveries was that a ***submerged***, ***irregular shaped*** object displaces a volume of water equal to the volume of the object.

Archimedes used this discovery to prove that the goldsmith of the king of Syracuse had adulterated a gold crown with silver. Archimedes realized that he could check the density of the crown because he could measure its volume accurately. The story goes that the crown was proven to be impure, and the unfortunate goldsmith was executed.

Figure 1 *Archimedes at the public bath (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Applications of Displacement

Commonly called ***water displacement***, the volume of displaced fluid is equal to the volume of an object fully immersed in a fluid. If an object is only partially submerged, the displaced volume is equal to **only the portion of the object below the surface**. Several methods exist for measuring ***displacement***. In one method, the increase in water level is recorded as the object is placed into the water. In another method, the object is placed into a container filled to the top with water, causing it to overflow. The overflow is collected and measured.

Figure 2 *Measuring the volume of an irregular shape using water displacement. (OpenStax/Wikimedia Commons) CC BY 4.0*

Archimedes' Principle of Flotation (Buoyancy)

> "Any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object."

Archimedes' principle of flotation may also be stated as:

> "A body immersed in a fluid loses as much weight as the weight of the fluid it displaces."

Objects denser than water will sink, but they still lose part of their weight when submerged. For example, a person can lift a heavier stone underwater than in air because the ***buoyant force*** of the water supports part of the weight. The upward force that a liquid exerts on an object is called ***buoyancy***. The force exerted by liquids on submerged objects—and the apparent loss of weight—was studied extensively by Archimedes.

Archimedes' principle works for any fluid. For our purposes, we will focus on fresh water, which has a ***density*** of:

$$62.4\frac{\text{lb}}{\text{ft}^3} = 1000\frac{\text{kg}}{\text{m}^3}$$

Example 1:

If you place a 1-cubic-foot object that weighs 63.0 lb into water, the object displaces 62.4 lb of water. Because it weighs

more than the displaced water, it will sink. It is, however, being buoyed up with a force of 62.4 lb, so if we weighed it in the water, it would only weigh 0.6 lb. This means its ***apparent weight*** in water is:

63.0 lb − 62.4 lb = 0.6 lb

In other words, the object appears much lighter in water because most of its weight is supported by buoyancy.

If we went to the ocean and put the same object into salt water, it would still weigh 63.0 lb, but would be buoyed up by a force of 64.3 lb, and it would float.

An object sinks in a fluid if the weight of the fluid it displaces is less than the weight of the object. A submerged object remains in ***equilibrium***, neither rising nor sinking, if the weight of the fluid it displaces exactly equals its own weight. If an object, when submerged, displaces a weight of fluid greater than its own weight, it will float.

Summary:

- An object sinks if it displaces less weight of fluid than its own weight.
- An object floats if it displaces more weight of fluid than its own weight.
- An object remains suspended if the two weights are equal (*equilibrium*).

Example 2:

A 1 m^3 object weighs 500 kg and is placed in fresh water. Will it float or sink?

Solution:

The object will float because fresh water has a density of 1000 kg/m^3. The object only needs to displace 0.5 m^3 of water to balance its weight.

Example 3:

Given copper weighs $558\frac{\text{lb}}{\text{ft}^3}$, how much would 100 lb of copper weigh when submerged in sea water?

Solution:

Volume of copper:

$$\frac{100}{558} = 0.179 \text{ ft}^3$$

Density of sea water:

$$64.3\frac{\text{lb}}{\text{ft}^3}$$

Buoyant force:

$$0.179 \times 64.3 = 11.52 \text{ lb}$$

New weight in water:
100 lb − 11.52 lb = 88.48 lb

The copper loses 11.52 lb (11.52%) of its weight when submerged.

Summary formula:
Percentage loss of weight =

$$\frac{\text{Density of fluid}}{\text{Density of object}}$$

Finding Specific Gravity of Liquids

A ***hydrometer*** is an instrument used to measure the ***specific gravity (SG)*** (or *relative density*) of liquids. This is the ratio of the density of a liquid to the density of water. Operation of the hydrometer is based on *Archimedes' principle* that a solid suspended in a fluid will be buoyed up by a force equal to the weight of the fluid displaced by the submerged part of the suspended solid. Thus, it floats higher in denser liquids and lower in less dense liquids.

A hydrometer is usually made of glass and consists of a cylindrical stem and a bulb weighted with mercury or lead shot to make it float upright. The liquid to be tested is poured into a tall container, often a *graduated cylinder*, and the hydrometer is gently lowered into the liquid of unknown specific gravity until it floats freely. The hydrometer sinks until the weight of unknown liquid displaced equals the weight of the hydrometer (Figure 3). The hydrometer must sink deeper in liquids of lesser density; therefore, the larger numbers are at the bottom and smaller numbers are at the top of the scale. The point at which the surface of the liquid touches the stem of the hydrometer is noted.

Hydrometers usually contain a scale inside the stem, so that the specific gravity can be read directly. A variety of scales are available depending on the application. Hydrometers may be calibrated for different uses, such as a lactometer for measuring the density of milk, a saccharometer for measuring the density of sugar in a liquid, or an alcohol meter for measuring higher levels of alcohol in spirits.

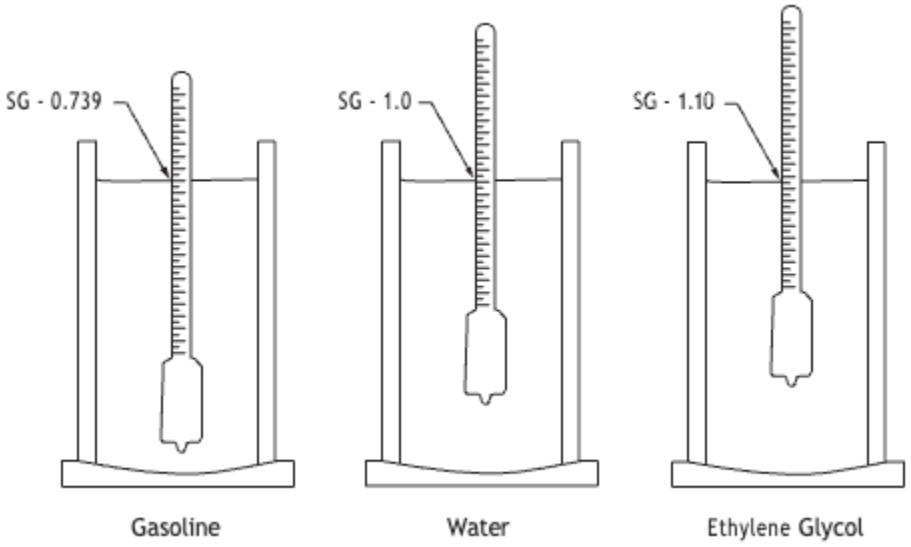

Figure 3 *Hydrometers showing the specific gravity (SG) of fluids of various density (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Self-Test C-1.13: Use Archimedes' Principles of Displacement and Floatation

Complete Self-Test C-1.13 and check your answers.

If you are using a printed copy, please find Self-Test C-1.13 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2441#h5p-21

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- **Figure 2** [Measuring the volume of an irregular shape…] CNX Chem 01 04 CylGold is by OpenStax [In *Chemistry*], retrieved from Wikimedia Commons, used under a CC BY 4.0 license.

C-1.14 Define Mechanical Advantages as it Relates to Fluid Power

Blaise Pascal (see C-1.12 Use Pascal's Theory of Pressure and Force) is usually credited with the basic principle that is the foundation of the ***fluid power*** industry. During his relatively short life (1623–1662), he experimented extensively with liquids and mechanical devices, including siphons, syringes, and tubes. This work provided proof of principles that many previous mathematicians and scientists had sought.

Figure 1 *Hydraulic scissor lift (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Remember that ***Pascal's law*** states that when there is an increase in ***pressure*** at any point in a ***confined fluid***, there is an equal increase at every other point in the container.

He is also credited with demonstrating and clearly defining the principles involved in the ***hydraulic press***: the multiplication of force and and the relationship between ***piston*** movement and force.

Most machines that move very large, very heavy objects use a ***hydraulic system*** that applies force to levers, gears, or pulleys. A hydraulic system uses a liquid under pressure to move loads. It is able to increase the ***mechanical advantage*** **(MA)** of the levers in the machine.

Modern construction projects use hydraulic equipment because the work can be done more quickly and safely. There are many practical applications of hydraulic systems that perform tasks, making work much easier.

The ***hydraulic lift*** is one of many mechanical systems that use Pascal's law. A hydraulic lift is a mechanical system that raises heavy objects, such as a vehicle on a service station lift. A hydraulic lift uses a fluid under pressure in a ***closed system***.

A hydraulic lift consists of a small cylinder and a large cylinder connected together by a pipe (Figure 2). Each cylinder is filled with a ***hydraulic fluid***, usually oil. Water is not used in a hydraulic lift for two reasons: it is not a good ***lubricant***, and it can cause parts of a system to rust.

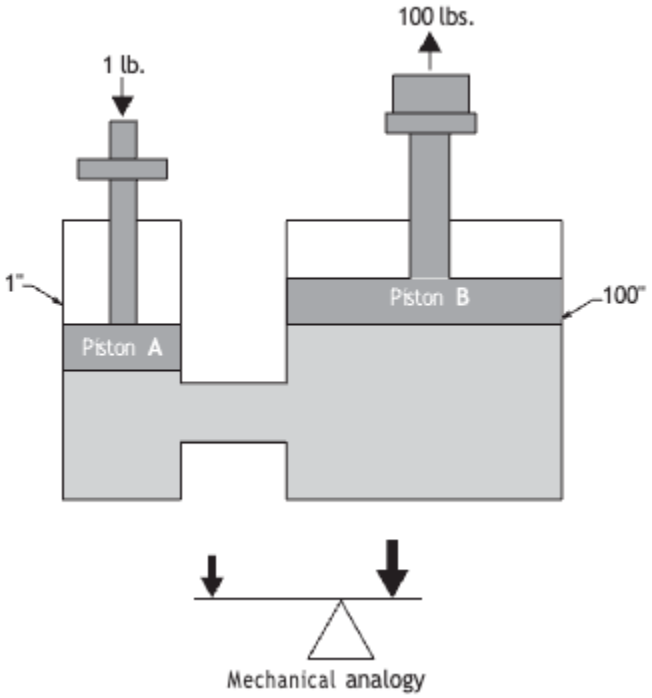

Figure 2 *Hydraulic cylinders providing increase in force (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Note that each cylinder also has a type of platform, or *piston*, that rests on the surface of the oil.

Using the relationship triangle shown in Figure 3, we can see that the force exerted by the large piston is the area of the piston multiplied by the pressure of the hydraulic fluid.

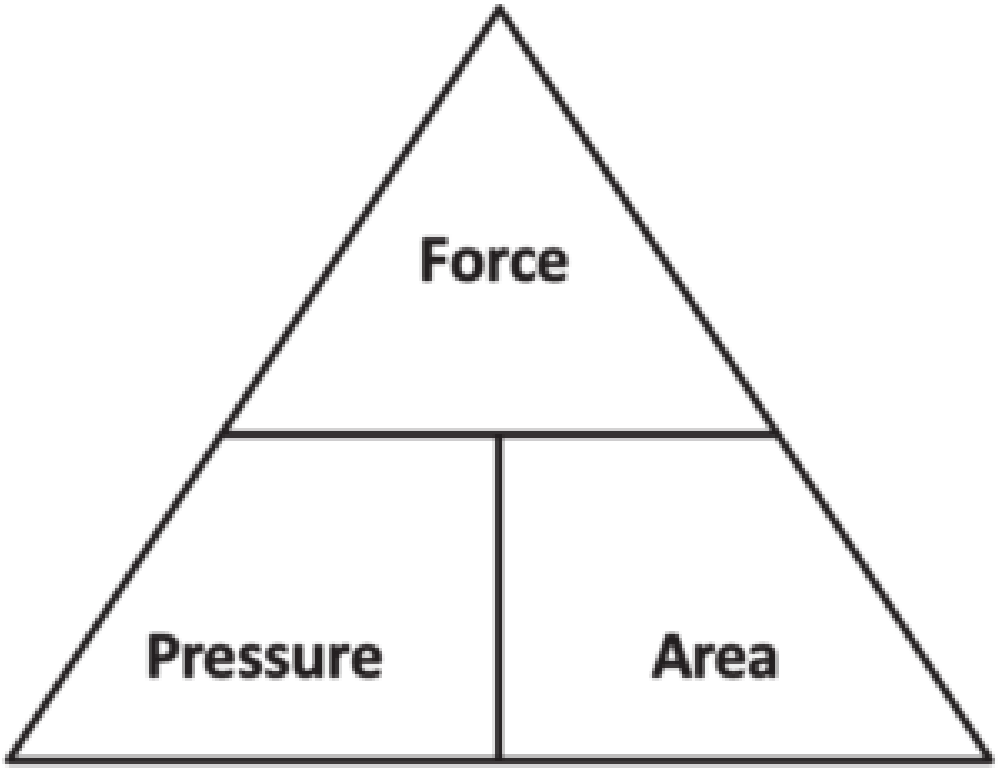

Figure 3 *Memory device for force-area-pressure formulas (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Suppose you apply 500 N of force to the small piston with an area of 5 cm^2. The pressure on the small piston is expressed in the following equation:

$$P = \frac{F}{A} \quad P = \frac{500\ N}{5\ cm^2} \quad P = 100\frac{N}{cm^2}$$

Pascal's law states that this pressure is transmitted unchanged throughout the liquid. Therefore, the large piston will also have the same pressure applied to it: $100\frac{N}{cm^2}$. However, the total area of the large piston is greater than the area of the small piston. The large piston's area is 50 cm^2.

This means the force on the large piston is greater.

$$100\frac{N}{cm^2} \times 50\ cm^2 = 5,000\ N$$

This is 10 times the force applied to the small piston.

Previously in this C-1 section, we stated that the ***pascal (Pa)*** is the standard unit of pressure. One pascal of pressure is a force of 1 newton per square metre. This is a small pressure unit, so most pressures are given in ***kilopascals (kPa)***.

$$\frac{1N}{cm^2} = 1\ Pa = 0.001\ kPa$$

Because a small effort force produces a large force on a load, a hydraulic lift provides a mechanical advantage.

Pascal's Law and Mechanical Advantage

In Figure 4 the diameter of the small piston of the hydraulic lift is 1 in.

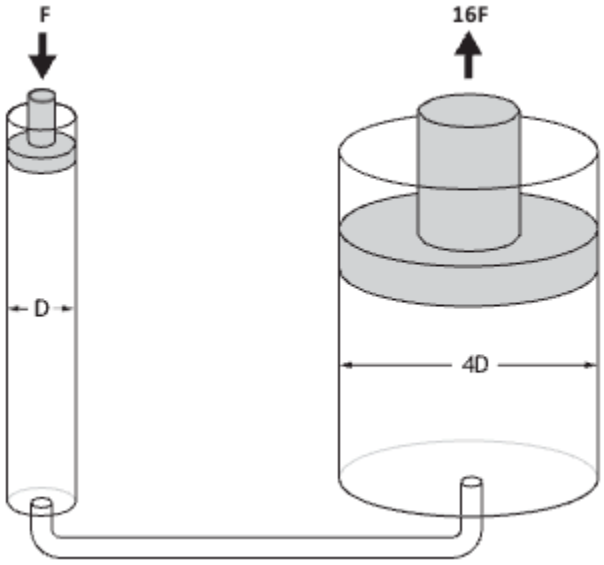

Figure 4 *Hydraulic cylinders providing increase in force (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Mechanical advantage is directly related to ***area***, not ***diameter***, so the area of the piston's face must be calculated:

$$A = D^2 \times 0.7854 \quad A = 1^2 \times 0.7854 \quad A = 0.7854 \text{ in.}^2$$

If you push down on the piston with a force of 10 lb, you will generate a pressure in the fluid of 12.73 psi:

$$P = \frac{F}{A} \quad P = \frac{10 \text{ lb}}{0.7854 \text{ in.}^2} \quad P = 12.73 \frac{\text{lb}}{\text{in.}^2}$$

Now examine the area of the large piston. The diameter is 4 in. This would have a corresponding area of:

$$A = D^2 \times 0.7854 A = 4^2 \times 0.7854 A = 12.566 \text{ in.}^2$$

This is an increase in area of 16 *times* the small piston area. According to Pascal's law, the pressure on every unit of area on that piston will be $12.73 \frac{\text{lb}}{\text{in.}^2}$. Since there are 12.566 in.^2 of area, the total force on the large piston will be:

$$F = P \times A \quad F = 12.73 \frac{\text{lb}}{\text{in.}^2} \times 12.566 \text{ in.}^2 \quad F = 159.97 \text{ lb}$$

This hydraulic lift has a mechanical advantage of 16. Unfortunately, mechanical advantage in hydraulic systems has a trade-off. That trade-off is the increased distance the smaller force must move to make the larger force move a smaller distance. Because of this reality, you would have to push the piston 16 times farther than the distance you could lift the load. In other words, you must push the piston farther to lift the load a shorter distance.

Calculating Mechanical Advantage (MA)

A machine makes work easier for you by increasing the amount of force that you exert on an object. This produces a ***mechanical advantage (MA)***, which is the amount of force that is multiplied by the machine. The force applied to the machine (by you) is the ***input force***. The force that is applied to the object (by the machine) is the ***output force***.

The mechanical advantage of a machine is the output force divided by the input force.

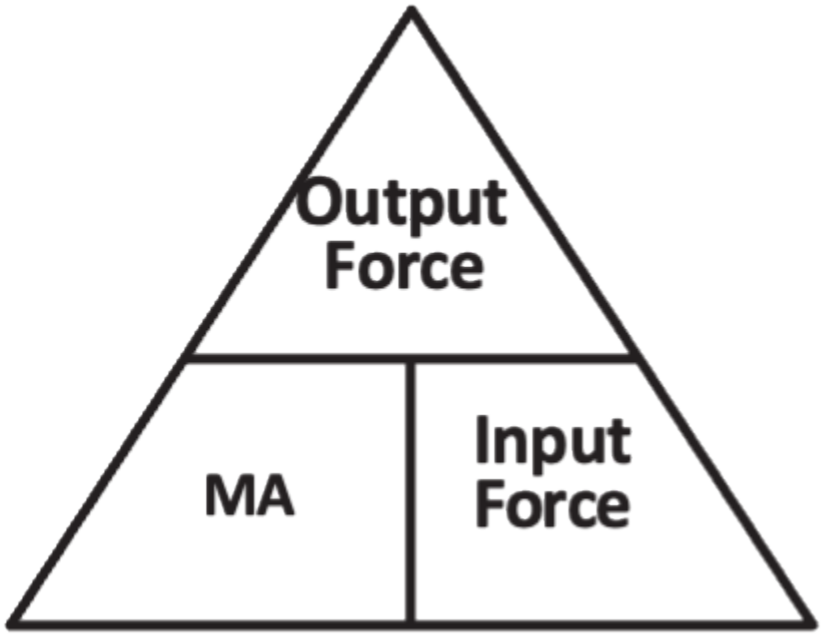

Figure 5 *Mechanical Advantage (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The mechanical advantage is the ***force ratio*** of a machine. The more a machine multiplies the force, the greater is the mechanical advantage of the machine.

Example:

According to engineering reports, 110 hydraulic jacks were used to lift the massive Ekofisk offshore complex in the North Sea. An output force of 390,000,000 N was required to raise the complex. What input force would have to be provided to each jack if the overall mechanical advantage of the jacks was 1,500?

Solution:

$$\text{Input Force} = \frac{\text{Output Force}}{\text{MA}} \quad \text{Input Force} = \frac{390,000,000\text{ N}}{1,500} \quad \text{Input Force} = 260,000\text{ N} \quad \text{Input Force for each jack} = \frac{260,000\text{ N}}{110\text{ jacks}} \quad \text{Input Force for each jack} = 2,363.6\text{ N}$$

Self-Test C-1.14: Define Mechanical Advantages as it Relates to Fluid Power

Complete Self-Test C-1.14 and check your answers.

If you are using a printed copy, please find Self-Test C-1.14 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2443#h5p-22

Complete the C-1.4 Self-Test: Hydraulic Jack Calculations Table (Question 8)

Using a separate sheet of paper, calculate the missing values in the table for each scenario. Show all your work and include the correct units for every answer. You may also print the table if that's easier (see link below). Answer keys for all self-tests are also in the back of this section.

For each row:

- Use the given values to solve for the unknowns.
- Apply the appropriate formulas (e.g., pressure = force ÷ area, area = diameter² × 0.7854, mechanical advantage = output force ÷ input force).
- Ensure your final answers are clearly labeled with units (e.g., lb, N, in², cm², psi, kPa).

Note:

- Some values are provided to help you calculate the remaining values.
- You may need to convert between units (e.g., mm to cm, or in to cm) where appropriate.

- Keep your calculations organized and easy to follow.

Helpful Tip:
Work step-by-step—first calculate area, then pressure, and finally force and mechanical advantage.

Downloadable/printable table: C-1.4_Self-Test_Hydraulic_Jack_Table

C-1.4 Self-Test: Hydraulic Jack Calculations Table (Question 8)

Small piston force	Small piston diameter	Small piston area	Small piston travel distance	Fluid pressure	Large piston diameter	Large piston area	Large piston travel distance	Force exerted by large piston	Mechanical advantage
25 lb	2.5 in.				7.5 in.		7 in.		
44 lb	3.7 in.		14 in.			73 $in.^2$			
78 lb	5.5 in.						12 in.		14
2,375 N	8 cm		1.8 m					9,449 N	
1,850 N		40 cm^2			27.64 cm		70 mm		15
						6,120 cm^2	113 mm	10,770 N	34

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C-1.15 Describe Factors that Affect Fluid Flow in a Piping System

Fluid flow in a piping system is influenced by several physical and mechanical factors. Understanding these factors helps predict how liquids will behave inside pipes, troubleshoot flow problems, and design systems that operate safely and efficiently. Variables such as viscosity, pipe roughness, velocity, and flow patterns all play a role in determining how easily a liquid moves through a pipe. The following sections explain these factors and how they affect overall system performance.

Viscosity

Viscosity measures a liquid's internal resistance to flow. It is a form of friction caused by the resistance of fluid molecules moving past one another as they flow through a pipe. In pipe flow, friction is increased by the internal irregularities of the pipe transporting the liquid. Internal bumps and unevenness in a pipe produce a friction force that opposes the liquid flow and slows down its velocity.

If the viscosity is high, the velocity of the liquid is low, and laminar flow occurs, meaning the liquid flows gently in layers through the pipe. A liquid with a low viscosity flows at a higher velocity, and turbulent flow occurs.

Laminar Flow and Turbulent Flow

When a fluid is flowing through a pipe, two types of flow may occur, depending on the velocity of the fluid:

- Laminar flow
- Turbulent flow

Laminar flow, sometimes known as ***streamline flow***, occurs when a fluid flows in parallel layers, with no disruption between the layers. At low velocity, the fluid tends to flow without mixing, and adjacent layers slide past one another like playing cards. There are no cross-currents perpendicular to the direction of flow, nor eddies or swirls of fluids. In laminar flow, the motion of the particles of fluid is very orderly, with all particles moving in straight lines parallel to the pipe walls.

Figure 1 *Laminar flow (Dubaj/Wikimedia Commons) Public Domain.*

Turbulent flow is the opposite of laminar flow, and occurs at higher velocities, where eddies or cross-currents of

fluid particles form, leading to lateral mixing. In non-technical terms, laminar flow is “smooth,” while turbulent flow is “rough.”

Laminar flow, therefore, causes a minimum amount of internal friction between the molecules, and the ***pressure drop (energy loss)*** will be relatively small. In comparison, turbulent flow causes a relatively large pressure drop because of the internal resistance caused by fluid particles colliding with each other and the pipe walls.

Ensuring laminar flow is an important consideration at certain points in a piping system. For example, it is especially desirable upstream from metering devices and pressure-regulating valves.

Ordinarily, the flow of fluid through a straight run of unobstructed pipe will be streamline (laminar) if the liquid is not travelling too fast. When the fluid is forced to change direction or an obstruction is encountered, turbulence is created. If it is necessary to install a metering device in a section of pipe where the flow is turbulent, a *straightening vane* (Figure 1) may be used to provide the streamline (laminar) flow necessary for accurate flow measurement.

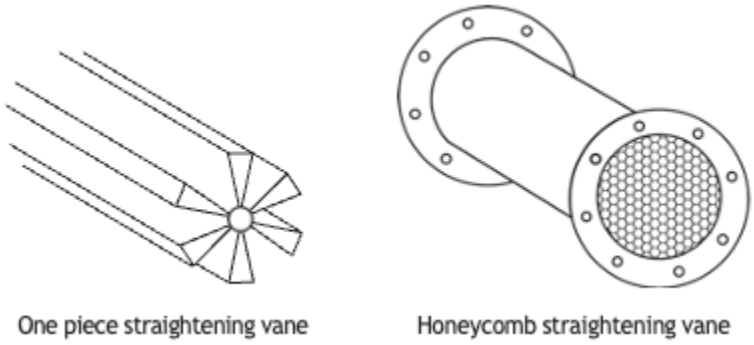


Figure 1 *Straightening vanes (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Flow Velocity

Velocity describes the speed of motion or flow. It is defined as the rate of motion per unit of time. The common units used to measure velocity of flow are $\frac{\text{ft.}}{\text{sec.}}$, $\frac{\text{ft.}}{\text{min.}}$ and $\frac{\text{m}}{\text{sec.}}$.

In a piping system, the velocity of flow changes when the pipe size changes. When the pipe size is reduced and the volume is constant, the same quantity of liquid must pass through the smaller section of pipe and can only do so by increasing its velocity.

Fluid Velocity and Pressure

Figure 2 shows what happens to pressure when fluid velocity increases.

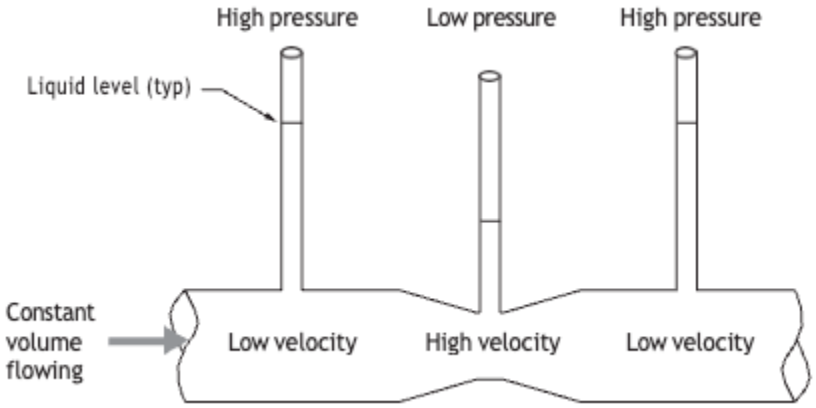


Figure 2 *Effect of fluid velocity on pressure (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

This illustration shows a series of three ***manometers*** measuring pressure over a length of pipe in which a liquid is flowing through a graduated ***venturi (narrowing)***. This is why pressure drops in narrow sections of pipe. The fluid velocity increases as it passes through the narrower section in order to maintain the same flow rate. At its narrowest point, it reaches its highest velocity and thus lowest flow pressure. Beyond this point, the venturi area increases again. The velocity of the fluid slows down and returns to the entering velocity, while the pressure increases again. A small pressure drop (loss) is observed between the first and third manometer due to friction encountered through the pipe.

Bernoulli's Principle

Daniel Bernoulli was a Swiss mathematician who pioneered many studies and theories in fluid mechanics. ***Bernoulli's principle*** states that "where velocity is greatest, pressure is least." This means that as fluid speed increases, pressure decreases.

"Faster flow = lower pressure"

"Slower flow = higher pressure"

Bernoulli's principle can be derived from the principle of ***conservation of energy***. This states that, in a steady flow, the sum of all forms of energy in a fluid along a pipeline is the same at all points on that pipeline. This requires that the sum of ***kinetic energy***, ***potential energy*** and ***internal energy*** remains constant. Thus an increase in the speed (velocity) of the fluid—implying an increase in the kinetic energy—occurs with a simultaneous decrease in the sum of the potential energy and internal energy (pressure energy).

Pressure Drop

The loss of pressure, or *pressure drop*, due to friction as a fluid flows through a piping system may be measured with a gauge or manometer. Pressure drop is often expressed in units of psi, inches of mercury, inches of water column or kPa. The drop in pressure due to friction is also called ***friction head***.

Some of the factors governing the pressure drop due to friction are:

- Viscosity of fluid
- Length of pipe
- Velocity of flow
- Size and type of pipe
- Number and type of fittings and valves
- Number and degree of bends

This pressure drop is observed in the following figure that examines pressure drop due to pipe length. When fluids at rest are in a closed tube, pressure is distributed equally throughout the tube. When the valve is opened and the fluid is allowed to flow, the pressure in the tube will be different at different points along the tube.

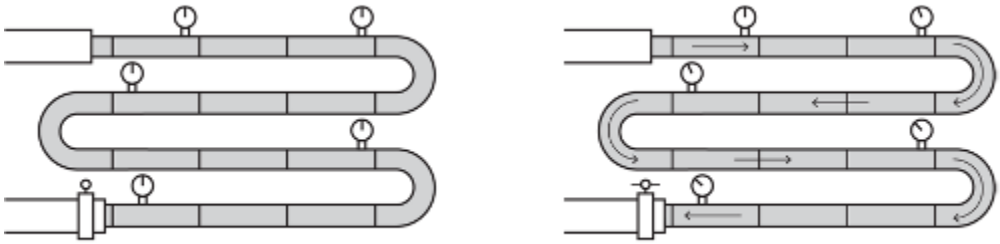


Figure 3 *Hydrodynamic properties (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

This pressure loss is also affected by material choice. For example, copper pipe typically causes more pressure loss than PVC. Smaller pipe also experiences more pressure drop than larger pipe.

An example of pressure drop due to fittings and valves is found in system design parameters of a natural gas system (Figure 4). In a 1-inch piping system, a 90° elbow has the equivalent pressure drop of 0.80 m of straight sch. 40 steel pipe. Compare this to a 1-inch globe valve that has the equivalent pressure drop of 8.87 m of straight sch. 40 steel pipe.

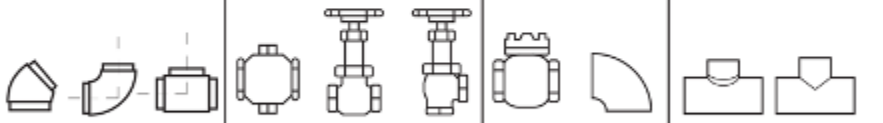
		Threaded fittings†			Valves (threaded, flanged, or welded)			90° welding elbows and smooth bends‡		Welding tees	
		Elbows									
		45°	90°	Tee	Plug	Globe	Angle	Swing Check	R/d§ = 1 ½	Forged	Mitre**
k factor		0.42	0.9	1.8	0.9	10	5	25	0.36	1.35	1.8
n (L/D ratio††)		14	30	60	30	333	167	83	12	45	60
NOMINAL PIPE SIZE, IN (SCHEDULE 40)	INSIDE DIAMETER (d), mm										
¾	12.52	0.18	0.37	0.75	0.37	4.18	2.09	1.04	0.15	0.56	0.75
½	15.80	0.22	0.47	0.94	0.47	5.27	2.64	1.29	0.19	0.71	0.94
¾	20.93	0.29	0.63	1.26	0.63	6.98	3.47	1.74	0.25	0.94	1.26
1	26.64	0.37	**0.80**	1.60	0.80	**8.87**	4.45	2.22	0.32	1.20	1.60
1 ¼	35.05	0.49	1.05	2.10	1.05	11.67	5.82	2.92	0.42	1.58	2.10
1 ½	40.89	0.49	1.23	2.45	1.23	13.62	6.83	3.41	0.49	1.84	2.45

Figure 4 *Table Resistance of Bends etc. (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0 (Long description)*

Self-Test C-1.15: Describe Factors that Affect Fluid Flow in a Piping System

Complete Self-Test C-1.15 and check your answers.

If you are using a printed copy, please find Self-Test C-1.15 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2445#h5p-23

Long Description

Long description of Figure 4 table: Pipe fitting loss coefficients and dimensions

This table presents engineering data used to calculate friction losses in piping systems. It compares different types of pipe fittings and valves by showing their **k factors** (loss coefficients), **equivalent length ratios (L/D)**, and how these relate to different **nominal pipe sizes**.

Overall Structure

The table is organized into vertical sections based on fitting type:

1. **Threaded fittings (standard):** Includes: 45° elbows, 90° elbows, and tees
2. **Valves (threaded, flanged, or welded):** Includes: plug valves, globe valves, and angle valves
3. **90° welding elbows and smooth bends:** Includes: swing check valves and long-radius bends
4. **Welding tees:** Includes: forged tees and mitre bends

Each category shows:

- A **k factor** (resistance to flow)
- An **n (L/D ratio)** representing equivalent pipe length

Top Rows: Flow Resistance Values

k factor (dimensionless)

This row shows how much resistance each fitting adds to fluid flow:

- 45° elbow: 0.42
- 90° elbow: 0.9
- Tee: 1.8
- Plug valve: 0.9
- Globe valve: 10 (very high resistance)
- Angle valve: 5
- Swing check valve: 25 (very high resistance)
- Smooth bend: 0.36 (low resistance)

- Forged tee: 1.35
- Mitre bend: 1.8

Equivalent Length Ratio (n or L/D)

This converts fittings into an equivalent length of straight pipe:

- 45° elbow: 14
- 90° elbow: 30
- Tee: 60
- Plug valve: 30
- Globe valve: 333 (very large equivalent length)
- Angle valve: 167
- Swing check valve: 83
- Smooth bend: 12
- Forged tee: 45
- Mitre bend: 60

Lower Section: Pipe Sizes and Dimensions

The bottom portion lists nominal pipe sizes (Schedule 40) along with their inside diameters in millimetres and metres.

Pipe sizes shown include:

- ⅜ inch (12.52 mm / 0.01252 m)
- ½ inch (15.80 mm / 0.01580 m)
- ¾ inch (20.93 mm / 0.02093 m)
- 1 inch (26.64 mm / 0.02664 m)
- 1¼ inch (35.05 mm / 0.03505 m)
- 1½ inch (40.89 mm / 0.04089 m)

Equivalent Lengths for Each Fitting

For each pipe size, the table shows how much **straight pipe length (in metres)** each fitting is equivalent to in terms of resistance.

For example:

- A **½-inch pipe**:
  - 45° elbow ≈ 0.22 m
  - 90° elbow ≈ 0.47 m
  - Tee ≈ 0.94 m
  - Globe valve ≈ 5.27 m

- A **1-inch pipe**:
  - 45° elbow ≈ 0.37 m
  - 90° elbow ≈ 0.80 m
  - Tee ≈ 1.60 m
  - Globe valve ≈ 8.87 m
- A **1½-inch pipe**:
  - 45° elbow ≈ 0.49 m
  - 90° elbow ≈ 1.23 m
  - Tee ≈ 2.45 m
  - Globe valve ≈ 13.62 m

Visual Elements

Small line drawings are included above each column to visually represent each fitting type, such as:

- Bent pipe sections for elbows
- T-shaped junctions for tees
- Valve symbols with handles
- Smooth curved bends

Key Takeaway

The table helps users estimate how much resistance different fittings add to a piping system by:

- Comparing fittings using **k factors**
- Converting them into **equivalent pipe lengths**
- Adjusting values based on **pipe size**

This information is commonly used in plumbing and engineering to calculate pressure losses and design efficient piping systems.

[Back to Figure 4]

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Note: these videos align with the open textbooks *Math for Trades: Volume 1* and *Math for Trades: Volume 2*. All videos are by Chad Flinn and available under a Creative Commons Attribution 4.0 Licence.:

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- **Figure 1** Laminar flow was adapted by TRU Open Press from Dubaj at Wikimedia Commons, and it is in the public domain. Dubaj illustration vectorized by Guillaume Paumier (user:guillom).

C-1.16 Describe Factors that Affect Gas Volumes, Pressures and Temperatures

Gases behave differently from solids and liquids, so we use specific methods to calculate and understand how they act under different conditions. Unlike liquids and solids, gases have no fixed volume or shape; they expand or contract to fill whatever container they are in. When studying gases, we focus on three key variables that determine their behaviour:

- Pressure
- Volume
- Temperature

Pressure is measured as force per unit area. The standard metric unit for pressure is the kilopascal (kPa). In the imperial system, the units of $\frac{\text{lb.}}{\text{in.}^2}(\text{psi})$ are commonly used. The equation below shows the conversion between these units:

$$1 \text{ psi} = 6.8947 \text{ kPa}$$

When converting these pressures in many of the code books and on the job site, we use a soft ***conversion*** to make the task easier:

$$1 \text{ psi} = 7 \text{ kPa}$$

The Gas Laws of Boyle, Gay-Lussac, and Charles

The early ***gas laws*** were developed at the end of the eighteenth century, when scientists began to realize a common relationship between the pressure, ***volume*** and ***temperature*** characteristics of all gases. Gases behave in a similar way over a wide variety of conditions because they all have widely-spaced particles (***molecule***s). These gas laws provide predictable results for most gases under moderate pressure and temperature.

It should be noted that when working with these gas laws, ***all temperatures and pressures must be expressed in absolute units***. This means using psia or kPa (absolute) for ***pressure***, and ***Rankine (°R)*** or ***Kelvin (K)*** for temperature.

Absolute pressure conversion

- psig + 14.7 = psia
- kPa + 101.325 = kPa (ab)

Absolute temperature conversion

- °F + 460 = °R
- °C + 273 = K

Boyle's Law

Boyle's law (named after Irish physicist Robert Boyle) describes the relationship between the pressure and volume of a gas. According to this law, the *absolute pressure* exerted by a gas held at a ***constant*** temperature varies inversely with the volume of the gas.

For example, if the volume of a gas is halved, the ***absolute pressure*** would be doubled; and if the volume of a gas is doubled, then the absolute pressure is halved. The reason for this effect is that a gas is made up of loosely spaced molecules moving at random. If a gas is compressed in a container, these molecules are pushed together; thus the gas occupies less volume. The molecules, having less space in which to move, collide with the walls of the container more frequently and thus exert an increased pressure.

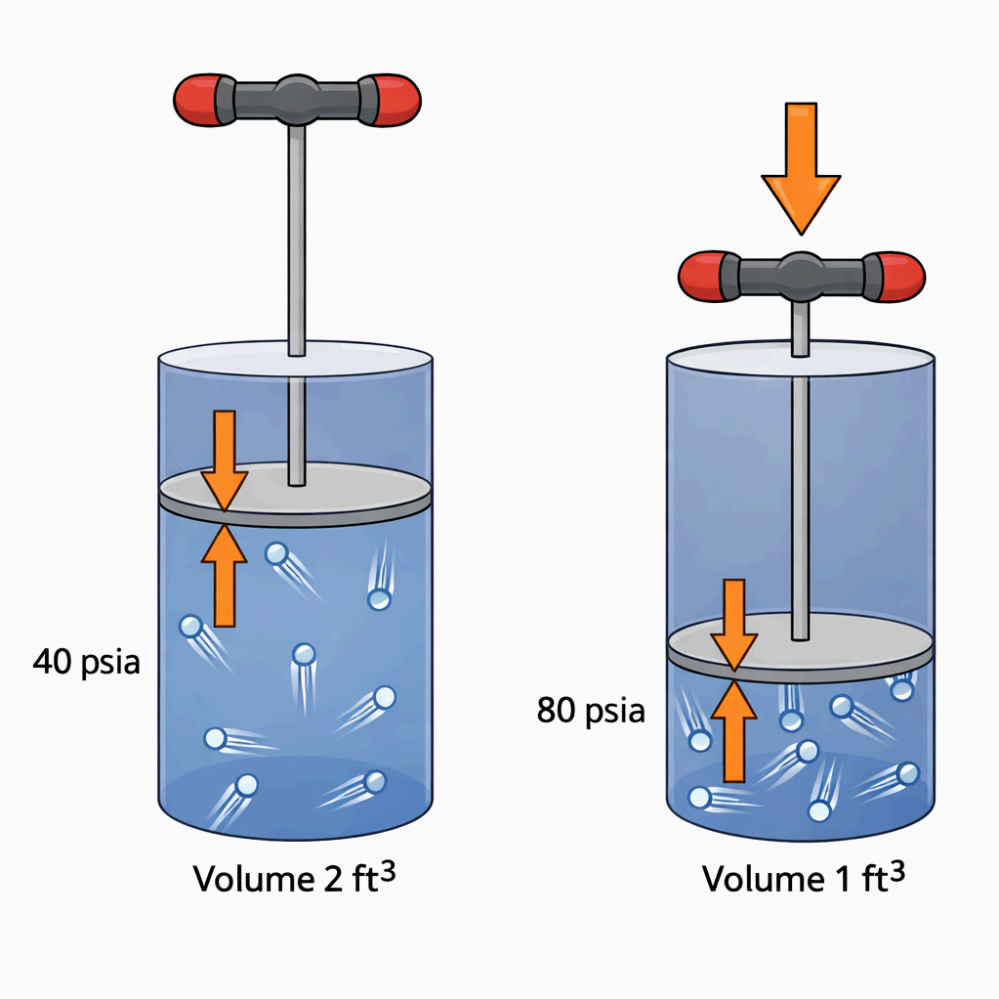

Figure 1 *Boyle's law, showing that when volume is reduced by half absolute pressure doubles (TRU Open Press/OpenAI (adapted) from BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Boyle's Law Calculations

Boyle's law may be stated as follows:

The volume of any dry gas varies inversely with the absolute pressure when the temperature remains constant.

This is expressed in the following formula:

$$V_1P_1 = V_2P_2$$

Where:

V_1 = the original volume V_2 = the new volume P_1 = the original absolute pressure P_2 = the new absolute pressure

Example 1:

If the volume of a gas is 9 ft^3 at a pressure of 25 psig, what will be the volume at 47 psig?

Solution:

The first step is to find the values for the given variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 9 ft^3 V_2 = the new volume = the unknown variable. This is what we will solve for. P_1 = the original absolute pressure = 25 psig + 14.7 psia = 39.7 psia P_2 = the new absolute pressure = 47 psig + 14.7 psia = 61.7 psia

The second step is to transpose the Boyle's law formula to isolate the unknown variable. In this example it is V_2:

$$\frac{V_1P_1}{P_2} = V_2$$

The third step is to substitute the known variable into the transposed equation and solve:

$$\frac{9\,ft^3 \times 39.7\,psia}{61.7\,psia} = V_2$$
$$5.79\,ft^3 = V_2$$

Example 2:

If the volume of a gas is 17 ft^3 at a pressure of 87 psig, what will be the ***gauge pressure*** in the container if the volume is reduced to 4 ft^3?

Solution:

As in the previous example, the first step is to find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 17 ft^3 V_2 = the new volume = 4 ft^3 P_1 = the original absolute pressure = 87 psig + 14.7 psia = 101.7 psia P_2 = the new absolute pressure = the unknown variable. This is what we will solve for.

The second step is to transpose the Boyle's law formula to isolate the unknown variable. In this example it is P_2:

$$\frac{V_1P_1}{V_2} = P_2$$

The third step is to substitute the known variables into the transposed equation and solve. Note that the answer in your calculator will be in psia. This is because you entered P_1 as an absolute pressure. In order to get gauge pressure, you will have to subtract an atmosphere (14.7 psia):

$$\frac{17\ \text{ft}^3 \times 101.7\ \text{psia}}{4\ \text{ft}^3} = \text{P}_2 \quad \frac{17\ \text{ft}^3 \times 101.7\ \text{psia}}{4\ \text{ft}^3} = 432.23\ \text{psia} \quad 432.23\ \text{psia} - 14.7\ \text{psia} = 417.53\ \text{psig}$$

Example 3:

A captive volume of gas is pressurized to 200 kPa. When the volume of the gas is reduced to 0.75 m^3, the gauge pressure increased to 370 kPa. What was the original volume the gas occupied when the pressure was 200 kPa?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = the unknown variable. This is what we will solve for. V_2 = the new volume = 0.75 m^3 P_1 = the original absolute pressure = 200 kPa + 101.325 = 301.325 kPa (ab) P_2 = the new absolute pressure = 370 kPa + 101.325 = 471.325 kPa (ab)

Transpose the Boyle's law formula to isolate the unknown variable. In this example it is V_1:

$$\text{V}_1 = \frac{\text{P}_2\text{V}_2}{\text{P}_1}$$

Substitute the known variable into the transposed equation and solve:

$$\text{V}_1 = \frac{471.325\ \text{kPa (ab)} \times 0.75\ \text{m}^3}{301.325\ \text{kPa (ab)}} \quad \text{V}_1 = 1.17\ \text{m}^3$$

Example 4:

A captive volume of gas occupies a volume of 7 m^3. When the volume of the gas is reduced to 4.6 m^3, the gauge pressure increases to 420 kPa. What was the original gauge pressure of the gas before the volume was reduced?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 7 m^3 V_2 = the new volume = 4.6 m^3 P_1 = the original absolute pressure = the unknown variable. This is what we will solve for. P_2 = the new absolute pressure = 420 kPa + 101.325 = 521.325 kPa (ab)

Transpose the Boyle's law formula to isolate the unknown variable. In this example it is P_1:

$$\text{P}_1 = \frac{\text{P}_2\text{V}_2}{\text{V}_1}$$

Substitute the known variables into the transposed equation and solve. Note that the answer in your calculator will be in kPa (ab). This is because you entered P_2 as an absolute pressure. In order to get gauge pressure, you will have to subtract an atmosphere (101.325 kPa (ab)).

$$\text{P}_1 = \frac{4.6\ \text{m}^3 \times 521.325\ \text{kPa (ab)}}{7\ \text{m}^3} \quad \text{P}_1 = 342.59\ \text{kPa (ab)} \quad \text{P}_1 = 342.59\ \text{kPa (ab)} - 101.325\ \text{kPa (ab)} = 241.27\ \text{kPa}$$

Gay-Lussac's Law

Joseph-Louis Gay-Lussac, a French physicist who experimented with the effect of temperature on the pressure exerted by a gas, concluded that with the volume held constant, the absolute pressure exerted by a gas is in direct proportion to the ***absolute temperature***.

In Figure 2, the volume was held constant, while the absolute temperature was raised from 480°R to 960°R. As a result, there was a corresponding increase in absolute pressure in the container from 40 psia to 80 psia.

Gay-Lussac's Law Calculations

Gay-Lussac's law may be stated as follows:

The absolute pressure of any dry gas varies directly with the absolute temperature when the volume remains constant.

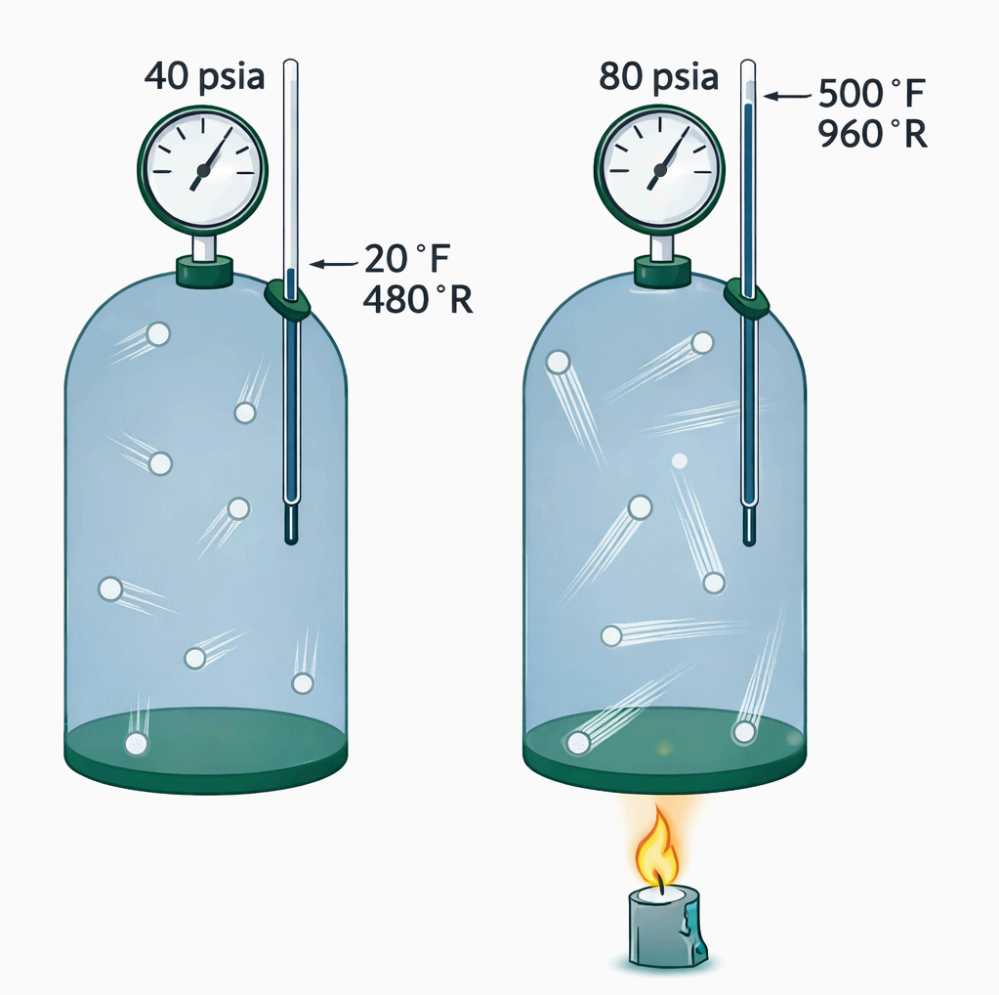

Figure 2 *Gay-Lussac's law, showing that when absolute temperature doubles, absolute pressure also doubles (TRU Open Press/OpenAI (adapted) from BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

This relationship may be expressed using the following formula:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Where:

P_1 = the original absolute pressure P_2 = the new absolute pressure T_1 = the original absolute temperature T_2 = the new absolute temperature

Example 1:

The pressure of a gas in a container is 25 psig at 70 °F room temperature. What will be the gauge pressure when the gas is heated to 115 °F?

Solution:

Find the values for the known variable, which will isolate the unknown variable for us to solve:

P_1 = the original absolute pressure = 25 psig + 14.7 = 39.7 psia P_2= the new absolute pressure = the unknown variable. This is what we will solve for. T_1 = the original absolute temperature = 70 °F + 460 = 530°R T_2 = the new absolute temperature = 115 °F + 460 = 575°R

Transpose the Charles's law 1 formula to isolate the unknown variable. In this example it is P_2:

$$\frac{P_1 T_2}{T_1} = P_2$$

Substitute the known variables into the transposed equation and solve. Remember that the answer in your calculator will be in psia, so you must change this value to psig:

$$\frac{39.7 \text{ psia} \times 575^\circ\text{R}}{530^\circ\text{R}} = P_2 \quad 43.07 \text{ psia} = P_2 \quad 43.07 \text{ psia} - 14.7 \text{ psia} = 28.37 \text{ psig}$$

Example 2:

The pressure of a gas in a container is 46 psig at 6 °F. The gas is heated until the gauge pressure reaches 62 psig. What is the final temperature of the gas in °F when the pressure gauge reaches 62 psig?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

P_1 = the original absolute pressure = 46 psig + 14.7 = 60.7 psia P_2 = the new absolute pressure = 62 psig + 14.7 = 76.7 psia T_1 = the original absolute temperature = 6 °F + 460 = 466°R T_2= the new absolute temperature = the unknown variable. This is what we will solve for.

Transpose the Charles's law 1 formula to isolate the unknown variable. In this example it is T_2:

Substitute the known variables into the transposed equation and solve. Remember that the answer in your calculator will be in °R, so you must change this value to °F :

$$T_2 = \frac{76.7 \text{ psia} \times 466^\circ\text{R}}{60.7} \quad T_2 = 588.83^\circ\text{R} \quad 588.83^\circ\text{R} - 460 = 128.83^\circ\text{F}$$

Example 3:

The pressure of a gas in a container is 55 kPa. The gas is heated until it reaches 110 °C and the gauge pressure reaches 130 kPa. What was the temperature of the gas in °C when the heating process began?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

P_1 = the original absolute pressure = 55 kPa + 101.325 kPa (ab) = 156.325 kPa (ab) P_2 = the new absolute pressure = 130 kPa + 101.325 kPa (ab) = 231.325 kPa (ab) T_1 = the original absolute temperature = the unknown variable. This is what we will solve for. T_2 = the new absolute temperature = 110 °C + 273 = 383 K

Transpose the Charles's law 1 formula to isolate the unknown variable. In this example it is T_1:

$$\frac{P_1 T_2}{P_2} = T_1$$

Substitute the known variables into the transposed equation and solve. Remember that the answer in your calculator will be in K, so you must change this value to °C :

$$\frac{156.325 \text{ kPa (ab)} \times 383 \text{ K}}{231.325 \text{ kPa (ab)}} = T_1 \quad 258.82 \text{ K} = T_1 \quad 258.82 \text{ K} - 273 = 14.18^{\circ}\text{C}$$

Charles' Law

Working with unpublished material by Joseph Louis Gay-Lussac, Jacques Charles studied how heat affects the expansion of gases. He observed that when the pressure of a gas remains constant, its volume increases in direct proportion to its absolute temperature. This means that if the temperature of a gas doubles, its volume also doubles; if the temperature is reduced by half, the gas occupies half the original volume.

Charles' Law may be stated as follows: ***The volume of any dry gas varies directly with the absolute temperature when the pressure remains constant.***

This may be expressed as the following formula:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Where:

V_1 = the original volume V_2 = the new volume T_1 = the original absolute temperature T_2 = the new absolute temperature

Example 1:

The volume of a gas sample is 43 ft^3 at 90 °F. What volume would this gas sample occupy if it were heated to 115 °F and the gas pressure remained constant?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 43 ft^3 V_2 = the new volume = the unknown variable. This is what we will solve for. T_1 = the original absolute temperature = 90 °F + 460 = 550 °R T_2 = the new absolute temperature = 115 °F + 460 = 615 °R

Transpose the Gay-Lussac's law formula to isolate the unknown variable. In this example it is V_2:

$$\frac{V_1 T_2}{T_1} = V_2$$

Substitute the known variables into the transposed equation and solve:

$$\frac{43\ \text{ft}^3 \times 615^\circ\text{R}}{550^\circ\text{R}} = V_2 \quad 48.08\ \text{ft}^3 = V_2$$

Example 2:

The temperature of a gas sample is measured at 22°C. The same sample is heated to 61°C with a heater. After the heating process, the gas sample has volume of 33 m^3 and the gas pressure has remained constant. What volume did this gas sample occupy before it was heated?

Solution:

Find the values for the known variable, which will isolate the unknown variable for us to solve:

V_1 = the original volume = the unknown variable. This is what we will solve for. V_2 = the new volume = 33 m^3 T_1 = the original absolute temperature = 22°C + 273 = 295 K T_2 = the new absolute temperature = 61°C + 273 = 334 K

Transpose the Gay-Lussac's law formula to isolate the unknown variable. In this example it is V_1:

$$V_1 = \frac{V_2 T_1}{T_2}$$

Substitute the known variables into the transposed equation and solve:

$$V_1 = \frac{33\ \text{m}^3 \times 295\ \text{K}}{334\text{K}} = V_2 \quad V_2 = 29.15\ \text{m}^3$$

Example 3:

The volume of a gas sample is measured at 42 m^3 when the temperature is –17°C. The air is heated to the point where the volume of the air is now 49 m^3. Assuming constant pressure, what is the temperature (°C) of the air sample at the new volume?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 42 m^3 V_2 = the new volume = 49 m^3 T_1 = the original absolute temperature = –17°C + 273 = 256 K T_2 = the unknown variable. This is what we will solve for.

Transpose the Gay-Lussac's law formula to isolate the unknown variable. In this example it is T_2:

$$T_2 = \frac{V_2 T_1}{V_1}$$

Substitute the known variables into the transposed equation and solve. Remember that the answer in your calculator will be in K, so you must change this value to °C:

$$T_2 = \frac{49\ m^3 \times 256\ K}{42\ m^3} \quad T_2 = 298.67\ K \quad 298.67K - 273 = 25.67^\circ C$$

Combined Gas Law

All the gas laws studied in this section have had a constant involved:

- In Boyle's law, the temperature of the gas is assumed constant.
- In Charles's law, the pressure of the gas is assumed constant.
- In Gay-Lussac's law, the temperature of the gas is assumed constant.

Many times, however, a change in temperature or another of these factors may simultaneously change both the pressure and volume occupied by a gas. The ***combined gas law*** enables us to deal with such circumstances.

The combined gas law is not a new law but a combination of Boyle's and Charles's laws, hence the name the combined gas law. In short, this law is used when it is difficult to keep the volume, temperature or pressure constant.

Combined Gas Law Calculations

The combined gas law may be expressed by the following formula:

$$\frac{V_1 P_1}{T_1} = \frac{V_2 P_2}{T_2}$$

Where:

V_1 = the original volume V_2 = the new volume P_1 = the original absolute pressure P_2 = the new absolute pressure T_1 = the original absolute temperature T_2 = the new absolute temperature

Remember: as with all gas laws, the **temperature and pressure must be in absolute terms**.

Example 1:

An air sample has a volume of 44 ft^3 when the pressure is 20 psig and the temperature is 80 °F. The air is cooled to 70 °F, at which time the pressure also drops to 18 psig. What volume does the air now occupy in order to result in these findings?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 44 ft^3 V_2 = the new volume = the unknown variable. This is what we will solve for. P_1 = the original absolute pressure = 20 psig + 14.73 psia = 34.73 psia P_2 = the new absolute pressure = 18 psig + 14.73 psia = 32.73 psia T_1 = the original absolute temperature = 80 °F + 460 = 540 °R T_2 = the new absolute temperature = 70 °F + 460 = 530 °R

Transpose the combined gas law formula to isolate the unknown variable. In this example, it is V_2:

$$\frac{V_1 P_1 T_2}{T_1 P_2} = V_2$$

Substitute the known variables into the transposed equation and solve :

$$\frac{44\ \text{ft}^3 \times 34.73\ \text{psia} \times 530^\circ\text{R}}{540^\circ\text{R} \times 32.73\ \text{psia}} = \text{V}_2 \quad 45.82\ \text{ft}^3 = \text{V}_2$$

Example 2:

A 3-m^3 expansion bladder is filled with air to a pressure of 50 kPa on a warm summer day. The temperature of the air is measured at 22°C during the filling process. Six months later, the bladder conditions are measured. The volume of the bladder is now 2.7 m^3 and the pressure has dropped to 42 kPa. Assuming the bladder isn't leaking, what is the current temperature of the air (°C)?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 3 m^3 V_2 = the new volume = 2.7 m^3 P_1 = the original absolute pressure = 50 kPa + 101.325 kPa (atm) = 151.325 kPa (ab) P_2 = the new absolute pressure = 42 kPa + 101.325 kPa (atm) = 143.325 kPa (ab) T_1 = the original absolute temperature = 22°C + 273 = 295 K T_2 = the new absolute temperature = the unknown variable. This is what we will solve for.

Transpose the combined gas law formula to isolate the unknown variable. In this example it is T_2:

$$\text{T}_2 = \frac{\text{V}_2\text{P}_2\text{T}_1}{\text{V}_1\text{P}_1}$$

Substitute the known variables into the transposed equation and solve. Remember that the answer in your calculator will be in K, so you must change this value to °C:

$$\text{T}_2 = \frac{2.7\ \text{m}^3 \times 143.325\ \text{kPa (ab)} \times 295\ \text{K}}{3\ \text{m}^3 \times 151.325\ \text{kPa (ab)}} \quad \text{T}_2 = 251.46\ \text{K} \quad 251.46\ \text{K} - 273 = -21.53^\circ\text{C}$$

Example 3:

A captive nitrogen sample is measured with a volume of 32 ft^3, a temperature of 39 °F and a pressure of 76 psig. The nitrogen is heated to a point where the conditions change so that the temperature is now 60 °F and the volume is now 55 ft^3 What pressure (psig) would the nitrogen be at in order to cause the new conditions?

Solution:

Find the values for the known variables, which will isolate the unknown variable for us to solve:

V_1 = the original volume = 32 ft^3 V_2 = the new volume = 55 ft^3 P_1 = the original absolute pressure = 76 psig + 14.7 psia = 90.7 psia P_2 = the new absolute pressure = the unknown variable. This is what we will solve for. T_1 = the original absolute temperature = 39 °F + 460 = 499 °R T_2 = the new absolute temperature = 60 °F + 460 = 520 °R

Transpose the combined gas law formula to isolate the unknown variable. In this example it is P_2:

$$\frac{\text{V}_1\text{P}_1\text{T}_2}{\text{T}_1\text{V}_2} = \text{P}_2$$

Substitute the known variables into the transposed equation and solve. Remember that the answer in your calculator will be in psia, so you must change this value to psig:

$$\frac{32\ \text{ft}^3 \times 90.7\ \text{psia} \times 520^\circ\ \text{R}}{499^\circ\text{R} \times 55\ \text{ft}} = \text{P}_2 \quad 54.99\ \text{psia} = \text{P}_2 \quad 54.99\ \text{psia} - 14.7 = 40.29\ \text{psig}$$

Self-Test C-1.16: Describe Factors that Affect Gas Volumes and Pressures

Complete Self-Test C-1.16 and check your answers.

If you are using a printed copy, please find Self-Test C-1.16 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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C-1.17 Calculate the Expansion and Contraction of Various Piping Materials Due to Heating and Cooling

All piping systems expand and contract with changes in temperature. This issue must be addressed with appropriate system design to prevent damage to the system. ***Expansion*** during heating and ***contraction*** during cooling are typically accommodated at changes in direction within the piping system. Long, straight runs are more susceptible to measurable movement, so ***expansion loops*** or ***offsets*** are required to absorb these forces without damaging the system.

The rate of ***linear expansion*** does not vary with pipe size; the primary factor is the type of piping material. The effects of expansion/contraction are most pronounced on hot water or ***steam lines*** in which the ***temperature changes (ΔT)*** are greater.

To calculate the amount of expansion or contraction, the ***coefficient of expansion (COE)*** must be known for the material. These coefficients are standardized and are based on temperature change. Separate coefficients are provided for °F and °C for each material. Because the COE is a ratio, it can be applied to any unit of length (inches, feet, millimetres, metres, etc.).

Table 1 shows the coefficients of linear expansion for commonly used piping materials including ***ferrous metals*** (alloys that contain iron), ***non-ferrous metals*** (alloys without iron), and ***thermoplastic pipe*** (sometimes called *thermosoftening plastic*). These are used in calculating the amount of expansion or contraction that may occur in piping systems.

Table 1: Coefficients of Linear Expansion for Piping Materials

Piping Material	Coefficient of Linear Expansion (COE)	
	Units of Measure / °F	Units of Measure / °C
Aluminum	0.0000128	0.0000231
Carbon steel	0.0000065	0.0000117
Cast iron	0.0000059	0.0000106
Copper	0.0000093	0.0000168
Stainless steel	0.0000099	0.0000178
ABS (acrylonitrile-butadiene styrene)	0.000035	0.000063
HDPE (high-density polyethylene)	0.000067	0.00012
PE (polyethylene)	0.000083	0.00015
CPVC (chlorinated polyvinyl chloride)	0.000044	0.000079
PVC (polyvinyl chloride)	0.000028	0.0000504

Note: The high expansion coefficients for the plastic materials make plastic piping extremely sensitive to change in temperature. The design of plastic piping systems must include accommodation for high expansion.

Linear expansion can be expressed through the following equation:

$$\mathrm{Ch} = \mathrm{COE} \times \mathrm{L} \times \Delta \mathrm{T}$$

Where:

Ch = Change in length due to expansion or contraction COE = Coefficient of linear expansion L = Original length $\Delta \mathrm{T}$ = Temperature change of the piping material

Example:

Calculate the change in length of 55 feet of copper tube for a temperature change from 43°F to 185°F.

Solution:

$$\mathrm{Ch} = \mathrm{COE} \times \mathrm{L} \times \Delta \mathrm{T} \quad \mathrm{Ch} = 0.0000093 \times 55 \text{ ft} \times (185^\circ \mathrm{F} - 43^\circ \mathrm{F}) \quad \mathrm{Ch} = 0.0000093 \times 55 \text{ ft} \times 142^\circ \mathrm{F} \quad \mathrm{Ch} = 0.072633 \text{ ft}$$

Convert the answer to the nearest $\frac{1}{16}$in. :

$$0.072633 \text{ ft} \times 12 = 0.8716 \text{ in.} \times 16 = \frac{13.95}{16} \text{ in.} = \frac{14}{16} \text{ in.} = \frac{7}{8} \text{ in.}$$

Note: When calculating the ***change in length (Ch)***, the answer displayed on your calculator will be in the same units as the original length entered. This observation is true for both the metric and imperial systems. If you need to solve for an answer in inches or millimetres, it is sometimes more convenient to enter the original length into your calculator in that unit.

Example:

Calculate the change in length of 22 m of cast iron for a temperature change from 8°C to 22°C.

Solution:

$$\text{Ch} = \text{COE} \times \text{L} \times \Delta\text{T} \quad \text{Ch} = 0.0000106 \times 22\ \text{m} \times (22^{\circ}\text{C} - 8^{\circ}\text{C}) \quad \text{Ch} = 0.0000106 \times 22\ \text{m} \times 14^{\circ}\text{C} \quad \text{Ch} = 0.0032648\ \text{m}$$

Convert the answer to mm:

$$0.0032648\ \text{m} \times 1,000 = 3.26\ \text{mm}$$

Piping System Flexibility

The piping system must be sufficiently flexible to accommodate the movements of the components as they expand. In many cases the flexibility of the piping system, due to the length of the pipe and the number of bends and supports, means that no undue ***stress*** is imposed. In other installations, however, it will be necessary to incorporate some specific means of achieving this required flexibility. These include ***expansion fittings*** and ***expansion loops***.

Expansion Fittings

An expansion fitting is one method of accommodating expected expansion. These fittings are placed within a pipeline and are designed to accommodate expansion and contraction without the total length of the pipeline changing. These are often referred to as an ***expansion bellows*** due to the bellows-type construction of the ***expansion sleeve*** (Figure 1).

Figure 1 *Bellows-type in-line expansion fitting* (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

Other expansion fittings can be made from the same piping in the form of a fabricated *expansion loop*. This can be a less-expensive option to satisfy the requirement for expansion control, but more space is typically needed to accommodate the piping arrangement.

Expansion Loops

Expansion loops can be fabricated from straight pipe and elbows welded together. If job-site specifications do not allow fabricated loops, manufacturers provide a variety of pre-made loop designs that may be used (Figure 2).

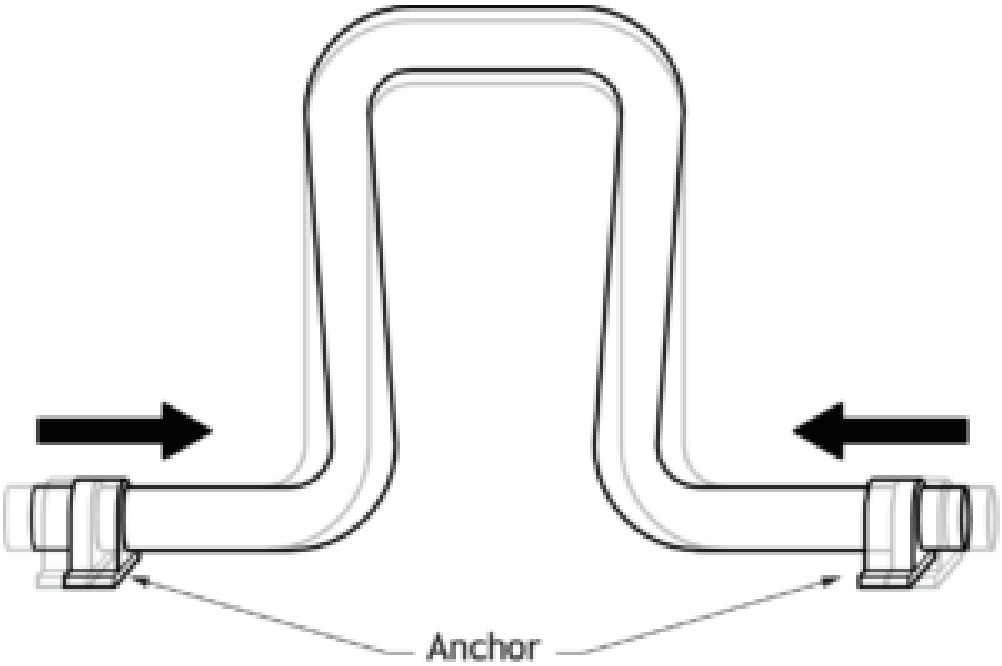

Figure 2 *Manufactured expansion loop (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Self-Test C-1.17: Calculate the Expansion and Contraction of Various Piping Materials Due to Heating and Cooling

Complete Self-Test C-1.17 and check your answers.

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C-1.18 Define Methods of Heat Transfer

Methods of Heat Transfer

There are three ways heat can be transferred from one substance to another or from one place to another:

- Conduction
- Convection
- Radiation

In most real-world situations, more than one method of heat transfer occurs at the same time. As a tradesperson, you need to be aware that various heat exchange processes are possible between a building and the external environment. Heat flows by direct conduction through various solid building elements such as walls, roof, ceiling, floor, etc. Heat transfer also occurs from different surfaces by convection and radiation. Solar radiation is transmitted through windows and absorbed by interior building surfaces. ***Evaporation*** of water may also occur, producing a cooling effect.

Heat is also gained in the space due to the presence of human occupants and the heat given off by lights and equipment. The interaction between a human body and the indoor environment is extensive. Due to ***metabolic*** processes, the body continuously produces heat, part of which is used to perform work, while the remainder is dissipated to the environment to maintain body temperature. The body exchanges heat with its surroundings by convection, radiation, evaporation and conduction. As heat is lost, a person feels cool. When heat is gained from the surroundings, the rate of heat loss decreases, and the person feels warm and may begin to perspire. Perspiration causes evaporation on the skin, creating a natural cooling effect.

Conduction

Thermal conduction is the process of heat transfer from one part of an object at a higher temperature to another (or between objects in direct contact) at a lower temperature. This happens with negligible movement of molecules, as heat is transferred from one molecule to another through direct contact. Heat can be conducted through solids, liquids and gases; however, some materials conduct more rapidly than others do (Figure 1). Materials with tight molecular structures lend themselves better to conduction. For example, metals are good conductors, while wood acts as an insulator. Metals conduct heat away from your hand quickly, which produces a “cold” sensation. When you touch a metal surface, heat flows rapidly from your hand into the metal. Wood does not conduct heat away from your hands as well as metals, so wood, even at the same temperature, feels “warmer” than the metal.

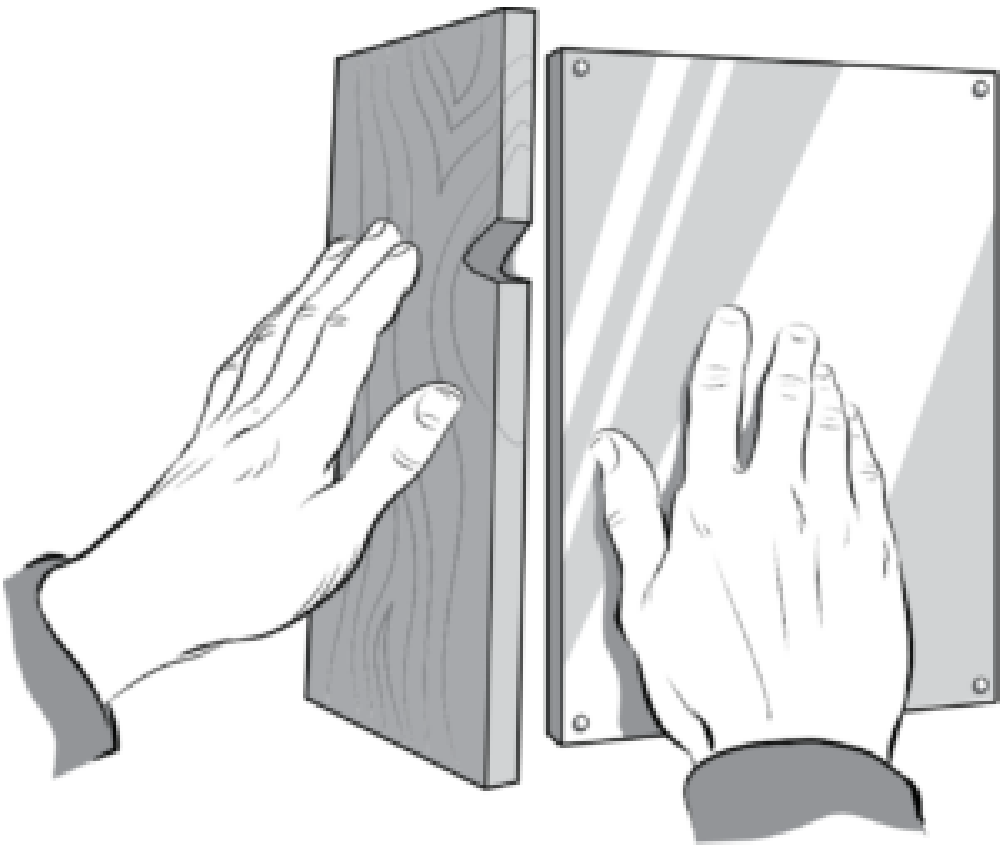

Figure 1 *Conduction heat transfer rates differ depending on material (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Convection

In fluids, thermal energy is transferred from warm areas to cooler areas by *convection*. Convection occurs when warmer regions of a fluid (liquid or gas) rise and cooler regions sink. Cooler liquid or gas then takes the place of the warmer areas that have risen higher due to a drop in ***density***. This results in a continuous circulation pattern called a ***convection current***.

A domestic water heater is a good example of these convection currents. The burner in the combustion chamber produces hot flue gases resulting from the combustion process. These flue gases transfer their heat to the water in the bottom of the heater initially by conduction. The hot water at the bottom of the heater has a reduction in density compared to the cooler water and rises to the top of the heater. The denser, cooler water then drops to the lower portion of the heater, where it is heated again. As layers of temperatures develop within the tank, the result is termed ***temperature stratification***. Eventually, the whole tank will be heated to the tank set point. This continuous movement of fluid transfers heat throughout the system. The hot water collects at the top of the tank, from where it is distributed to the plumbing fixtures as required.

Another good example of convection is in a hydronic heating system using radiators or convectors (Figure 2). The room air surrounding the warm convector is heated and rises to the ceiling level. As the warm air loses its heat to the cooler window area and outside wall, it drops to the floor (becoming more dense), where it is drawn back into the convector to be heated again and complete the cycle, providing comfort.

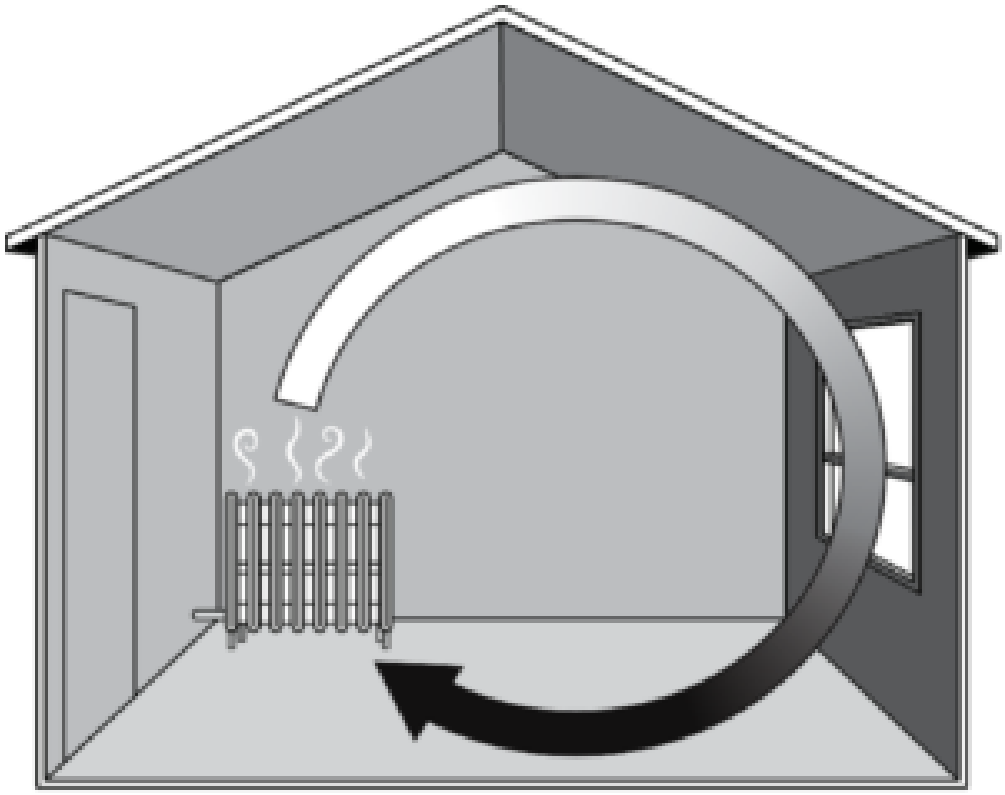

Figure 2 *Convection heat transfer used in space heating (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Radiation

The third major form of heat transfer is radiation, which includes both visible light and invisible ***electromagnetic waves*** such as ***ultraviolet (UV)*** and ***infrared radiation***. Unlike conduction and convection, radiation does not require a medium, which is why heat from the sun can travel through millions of miles of space to reach the earth (Figure 3). This amount of heat transfer cannot occur via convection or by conduction, as conduction requires direct contact between materials, and convection requires the movement of fluids, so neither can transfer heat through empty space.

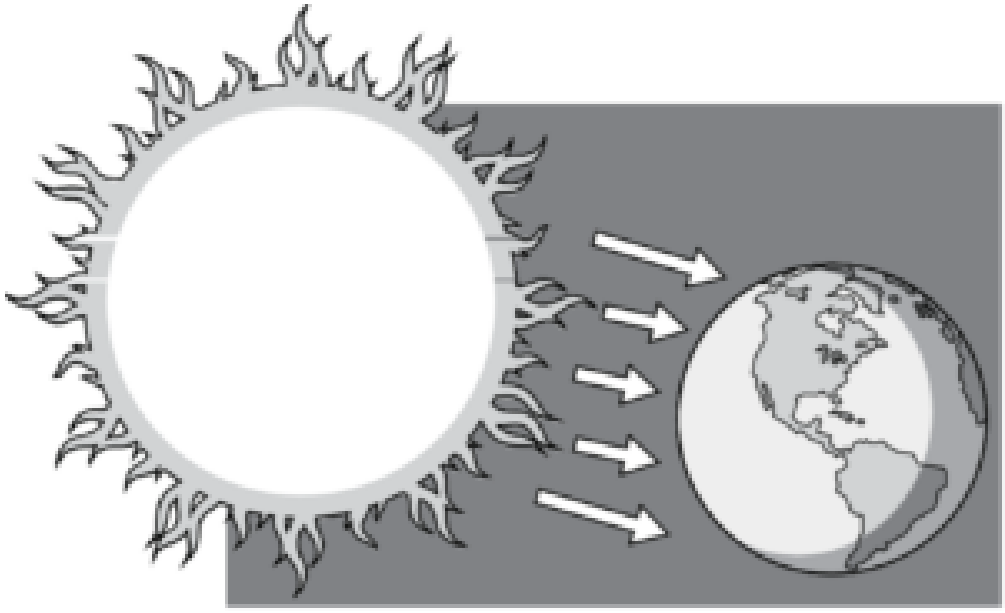

Figure 3 *Radiation heat transfer from the sun, through space to heat the Earth (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Often the energy of heat is visible as light, such as that coming from a hot campfire. This light, being a wave, carries energy. When this light reaches you, part of the energy of the wave gets converted back into heat, which is why you feel warm sitting beside a campfire. Some of the light can be in the form of visible light that we can see, but a great deal of the light emitted is infrared light, whose longer wavelength is detectable only with special infrared detectors. As an object becomes hotter, it emits more energy at shorter wavelengths, producing more visible light while still emitting infrared radiation. For example, human beings, at a temperature of about 37 °C, emit almost exclusively infrared light, which is why we don't see each other glowing in the dark. On the other hand, the hot filament of a light bulb emits considerably more visible light.

Self-Test C-1.18: Define Methods of Heat Transfer

Complete Self-Test C-1.18 and check your answers.

In each of the following situations, identify the method of heat transfer taking place (conduction, convection, radiation). More than one process may be occurring.

If you are using a printed copy, please find Self-Test C-1.18 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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C-1.19 Perform Heat Load Calculations

Heat load calculations are used to determine how much heat energy is required to change or maintain the temperature of fluids in a piping system. These calculations are important in applications such as hot water systems, boilers, hydronic heating, and process piping. To perform accurate heat load calculations, students must understand several heat-related properties, including *specific heat*, *temperature change*, and *mass*. The following section introduces specific heat, which is the amount of heat needed to raise or lower the temperature of a substance.

Specific Heat

Specific heat is the amount of heat necessary to raise or lower the temperature of a unit mass of a substance by one degree. In the imperial system, specific heat references the number of *British thermal units* (BTU) required to change 1 lb. of a substance 1 °F. For example, adding 1 BTU of heat energy to 1 lb. of water would increase the temperature by 1 °F. When substances other than water are heated, different values occur. For instance, ice and steam do not have the same specific heat as water, although they are really just water in different states. Both ice and steam have a specific heat of $0.5 \frac{\frac{\text{BTU}}{\text{lb.}}}{^{\circ}\text{F}}$. Therefore, adding 1 BTU of heat energy to one pound of either of these substances would cause a 2 °F temperature rise.

In the metric system, specific heat is calculated as the number of calories needed to raise or lower the temperature of 1 gram of a given substance by 1 °C. The ***heat capacity*** of water in metric is calculated as 4.19 kJ/(kg · °C).

In either system, specific heat compares the amount of heat required to change the temperature of a substance to that required for an equal mass of water.

Table 1 gives the specific heats of several substances.

Table 1: Specific Heat of Various Substances

Substance	**Specific Heat** $\frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}}$	**Specific Heat** $\frac{\frac{\text{Cal}}{\text{gram}}}{^\circ\text{C}}$
Aluminum	0.224	0.224
Brick	0.22	0.22
Concrete	0.156	0.156
Copper	0.092	0.092
Ice	0.5	0.5
Steel	0.116	0.116
Water	1	1
Sea water	0.94	0.94
Steam	0.5	0.5
Air (average)	0.24	0.24

Key Idea: Specific heat tells you how much energy is needed to change temperature. Some materials heat up quickly, while others require much more energy.

Total Heat

Total heat is the combined amount of sensible heat and latent heat needed to change a substance from one condition to another. It includes both the heat that changes temperature (sensible) and the heat that changes state, such as melting or boiling (latent).

Sensible Heat

Sensible heat is heat that can be measured by a thermometer or felt by our sense of touch (thus "sensible"). If a substance is heated and the temperature rises, the increase is called *sensible heat gain*. Likewise, if heat is removed and the temperature decreases, the result would be *a sensible heat loss.*

Sensible heat considers that there is no change of state of the material, only a temperature change. An example of this would be water heating in a pan. As heat is added to the water, its temperature will rise until it reaches its atmospheric boiling point. The temperature cannot rise above this point until all the water has boiled into steam. Once this occurs, the steam's temperature can be raised using additional sensible heat (steam raised in temperature above its saturation temperature is called *superheated steam*).

Latent Heat

Latent heat is defined as the quantity of heat absorbed or released by a substance undergoing a change of state (such as ice changing to water or water changing to steam) at a constant temperature. Because there is no temperature change that can be measured or "sensed" during *phase change*, the heat that causes the change of state is known as hidden or latent heat. Going back to our earlier example of water heating in a pan, once the water has been brought to the boiling point, water keeps absorbing heat but the temperature remains constant. All of the input heat energy at this point is used to physically change the state from water to steam. As stated earlier, once the water has been vaporized to steam, the temperature will increase, but the heat input will now be sensible heat.

There are two separate latent heats: latent heat of fusion and latent heat of vaporization.

Latent heat of fusion is either lost or gained during the transformation of a solid to a liquid or a liquid to a solid. For example, the latent heat of fusion for ice to water or water to ice is $144\frac{\text{BTU}}{\text{lb.}}$.

Latent heat of vaporization is either lost or gained during the transformation of a liquid to a gas or a gas to a liquid. For example, the latent heat of vaporization for water to steam or steam to water is $970.4\frac{\text{BTU}}{\text{lb.}}$ at 0 *psig*.

Three States of Matter

The graph in Figure 1 illustrates the sensible and latent heat characteristics of water at ***atmospheric pressure***. The graph begins in the lower left corner, with ice at 0 °F (−17.8 °C), and extends above the boiling point of water into the superheated steam range. Notice that the temperature (°C and °F) of the substance is plotted on the left-hand vertical axis and the heat content (BTU) is plotted on the horizontal axis. Note that during the sensible heat sections, as heat is added, the temperature rises proportionally; and that during the latent heat sections, as heat is added, no temperature increase is experienced.

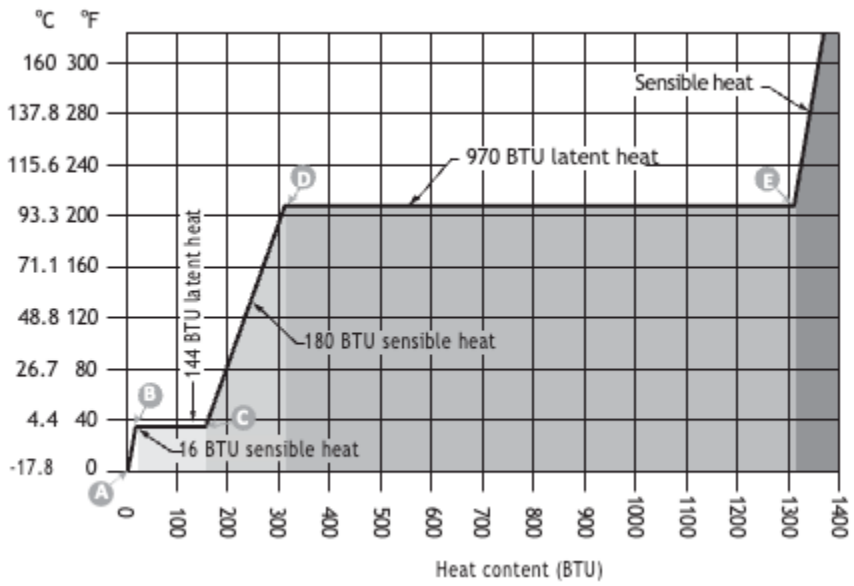

Figure 1 *Sensible and latent heat characteristics of water at 0 psig (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The line starting in the lower left in the graph (point A) represents the temperature of ice. As heat is added to the ice (from point A to point B), the temperature increases at a rate of $0.5\frac{\text{BTU}}{\text{lb.}}{}^{\circ}\text{F}$ (the specific heat of ice) up to freezing temperature of 32 °F. This is a sensible heat gain. Note that it takes 16 BTU to raise the temperature to 32 °F.

From point B to point C, the line is horizontal. This shows that even though the ice is absorbing heat, the temperature does not change and the ice is transformed to water. It takes $144\frac{\text{BTU}}{\text{lb.}}$ to change 1 lb. of ice to 1 lb. of water. This heat gain is known as the ***latent heat of fusion***.

Point C represents water at 32 °F. Adding more heat to the water will result in a rise in temperature, a sensible heat gain. Between the ***freezing*** and ***boiling points*** (points C and D), the water temperature will increase with added heat at the rate of 1 BTU/lb. °F (specific heat of water), which is indicated by the sloping line. Notice that the total heat energy input over this range (32–212 °F) is $180\frac{\text{BTU}}{\text{lb.}}$.

At point D, we now have water ***saturated*** with heat, and any heat absorbed from this point will be used to transform the water to steam. From point D to point E, the line is once again horizontal.

This shows that even though the water is absorbing heat, the temperature does not change and the water is transformed to steam while at 212 °F. It takes $970.4\frac{\text{BTU}}{\text{lb.}}$ to change 1 lb. of water to 1 lb. of steam. This heat gain is known as the ***latent heat of vaporization***.

At point E, we now have ***saturated steam*** at 212 °F. Adding more heat to the steam will result in a rise in temperature,

a sensible heat gain. The steam temperature increases with added heat at the rate of $0.5\frac{\text{BTU}}{\text{lb.}}{}^{\circ}\text{F}$ (specific heat of steam), which is indicated by the sloping line extending to the top of the graph.

The following formulas allow you to calculate how much heat energy is required in real trade applications.

Imperial Calculations (BTU Requirements)

The formula for calculating the quantity of heat required to take a given weight of a substance through a specified temperature change is the ***sensible heat equation***. It is expressed as follows:

$$\text{BTU required} = \text{weight of the substance (lb.)} \times \text{temperature change throughout the process } (^{\circ}\text{F}) \times \text{specific heat of the substance}(\frac{\frac{\text{BTU}}{\text{lb.}}}{^{\circ}\text{F}})$$

This is expressed as the following equation:

$$\text{BTU} = \text{lb.} \times {}^{\circ}\text{F} \times (\frac{\frac{\text{BTU}}{\text{lb.}}}{^{\circ}\text{F}})$$

The formula for calculating the quantity of heat required to take a given weight of a substance through a change of state is the ***latent heat equation***. It is expressed as follows:

$$\text{BTU required} = \text{weight of the substance (lb.)} \times \text{latent heat content } (144\frac{\text{BTU}}{\text{lb.}} \text{ for fusion or } 970.4\frac{\text{BTU}}{\text{lb.}} \text{ for vaporization})$$

This is expressed as the following equation :

$$\text{BTU} = \text{lb.} \times \text{latent heat content } (\frac{\text{BTU}}{\text{lb.}})$$

Example 1:

Determine the quantity of heat energy (BTU) required to increase the temperature of 1 lb. of water from 40 °F to 175 °F.

The specific heat of water = $1\frac{\text{BTU}}{\text{lb.}}{}^{\circ}\text{F}$.

Solution:

$$\text{BTU} = 1 \text{ lb.} \times (175 {}^{\circ}\text{F} - 40 {}^{\circ}\text{F}) \times 1\frac{\frac{\text{BTU}}{\text{lb.}}}{^{\circ}\text{F}} \quad \text{BTU} = 1 \text{ lb.} \times 135 {}^{\circ}\text{F} \times 1\frac{\frac{\text{BTU}}{\text{lb.}}}{^{\circ}\text{F}} \quad \text{BTU} = 135$$

The quantity of heat required to raise the temperature of 1 pound of water from 40 °F to 175 °F is 135 BTU.

***Note*: Always** check your units. The final answer for heat should be in BTU (or kJ in metric). If units do not match, the calculation is likely incorrect.

Example 2:

Determine the quantity of heat energy required to raise the temperature of 8 imp. gallons of water from 55 °F to 130 °F.

Solution:

The first step is to change the imperial gallons of water to weight (lb.). We know that one imperial gallon of water weighs 10 lb. Therefore, 8 imp. gallons of water will weigh 80 lb. Now that the weight has been determined, the sensible heat equation can be used:

$$\text{BTU} = 80 \text{ lb.} \times (130 \ ^\circ\text{F} - 55 \ ^\circ\text{F}) \times 1 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 80 \text{ lb.} \times 75 \ ^\circ\text{F} \times 1 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 6,000$$

The heat energy required to raise the temperature of 8 imperial gallons of water from 55 °F to 130 °F is 6,000 BTU.

Example 3:

Determine the quantity of heat energy required to raise the temperature of 4 lb. of ice at 32 °F to steam at 212 °F at atmospheric pressure.

Remember:

- Latent heat of fusion (LHF) for water is 144 $\frac{\text{BTU}}{\text{lb.}}$
- Latent heat of vaporization (LHV) for water is 970.4 $\frac{\text{BTU}}{\text{lb.}}$ (often rounded to 970 $\frac{\text{BTU}}{\text{lb.}}$)

Solution:

This problem will have three heat gains: a sensible gain as we raise the temperature of the water and two latent heat gains as we transform ice to water and later from water to steam. The total heat energy required will be the sum of the three separate gains.

Step 1. Latent heat (LHF)

First, we need to determine the quantity of heat energy required to change 4 lb. of ice at 32 °F to water at 32 °F. Because this is a latent heat gain, we will use the latent heat equation:

$$\text{BTU} = 4 \text{ lb.} \times 144 \frac{\text{BTU}}{\text{lb.}} \quad \text{BTU} = 576$$

Step 2. Sensible heat

Next, we must determine the quantity of heat energy required to raise the temperature of 4 lb. of water at 32 °F to water at 212 °F. Because this is a sensible heat gain, we will use the sensible heat equation:

$$\text{BTU} = 4 \text{ lb.} \times (212 \ ^\circ\text{F} - 32 \ ^\circ\text{F}) \times 1 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 4 \text{ lb.} \times 180 \ ^\circ\text{F} \times 1 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 720$$

Step 3. Latent heat (LHV)

Next, we determine the quantity of heat energy required to change 4 lb. of water at 212 °F to steam at 212 °F. Because this is a latent heat gain, we will use the latent heat equation:

$$\text{BTU} = 4 \text{ lb.} \times 970 \frac{\text{BTU}}{\text{lb.}} \quad \text{BTU} = 3,880$$

The total heat energy required will be the sum of the three separate gains:

$$576 + 720 + 3,880 = 5,176 \text{ BTU}$$

Example 4:

Determine the quantity of heat energy required to raise the temperature of 250 lb. of ice at 6 °F to steam at 277 °F.

Solution:

This problem will have five heat gains. Three will be sensible gains as we raise the temperatures of the ice, water and steam. There will also be two latent heat gains as we transform ice to water and water to steam. The total heat energy required will be the sum of the five separate gains.

Step 1. Sensible heat

First determine the quantity of heat energy required to raise the temperature of 250 lb. of ice at 6 °F to ice at 32 °F. Because this is a sensible heat gain, we will use the sensible heat equation :

$$\text{BTU} = 250 \text{ lb.} \times (32 \text{ }^\circ\text{F} - 6 \text{ }^\circ\text{F}) \times 0.5 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 250 \text{ lb.} \times 26 \text{ }^\circ\text{F} \times 0.5 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 3,250$$

Step 2. Latent heat (LHF)

Next find the quantity of heat energy required to change 250 lb. of ice at 32 °F to water at 32 °F. Because this is a latent heat gain, we will use the latent heat equation:

$$\text{BTU} = 250 \text{ lb.} \times 144 \frac{\text{BTU}}{\text{lb.}} \quad \text{BTU} = 36,000$$

Step 3. Sensible heat

Now determine the quantity of heat energy required to raise the temperature of 250 lb. of water at 32 °F to water at 212 °F. Because this is a sensible heat gain, we will use the sensible heat equation:

$$\text{BTU} = 250 \text{ lb.} \times (212 \text{ }^\circ\text{F} - 32 \text{ }^\circ\text{F}) \times 1 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 250 \text{ lb.} \times 180 \text{ }^\circ\text{F} \times 1 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 45,000$$

Step 4. Latent heat (LHV)

Next find the quantity of heat energy required to change 250 lb. of water at 212 °F to steam at 212 °F. Because this is a latent heat gain, we will use the latent heat equation:

$$\text{BTU} = 250 \text{ lb.} \times 970 \frac{\text{BTU}}{\text{lb.}} \quad \text{BTU} = 242,500$$

Step 5. Sensible heat

Now find the quantity of heat energy required to raise the temperature of 250 lb. of steam at 212 °F to steam at 277 °F. Because this is a sensible heat gain, we will use the sensible heat equation:

$$\text{BTU} = 250 \text{ lb.} \times (277 \text{ }^\circ\text{F} - 212 \text{ }^\circ\text{F}) \times 0.5 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 250 \text{ lb.} \times 65 \text{ }^\circ\text{F} \times 0.5 \frac{\frac{\text{BTU}}{\text{lb.}}}{^\circ\text{F}} \quad \text{BTU} = 8,125$$

The total heat energy required will be the sum of the five separate gains:

$$3,250 + 36,000 + 45,000 + 242,500 + 8,125 = 334,875 \text{ BTU}$$

These calculations are used in real applications such as sizing boilers, determining heating requirements, and designing hydronic systems.

Self-Test C-1.19: Perform Heat Load Calculations

Complete Self-Test C-1.19 and check your answers.

If you are using a printed copy, please find Self-Test C-1.19 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2453#h5p-27

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C-1.20 Describe Characteristics of Hydrocarbon Gases

Hydrocarbon gases are widely used in the gasfitting and piping industries for heating, cooking, and industrial processes. These gases are made up of hydrogen and carbon atoms and behave differently depending on their composition and how they are stored. Understanding the basic characteristics of hydrocarbon gases—such as where they come from, how they are processed, and how they are made safe for use in real applications—is essential for anyone working with natural gas and liquefied petroleum gases.

The three fuel gases most commonly used in the gas industry are ***natural gas (NG)*** and two ***liquefied petroleum (LP)*** gases—***propane*** and ***butane***. They are part of the group of gases known as *hydrocarbons*, which are mixtures of hydrogen (H) and carbon (C).

Natural gas occurs in nature as a mixture of ***methane*** and other gases. Propane is a ***byproduct*** of natural gas processing. Natural gas must be cleaned of impurities before being distributed, and byproducts of this process include hydrocarbons like propane in addition to butane, ***ethane*** and pentane. The difference between propane and natural gas in domestic use is mostly their difference in cost, storage considerations and risk factors. There is very little difference, however, in how they perform in appliances for heating, cooking, or drying.

Natural gas, propane and butane are colourless, odourless gases. As a safety measure, a foul-smelling ***odourant*** called *mercaptan* is added to the fuel gas mixture by the gas purveyor so that hazardous gas leaks are detectable.

Gas Chemistry of Natural Gas

Natural gas has two major components:

- Methane = 87.4%
- Ethane = 6.8%

Since most of its content is methane, for convenience, natural gas is usually represented by the chemical formula for methane (CH4). Figure 1 shows the molecular diagram for methane.

Note: In figure 1, the letter C refers to carbon and the letter H refers to hydrogen.

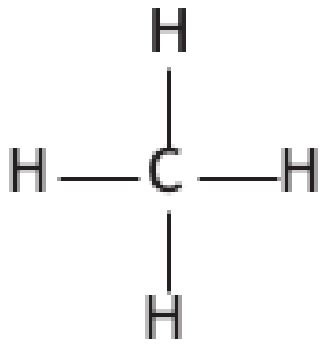

Figure 1 *Diagram of methane molecule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Gas Chemistry of Propane

Propane is also a hydrocarbon and is classified as an ***LP (liquefied petroleum) gas***. LP gases are refined, stored and transported as a liquid under moderate temperature and pressure. They are then vaporized prior to use within a gas-burning appliance. Figure 2 shows the chemical structure of a propane molecule (C_3H_8).

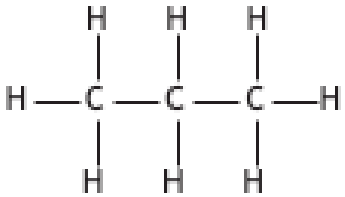

Figure 2 *Diagram of propane molecule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Gas Chemistry of Butane

Butane is also a hydrocarbon and, like propane, is classified as an LP gas. Figure 3 shows the chemical structure of a butane molecule (C_4H_{10}).

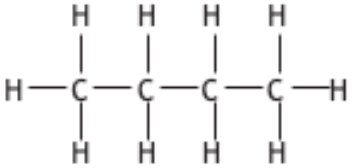

Figure 3 *Diagram of butane molecule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Heat Content (Calorific Value [CV])

Different fuel gases release different amounts of heat energy when they burn. This energy output is known as the ***calorific value*** or *heat content* of the fuel. Understanding calorific value is important because it affects appliance performance, gas sizing, efficiency, and overall system design.

The table below compares the heat content of natural gas, propane, and butane in several common units. These values show how much heat each fuel produces per unit volume.

Table 1: Calorific Values of Various Fuel Gases

Fuel Gas	**Calorific Value** $\frac{\text{BTU}}{\text{ft.}^3}$	**Calorific Value** $\frac{\text{kW}}{\text{m}^3}$	**Calorific Value** $\frac{\text{kW}}{\text{ft.}^3}$	**Calorific Value** $\frac{\text{BTU}}{\text{m}^3}$
Natural gas	1,000	10.35	0.293	35,310
Propane	2,500	25.86	0.732	88,275
Butane	3,200	33.1	0.937	112,992

Specific Gravity

As mentioned earlier in this competency, ***specific gravity (SG)***, often termed *relative density*, is the comparison of the weight of a gas to the weight of an equal volume of air (or water for liquids). All three of the gases covered in this section are used in the combustion process while in the ***vapour state***. It is essential to understand the SG of each gas. Table 2 gives the specific gravity of natural gas, propane, and butane as vapours.

Table 2: Specific Gravity of Natural Gas, Propane, and Butane as Vapour

Fuel Gas	**Specific Gravity as a Vapour**
Natural gas	0.6
Propane	1.5
Butane	2.0

As the ***molecular weight*** of a fuel gas increases, its specific gravity (SG) also increases compared to air. Natural gas has a specific gravity of about 0.6, which means it is lighter than air and will rise toward the ceiling if it leaks. Propane and butane, however, are heavier than air. If an LP-gas leak occurs, the gas can settle and collect in low areas, creating a significant safety hazard.

When these gases are in their liquid state, their specific gravity is compared to water instead of air. Table 3 shows the specific gravity of common fuel gases in liquid form.

Table 3: Specific Gravity of Propane, Butane, and Natural Gas as Liquid

Fuel Gas	Specific Gravity as a Liquid
Propane	0.51
Butane	0.58
Natural gas (LNG)	0.42–0.50 (approx.)

Note: *Liquefied natural gas* (LNG) has a lower specific gravity than water and will float if released in liquid form. However, as it vaporizes, it becomes lighter than air and will rise.

Flame Speed

Flame speed is the rate at which a flame moves through a gas–air mixture as it burns.

It is important to understand that flame speed is not the same as gas flow speed. Two things are happening at the burner:

- The gas–air mixture velocity (how fast the gas is leaving the burner)
- The flame speed (how fast the flame travels through the mixture)

A ***stable flame*** occurs when these two speeds are equal. When the gas–air mixture velocity matches the flame speed, the flame remains steady at the burner port.

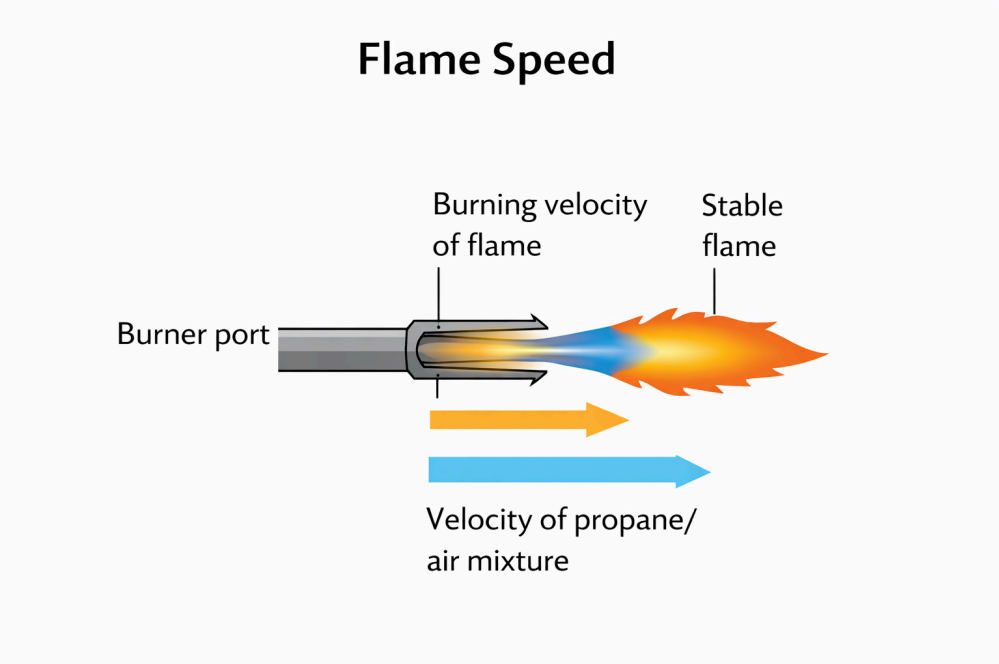

Figure 4 *Flame speed and gas-air mixture of propane velocity at a burner* (TRU Open Press/OpenAI, 2026) CC BY-NC-SA 4.0

Understanding Flame Stability

- If the **gas velocity is too high**, the flame may lift off or blow out
- If the **flame speed is too high**, the flame may travel back into the burner (***flashback***)

For safe operation, these two must remain balanced.

Safety Note: Flashback can damage equipment and create a serious hazard. Proper burner adjustment is critical.

Typical Flame Speeds of Common Fuel Gases

Different gases burn at different speeds. This affects burner design, safety, and performance.

Table 4: Approximate Flame Speeds of Common Fuel Gases

Fuel Gas	Approximate Flame Speed (ft/s)
Natural gas (methane)	1.0
Propane	1.5
Butane	1.3

Note: Flame speeds are approximate and can vary depending on mixture conditions and temperature.

Limits of Flammability

A correct gas–air mixture is necessary for combustion. If the mixture is not within the proper range, it will not burn.

- If there is too little gas, the mixture is too lean and will not burn
- If there is too much gas, the mixture is too rich and will not burn

The ***limits of flammability (also called explosive limits)*** define the range of gas–air mixtures that will ignite when an ignition source is present.

This range is defined by two values:

- ***Lower Flammable Limit (LFL)***: the minimum concentration of gas in air that can ignite.
- ***Upper Flammable Limit (UFL):*** the maximum concentration of gas in air that can ignite.
- Below the LFL⇒the mixture is too lean to burn (not enough fuel).
- Above the UFL⇒the mixture is too rich to burn (too much fuel, not enough oxygen).

Different gases have different ranges of flammability. Compare these four common fuel gases:

Table 5: Limits of Flammability

Fuel Gas	Lower Limit of Flammability	Upper Limit of Flammability
Methane	4%	15%
Propane	2%	10%
Butane	2%	8%
Acetylene	2.5%	81%

Ignition Temperatures

Ignition temperature is defined as the lowest temperature at which combustion begins and continues in a substance when it is heated in air. Table 6 lists the ignition temperatures of the three major fuel gases.

Table 6: Ignition Temperatures of the Three Major Fuel Gases

Fuel Gas	Ignition Temperature °F	Ignition Temperature °C
Natural gas	1,100 to 1,200	593 to 650
Propane	920 to 1,020	493 to 548
Butane	900 to 1,000	482 to 540

Flow Characteristics in Fuel Gas Piping

Six major factors affect the flow rate of fuel through a supply line connected to a heating appliance. To ensure that any appliance served by the piping system has enough fuel at the correct pressure to operate at its rated input, the pipe must be sized by taking all of the following flow characteristics into account.

Type of Gas

Since lighter (lower-density) gases flow through a pipe more easily than heavier gases, larger volumes of natural gas can flow through a pipe than propane or butane for a given pipe diameter and supply pressure. In addition, pressure losses due to friction are reduced with lower-***viscosity*** fuels.

Type of Pipe

When a gas flows through a pipe, the internal roughness of the pipe walls can create localized eddy currents within the fluid, adding resistance to the flow of the fluid. Pipes with smooth interior walls, like copper, have less resistance than materials with rough interior walls like black iron (carbon steel) pipe.

Length of Pipe

When gas flows through a pipe, friction along the interior walls limits the velocity of the fuel. The average velocity decreases as pipe length increases, which reduces the flow rate at the appliance. When sizing a gas distribution network, it is important to consider that the longer the pipe, the greater the resistance to flow. In order to limit this resistance, the pipe size may need to be increased during design to provide less friction and maintain the required flow rate.

Diameter of Pipe

If the system pressure behind the gas flow in a pipe is constant, the diameter of the pipe will directly affect the flow rate.

If the diameter of the pipe is increased, the flow rate will also increase. Flow rate is directly proportional to the pipe's internal area and increases significantly with the pipe's inside diameter.

Number of Fittings

Fittings such as elbows, tees, and valves represent a significant component of the pressure loss in most gas piping networks. Each fitting on a piping system adds resistance to gas flow. It is important to design a system with as few fittings as possible.

Pressure Drop

Pressure drop is the pressure difference between the gas supply (either the gas meter or a system pressure regulator) and a gas appliance. The Gas Code and design guidelines limit the amount of pressure drop allowed in these systems. The code limits this loss to ensure that sufficient pressure remains to provide the required flow rate. Good design of any piping system should limit the maximum pressure drop to maintain adequate flow pressure to fixtures and appliances.

Self-Test C-1.20: Describe Characteristics of Hydrocarbon Gases

Complete Self-Test C-1.20 and check your answers.

If you are using a printed copy, please find Self-Test C-1.20 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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Note: these videos align with the open textbooks *Math for Trades: Volume 1* and *Math for Trades: Volume 2*. All videos are by Chad Flinn and available under a Creative Commons Attribution 4.0 Licence.:

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- **Figure 4** Flame speed and gas-air mixture of propane velocity at a burner was created by TRU Open Press with assistance from OpenAI, 2026, and is subject t the CC BY-NC-SA 4.0license of this resource.

Self-Test C-1.1.1: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.1 and check your answers.

1. A site services contractor has 6 backhoe/loaders, 8 skid steer loaders, 4 excavators, 2 compactors and 3 de-watering rigs. How many pieces of equipment are employed on this site?

Answer: _____

2. If 187 PEX fittings are removed from a box shipped from the supplier with 300 fittings, how many fittings remain in the box?

Answer: _____

3. A construction job had 87 pipefitters. One day 9 pipefitters were transferred to another site. Three days later, 12 were transferred. On the fifth day, 3 quit. How many fitters were left on the job to finish the install?

Answer: _____

4. If we cut a piece of black iron pipe 21 ft. long into four pieces, the first 3.5 ft. long, the second 5.5 ft. long and the third 8 ft. long, what is the length of the remaining piece?

Answer: _____

5. A roll of PEX tubing is 1000 ft. long. If a 130-ft. piece is cut from each end, and two pieces 175 ft. and 188 ft. long are also cut, what is the length of the remaining roll?

Answer: _____

6. A wooden laminated beam weighs 41 lb. per foot. If the length of the beam is 22 ft., how much does the beam weigh?

Answer: _____

7. A load of black iron pipe contains a total of 3024 feet. If each pipe is 21 ft. long, how many lengths of pipe were shipped to the wholesaler?

Answer: _____

8. A sprinkler fitter used 42 pieces of 8-ft. pipe and 13 pieces of 16-ft. pipe. How many feet of pipe did he use?

Answer: _____

9. The following pump schedule is found at a mine site. When the four pumps are operating as designed, what is the

total number of US gallons/minute they will pump from the site?

- Pump 1 – 125 US gpm
- Pump 2 – 220 US gpm
- Pump 3 – 175 US gpm
- Pump 4 – 275 US gpm

Answer: _____ gpm

10. A gas fitter needs 12 three-piece pipe hanging brackets fabricated out of angle iron. If the three sides of each bracket measure 200 mm × 283 mm × 200 mm, how much angle iron will be required?

Answer: _____ mm

11. A drum of boiler treatment contains 50 gallons. If it takes 80 days to empty the drum, how many quarts per day are being used? (There are 4 quarts in a gallon.)

Answer: _____ quarts

12. A 150-litre container of lawn fertilizer is fed to an underground lawn sprinkler. If it takes 17 days to empty the container, how many litres per day are being used?

Answer: _____ litres

13. A length of 3-inch schedule 40 black iron pipe measures 21 ft. 8 in. long. Coupons 10 in. in length are cut from this pipe for welding practice. Disregarding any cutting losses, how many coupons can be cut from this length of pipe?

Answer: _____

14. Divide 1275 by 28 and multiply the quotient by 52.

Answer: _____

Answer Key: Self-Test C-1.1.1 is on the other page.

Answer Key: Self-Test C-1.1.1

1. 23
2. 113
3. 63
4. 4′
5. 377′
6. 902 lb.
7. 144 lengths
8. 544′
9. 795 US gpm
10. 8,196 mm
11. 2.5 quarts
12. 8.8 L
13. 26
14. 2,367.86

Self-Test C-1.1.2: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.2 and check your answers.

1. Reduce the following fractions to their lowest terms:

a. $\frac{18}{20}$ = _____ g. $\frac{14}{18}$ = _____

b. $\frac{3}{30}$ = _____ h. $\frac{8}{36}$ = _____

c. $\frac{14}{24}$ = _____ i. $\frac{20}{24}$ = _____

d. $\frac{4}{40}$ = _____ j. $\frac{4}{28}$ = _____

e. $\frac{44}{48}$ = _____ k. $\frac{25}{60}$ = _____

f. $\frac{4}{32}$ = _____

2. A circle contains 360 degrees. What part of a circle is:

a. 90 degrees = _____ d. 120 degrees = _____

b. 240 degrees = _____ e. 180 degrees = _____

c. 60 degrees = _____

3. How many eighths of an inch are there in the following mixed numbers?

a. $1\frac{3}{8}$ in. = _____ d. $5\frac{5}{8}$ in. = _____

b. $2\frac{1}{2}$ in. = _____ e. $12\frac{3}{8}$ in. = _____

c. $3\frac{3}{8}$ in. = _____ f. $20\frac{7}{8}$ in. = _____

4. Change the following mixed numbers to improper fractions:

a. $4\frac{3}{4}$ = _____ e. $7\frac{3}{4}$ = _____

b. $3\frac{2}{3}$ = _____ f. $9\frac{1}{2}$ = _____

c. $5\frac{1}{8}$ = _____ g. $3\frac{2}{5}$ = _____

d. $2\frac{7}{10}$ = _____ h. $3\frac{3}{8}$ = _____

5. Change the following improper fractions to mixed numbers:

a. $\frac{25}{3}$ = _____ g. $\frac{11}{9}$ = _____

b. $\frac{17}{6}$ = _____ h. $\frac{26}{3}$ = _____

c. $\frac{27}{5}$ = _____ i. $\frac{19}{2}$ = _____

d. $\frac{9}{2}$ = _____ j. $\frac{26}{8}$ = _____

e. $\frac{30}{4}$ = _____ k. $\frac{40}{7}$ = _____

f. $\frac{15}{12}$ = _____ l. $\frac{12}{5}$ = _____

Answer Key: Self-Test C-1.1.2 is on the other page.

Answer Key: Self-Test C-1.1.2

1. Reduce the following fractions to their lowest terms:

   a. $\frac{9}{10}$

   b. $\frac{1}{10}$

   c. $\frac{7}{12}$

   d. $\frac{1}{10}$

   e. $\frac{11}{12}$

   f. $\frac{1}{8}$

   g. $\frac{7}{9}$

   h. $\frac{2}{9}$

   i. $\frac{5}{6}$

   j. $\frac{1}{7}$

   k. $\frac{5}{12}$

2. A circle contains 360 degrees. What part of a circle is:

   a. $\frac{1}{4}$

   b. $\frac{2}{3}$

   c. $\frac{1}{6}$

   d. $\frac{1}{3}$

   e. $\frac{1}{2}$

3. How many eighths of an inch are there in the following mixed numbers?
    a. 11
    b. 20
    c. 27
    d. 45
    e. 99
    f. 167
4. Change the following mixed numbers to improper fractions:
    a. $\frac{19}{4}$
    b. $\frac{11}{3}$
    c. $\frac{41}{8}$
    d. $\frac{27}{10}$
    e. $3\frac{1}{4}$
    f. $\frac{19}{2}$
    g. $\frac{17}{5}$
    h. $\frac{27}{8}$
5. Change the following improper fractions to mixed numbers:
    a. $8\frac{1}{3}$
    b. $2\frac{5}{6}$
    c. $5\frac{2}{5}$
    d. $4\frac{1}{2}$
    e. $7\frac{1}{2}$
    f. $1\frac{1}{4}$

g. $1\frac{2}{9}$

h. $8\frac{2}{3}$

i. $9\frac{1}{2}$

j. $3\frac{1}{4}$

k. $5\frac{5}{7}$

l. $2\frac{2}{5}$

Self-Test C-1.1.3: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.3 and check your answers.

1. Add the following fractions. Change improper fractions to mixed numbers.

a. $\frac{3}{4}+\frac{1}{2}$ = _____

b. $\frac{3}{5}+\frac{1}{4}$ = _____

c. $\frac{9}{10}+\frac{3}{4}$ = _____

d. $\frac{1}{2}+\frac{2}{3}$ = _____

e. $\frac{1}{2}+\frac{7}{10}$ = _____

f. $\frac{1}{5}+\frac{1}{2}$ = _____

g. $\frac{3}{4}+\frac{1}{2}+\frac{3}{8}$ = _____

h. $\frac{7}{16}+\frac{3}{8}+\frac{3}{4}$ = _____

i. $\frac{4}{9}+\frac{2}{3}+\frac{11}{18}$ = _____

j. $\frac{1}{4}+\frac{7}{8}+\frac{1}{2}+\frac{5}{16}+\frac{7}{32}$ = _____

k. $\frac{5}{16}+\frac{31}{64}+\frac{11}{32}$ = _____

2. Subtract the following fractions:

a. $\frac{1}{3}-\frac{1}{18}$ = _____

b. $\frac{9}{14}-\frac{1}{4}$ = _____

c. $\frac{1}{6}-\frac{1}{10}$ = _____

d. $\frac{12}{14}-\frac{1}{2}$ = _____

g. $\frac{16}{55}-\frac{3}{11}$ = _____

h. $\frac{7}{43}-\frac{4}{86}$ = _____

i. $\frac{1}{7}-\frac{1}{21}$ = _____

j. $\frac{16}{19}-\frac{1}{4}$ = _____

e. $\frac{6}{7} - \frac{11}{21}$ = _____ k. $\frac{13}{22} - \frac{3}{6}$ = _____

f. $\frac{15}{29} - \frac{20}{58}$ = _____ l. $\frac{13}{16} - \frac{1}{4}$ = _____

3. Multiply the following sets of fractions and reduce to lowest terms:

a. $\frac{8}{15} \times \frac{3}{4}$ = _____ h. $\frac{1}{4} \times \frac{1}{7}$ = _____

b. $\frac{2}{7} \times \frac{3}{18}$ = _____ i. $\frac{7}{9} \times \frac{5}{8}$ = _____

c. $\frac{1}{2} \times \frac{1}{3}$ = _____ j. $\frac{3}{5} \times \frac{5}{6}$ = _____

d. $\frac{4}{7} \times \frac{1}{4}$ = _____ k. $\frac{3}{16} \times \frac{1}{4}$ = _____

e. $\frac{7}{10} \times \frac{3}{4}$ = _____ l. $\frac{7}{8} \times \frac{9}{16}$ = _____

f. $\frac{6}{7} \times \frac{5}{7}$ = _____ m. $\frac{6}{7} \times \frac{3}{8}$ = _____

g. $\frac{7}{9} \times \frac{3}{10}$ = _____

4. Cancel, multiply and reduce to lowest terms:

a. $\frac{1}{4} \times \frac{15}{2} \times \frac{12}{7}$ = _____ e. $\frac{7}{5} \times \frac{1}{2} \times \frac{4}{3}$ = _____

b. $\frac{11}{2} \times \frac{13}{11} \times \frac{1}{10}$ = _____ f. $\frac{4}{7} \times \frac{21}{11} \times \frac{5}{8}$ = _____

c. $4\frac{1}{2} \times \frac{5}{3} \times 1\frac{3}{10}$ = _____ g. $\frac{1}{4} \times 3\frac{1}{4} \times \frac{12}{3}$ = _____

d. $1\frac{5}{7} \times \frac{11}{6} \times 4\frac{1}{2}$ = _____ h. $7\frac{1}{3} \times \frac{3}{8} \times \frac{5}{6}$ = _____

5. Divide the fractions and cancel where possible:

a. $\frac{1}{7} \div \frac{8}{3}$ = _____ d. $\frac{1}{10} \div \frac{1}{6}$ = _____

b. $\frac{1}{6} \div \frac{5}{2}$ = _____ e. $\frac{1}{2} \div \frac{13}{7}$ = _____

c. $\frac{19}{9} \div 6\frac{2}{3}$ = _____ f. $\frac{17}{4} \div \frac{31}{3}$ = _____

6. Twelve (12) galvanized nipples of equal length are cut from a piece of pipe $66\frac{3}{4}$ in. long. How long is each nipple?

Answer: _____

7. A print shows a chase with two (2) 6-in. lines (O.D. = $6\frac{5}{8}$") a $\frac{11}{2}$ -in. line (O.D. = $1\frac{3}{4}$") and a 3-in. line (O.D. = $3\frac{1}{2}$"). How wide must the hole be to result in there being $\frac{11}{2}$ in. clearance between lines and 2 in. at each end?

Answer: _____

8. The job foreman instructs you to cut and thread 2-in. pipe to the following lengths: 2 ft. $5\frac{1}{2}$ in. ; 9 ft. $6\frac{1}{8}$ in. ; 4 ft. 0 in. ; and 5 ft. $9\frac{5}{8}$ in.

   a. Will one length of 21 ft. 2 in. be enough?

Answer: _____

   b. How much pipe will you be short or over?

Answer: _____

Answer Key: Self-Test C-1.1.3 is on the other page.

Answer Key: Self-Test C-1.1.3

1. Add the following fractions. Change improper fractions to mixed numbers.

    a. $1\frac{1}{4}$

    b. $\frac{17}{20}$

    c. $1\frac{13}{20}$

    d. $1\frac{1}{6}$

    e. $1\frac{1}{5}$

    f. $\frac{7}{10}$

    g. $1\frac{5}{8}$

    h. $1\frac{9}{16}$

    i. $1\frac{13}{18}$

    j. $2\frac{5}{32}$

    k. $1\frac{9}{64}$

2. Subtract the following fractions:

    a. $\frac{5}{18}$

    b. $\frac{11}{28}$

    c. $\frac{1}{15}$

    d. $\frac{5}{14}$

    e. $\frac{1}{3}$

f. $\frac{5}{29}$

g. $\frac{1}{55}$

h. $\frac{5}{43}$

i. $\frac{2}{21}$

j. $\frac{45}{76}$

k. $\frac{1}{11}$

l. $\frac{9}{16}$

3. Multiply the following sets of fractions and reduce to lowest terms:

a. $\frac{2}{5}$

b. $\frac{1}{21}$

c. $\frac{1}{6}$

d. $\frac{1}{7}$

e. $\frac{21}{40}$

f. $\frac{30}{49}$

g. $\frac{7}{30}$

h. $\frac{1}{28}$

i. $\frac{35}{72}$

j. $\frac{1}{2}$

k. $\frac{3}{64}$

l. $\frac{63}{128}$

m. $\frac{9}{28}$

4. Cancel, multiply and reduce to lowest terms:

a. $3\frac{3}{14}$

b. $\frac{13}{20}$

c. $9\frac{3}{4}$

d. $14\frac{1}{7}$

e. $\frac{14}{15}$

f. $\frac{15}{22}$

g. $1\frac{17}{48}$

h. $2\frac{7}{24}$

5. Divide the fractions and cancel where possible:

a. $\frac{3}{56}$

b. $\frac{1}{15}$

c. $\frac{19}{60}$

d. $\frac{3}{5}$

e. $\frac{7}{26}$

f. $1\frac{11}{40}$

6. Twelve (12) galvanized nipples of equal length are cut from a piece of pipe $66\frac{3}{4}$ in. long. How long is each nipple?

   a. 5 ft. $\frac{9}{16}$ in. or 89 in.

7. A print shows a chase with two (2) 6-in. lines (O.D. = $6\frac{5}{8}$„) a $\frac{11}{2}$ -in. line (O.D. = $1\frac{3}{4}$„) and a 3-in. line (O.D. = $3\frac{1}{2}$„). How wide must the hole be to result in there being $\frac{11}{2}$ in. clearance between lines and 2 in. at each end?

   a. 27 in.

8. The job foreman instructs you to cut and thread 2-in. pipe to the following lengths: 2 ft. $5\frac{1}{2}$ in. ; 9 ft. $6\frac{1}{8}$ in. ; 4 ft. 0 in. ; and 5 ft. $9\frac{5}{8}$ in.

   a. Will one length of 21 ft. 2 in. be enough?
      i. No
   b. How much pipe will you be short or over?
      i. Short by $7\frac{1}{4}$ in.

Self-Test C-1.1.4: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.4 and check your answers.

1. Add the following decimals:

a. 9.869 + 3.748 = _____ g. 5.114 + 3.25 = _____

b. 8.651 + 6.525 = _____ h. 6.806 + 1.307 = _____

c. 1.734 + 2.364 = _____ i. 1.007 + 2.692 = _____

d. 6.644 + 8.525 = _____ j. 1.156 + 3.772 = _____

e. 9.463 + 4.979 = _____ k. 0.832 + 3.068 = _____

f. 0.348 + 1.95 = _____

2. Subtract the following decimals:

a. 0.212 − 0.0923 = _____ g. 8.9321 − 8.6884 = _____

b. 7.9424 − 7.2035 = _____ h. 1.1393 − 0.1102 = _____

c. 9.3949 − 0.7979 = _____ i. 1.2037 − 0.8918 = _____

d. 6.2772 − 3.219 = _____ j. 7.7646 − 1.4895 = _____

e. 5.554 − 3.6097 = _____ k. 4.1128 − 1.5693 = _____

f. 2.2019 − 1.5055 = _____

3. Multiply the following decimals:

a. 7.5 × 5,311.4 = _____ g. 1,427.47 × 14.54 = _____

b. 289.5 × 48,960.6 = _____ h. 44.99 × 55.5 = _____

c. 6.402 × 51.9 = _____ i. 30.9 × 0.2 = _____

d. 84.144 × 0.378 = _____ j. 9,419.4 × 6.1 = _____

e. 0.075 × 77.64 = _____ k. 9.92 × 4,621.6 = _____

f. 0.436 × 8.867 = _____

4. Divide the following decimals:

a. 0.2107 ÷ 0.43 = _____ g. 548.2681 ÷ 39.19 = _____

b. 0.0064 ÷ 0.32 = _____ h. 2,659.1408 ÷ 88.52 = _____

c. 0.1218 ÷ 0.21 = _____ i. 2,392.4077 ÷ 43.97 = _____

d. 0.0693 ÷ 0.63 = _____ j. 3,931.9881 ÷ 42.43 = _____

e. 3,574.7888 ÷ 40.48 = _____ k. 0.2132 ÷ 0.82 = _____

f. 772.3285 ÷ 54.97 = _____

Answer Key: Self-Test C-1.1.4 is on the other page.

Answer Key: Self-Test C-1.1.4

1. Add the following decimals:
    a. 13.617
    b. 15.176
    c. 4.098
    d. 15.169
    e. 14.442
    f. 2.298
    g. 8.364
    h. 8.113
    i. 3.699
    j. 4.928
    k. 3.9
2. Subtract the following decimals:
    a. 0.1197
    b. 0.7389
    c. 8.597
    d. 3.0582
    e. 1.9443
    f. 0.6964
    g. 0.2437
    h. 1.0291
    i. 0.3119
    j. 6.2751
    k. 2.5435
3. Multiply the following decimals:
    a. 39,835.5
    b. 14,174,093.7
    c. 332.2638
    d. 31.806432
    e. 5.823
    f. 3.866012
    g. 20,755.4138
    h. 2,496.945
    i. 6.18
    j. 57,458.34
    k. 45,846.272
4. Divide the following decimals:
    a. 0.49
    b. 0.02
    c. 0.58
    d. 0.11
    e. 88.31
    f. 14.05

g. 13.99
h. 30.04
i. 54.41
j. 92.67
k. 0.26

Self-Test C-1.1.5: Add, Subtract, Multiply and Divide Whole Numbers, Fractions, Decimals and Percentages

Complete Self-Test C-1.1.5 and check your answers.

1. Express the following percentages as fractions and as decimals:

Percentage		Fraction	Decimal
a.	70%		
b.	58%		
c.	1.0%		
d.	0.01%		
e.	87%		

2. Express the following fractions as decimals and as percentages:

Fraction		Decimal	Percentage
a.	3/8		
b.	3/16		
c.	5/32		
d.	411/16		
e.	2/3		

3. Express the following decimals as fractions and as percentages:

Decimal		Fraction	Percentage
a.	0.65		
b.	0.20		
c.	1.333		
d.	1.625		
e.	2.790		

4. What is 76% of 2,189?

Answer: _____

5. What is 64% of 7,700?

Answer: _____

6. What is 67.5% more than 48?

Answer: _____

7. What is 15% less than 223?

Answer: _____

8. What % of 1,900 is 133?

Answer: _____

9. What % of 7,600 is 6,764?

Answer: _____

10. Which is larger? Use < , > or = for each pair

46% of 86 _____ 43% of 26

6% of 55 _____ 40% of 62

30% of 84 _____ 64% of 10

34% of 97 _____ 46% of 36

68% of 72 _____ 41% of 45

46% of 20 _____ 29% of 49

86% of 40 _____ 57% of 55

49% of 93 _____ 50% of 77

11. What would be your wage if a journeyman plumber earns $37.50/hr and you earn 55% of what they do?

Answer: _____

12. A $1\frac{1}{2}$" P-trap at the wholesaler now sells for $9.75, and a price increase of 8% will take effect next week. What will the same fitting cost after the increase?

Answer: _____

13. A gas-fired furnace is 93% efficient. If the appliance input is 78,000 BTUH, what is the output?

Answer: _____

Answer Key: Self-Test C-1.1.5 is on the other page.

Answer Key: Self-Test C-1.1.5

1. Express the following percentages as fractions and as decimals:

Percentage		Fraction	Decimal
a.	70%	$\frac{7}{10}$	0.7
b.	58%	$\frac{29}{50}$	0.58
c.	1.0%	$\frac{1}{100}$	0.01
d.	0.01%	$\frac{1}{10,000}$	0.0001
e.	87%	$\frac{87}{100}$	0.87

2. Express the following fractions as decimals and as percentages:

Fraction		Decimal	Percentage
a.	$\frac{3}{8}$	0.375	37.5%
b.	$\frac{3}{16}$	0.1875	18.75%
c.	$\frac{5}{32}$	0.15625	15.625%
d.	$4\frac{11}{16}$	4.6875	468.75%
e.	$\frac{2}{3}$	0.667	66.7%

3. Express the following decimals as fractions and as percentages:

Decimal		Fraction	Percentage
a.	0.65	$\frac{13}{20}$	65%
b.	0.20	$\frac{1}{5}$	20%
c.	1.333	$1\frac{1}{3}$	133%
d.	1.625	$1\frac{5}{8}$	162.5%
e.	2.790	$2\frac{79}{100}$	279%

4. What is 76% of 2,189?
    a. 1,663.64
5. What is 64% of 7,700?
    a. 4,928
6. What is 67.5% more than 48?
    a. 80.4
7. What is 15% less than 223?
    a. 189.55
8. What % of 1,900 is 133?
    a. 7%
9. What % of 7,600 is 6,764?
    a. 89%
10. Which is larger? Use < , > or = for each pair

46% of 86 > 43% of 26

6% of 55 < 40% of 62

30% of 84 > 64% of 10

34% of 97 > 46% of 36

68% of 72 > 41% of 45

46% of 20 < 29% of 49

86% of 40 > 57% of 55

49% of 93 > 50% of 77

11. What would be your wage if a journeyman plumber earns $37.50/hr and you earn 55% of what they do?
    a. $20.63
12. A $1\frac{1}{2}$" P-trap at the wholesaler now sells for $9.75, and a price increase of 8% will take effect next week. What will the same fitting cost after the increase?
    a. $10.53
13. A gas-fired furnace is 93% efficient. If the appliance input is 78,000 BTUH, what is the output?
    a. 72,540 BTUH

Self-Test C-1.2: Transpose Equations and Formulas

Complete Self-Test C-1.2 and check your answers.

1. Add the following sets of numbers:

a. $+3, +7$ = _____ e. $-19, -1$ = _____

b. $+6, +9$ = _____ f. $-37, -36$ = _____

c. $+1, -9$ = _____ g. $+12, -13$ = _____

d. $-8, -4$ = _____ h. $+39, -27$ = _____

2. Complete the following subtraction problems:

a. $(+12) - (-3)$ = _____ c. $(-3) - (+6)$ = _____

b. $(+90) - (+10)$ = _____ d. $(-3) - (+12)$ = _____

3. Complete the following multiplication problems:

a. $(+18) \times (+2)$ = _____ d. $(-11) \times (+7)$ = _____

b. $(-9) \times (+12)$ = _____ e. $(-7) \times (-32)$ = _____

c. $(-8) \times (-4)$ = _____

4. Complete the following division problems:

a. $(+14) \div (-2)$ = _____ c. $(-85) \div (+12)$ = _____

b. $(-9) \div (-7)$ = _____ d. $(+41) \div (-2)$ = _____

5. Solve each problem, using $f = 8$, $g = 9$ and $h = 10$.

a. $h + f = a \quad a =$ _____ f. $\frac{((f + h)g)}{2} = a \quad a =$ _____

b. $f^2 + 3g = y \quad y =$ _____

c. $h - 9 = b \quad b =$ _____

d. $\sqrt{g + \frac{h}{3}} = m \quad m =$ _____

e. $hfg = c \quad c =$ _____

g. $\frac{gf}{h} = d \quad d =$ _____

h. $3(h - f) = n \quad n =$ _____

i. $2f + 3g + 4h = x \quad x =$ _____

j. $\frac{(fg)^2}{h} = P \quad P =$ _____

6. Solve the following for a and check by substituting the answer into the original equation:

a. $a + 4 = 10 \quad a =$ _____

b. $a - 13 = 15 \quad a =$ _____

c. $2a + 12 - 7 = 14 \quad a =$ _____

7. Solve the following for b and check:

a. $14 + 12b = 99 - 2b \quad b =$ _____

b. $\frac{b}{15} = 3 \quad b =$ _____

c. $\frac{b}{2} + 5 = 2b \quad b =$ _____

d. $4b - 3 = 2b + 7 \quad b =$ _____

8. Solve the following proportions for a and check:

a. $\frac{a}{27} = \frac{9}{81} \quad a =$ _____

b. $\frac{3}{a} = \frac{8}{36} \quad a =$ _____

c. $\frac{1}{a} = \frac{7}{35} \quad a =$ _____

9. A fan turning at 1,500 RPM is moving 2,500 CFM of air. If the CFM is to be increased to 3,000, what must the new fan speed be?

RPM = _____

Answer Key: Self-Test C-1.2 is on the other page.

Answer Key: Self-Test C-1.2

1. Add the following sets of numbers:
    a. 10
    b. 15
    c. -8
    d. -12
    e. -20
    f. -73
    g. -1
    h. 12
2. Complete the following subtraction problems:
    a. 15
    b. 80
    c. -9
    d. -15
3. Complete the following multiplication problems:
    a. 36
    b. -108
    c. 32
    d. -77
    e. 224
4. Complete the following division problems:
    a. -7
    b. 1.2857
    c. -7.08
    d. -20.5
5. Solve each problem, using $f = 8$, $g = 9$ and $h = 10$.
    a. a = 18
    b. y = 91
    c. b = 1
    d. m = 3.51
    e. c = 720
    f. a = 81
    g. d = 7.2
    h. n = 6
    i. x = 83
    j. P = 518.4
6. Solve the following for a and check by substituting the answer into the original equation:
    a. 6
    b. 28
    c. 4.5
7. Solve the following for b and check:
    a. 6.0714

b. 45
c. 3.333
d. 5

8. Solve the following proportions for *a* and check:

a. 3
b. 13.5
c. 5

9. A fan turning at 1,500 RPM is moving 2,500 CFM of air. If the CFM is to be increased to 3,000, what must the new fan speed be?

a. 1,800 RPM

Self-Test C-1.3: Use Formulas to Calculate Perimeter, Circumference and Area

Complete Self-Test C-1.3 and check your answers.

1. Calculate the surface area of a totally enclosed square tank that is 92″ in. height.

Area: _____ in.^2

2. Calculate the area of a $1,200 \text{ mm} \times 1,575 \text{ mm}$ rectangle.

Area: _____ mm^2

3. What is the total surface area of a $1.2 \text{ m} \times 1.7 \text{ m} \times 1.35 \text{ m}$ totally enclosed box?

Area: _____ m^2

4. Calculate the area in square inches of a right triangle with a 2′ 9″ base and 4′ 3″ height.

Area: _____ in.^2

5. What is the square footage of a 52″ high right triangle with a 3′ 7″ base?

Area: _____ ft.^2

6. Calculate the area in square feet of a circle with an $18\frac{1}{2}$" radius.

Area: _____ ft.^2

7. What is the area of a manhole cover used on a 1,800 mm diameter opening?

Area: _____ mm^2

8. How many square metres of grating are there in a 1.1 m wide walkway around a tank with a diameter of 7 metres?

Area: _____ m^2

9. What is the surface area, in square feet, of a $2'6" \times 2'2" \times 28"$ fully enclosed rectangular tank?

Area: _____ ft.^2

10. What is the surface area of a totally enclosed cylindrical tank that is 4.6 m high and 1.8 m in diameter?

Area: _____ m^2

11. Calculate the number of square feet of surface area on a cylindrical vat with an open top that has a diameter of 2′ 7″ and a height of 20′ 4″.

Area: _____ $ft.^2$

12. A circle has an area of 94.5 $ft.^2$ Calculate the diameter of the circle.

Diameter: _____ ft.

Answer Key: Self-Test C-1.3 is on the other page.

Answer Key: Self-Test C-1.3

1. Calculate the surface area of a totally enclosed square tank that is 92″ in. height.
    a. 50,784 $in.^2$
2. Calculate the area of a 1,200 mm x 1,575 mm rectangle.
    a. 1,890,000 mm^2
3. What is the total surface area of a 1.2 m x 1.7 m x 1.35 m totally enclosed box?
    a. 11.91 m^2
4. Calculate the area in square inches of a right triangle with a 2′ 9″ base and 4′ 3″ height.
    a. 841.5 $in.^2$
5. What is the square footage of a 52″ high right triangle with a 3′ 7″ base?
    a. 7.764 $ft.^2$
6. Calculate the area in square feet of a circle with an 18 1/2″ radius.
    a. 7.467 $ft.^2$
7. What is the area of a manhole cover used on a 1,800 mm diameter opening?
    a. 2,544,696 mm^2
8. How many square metres of grating are there in a 1.1 m wide walkway around a tank with a diameter of 7 metres?
    a. 27.99 m^2
9. What is the surface area, in square feet, of a 2′ 6″ x 2′ 2″ x 28″ fully enclosed rectangular tank?
    a. 32.52 $ft.^2$
10. What is the surface area of a totally enclosed cylindrical tank that is 4.6 m high and 1.8 m in diameter?
    a. 31.1 m^2
11. Calculate the number of square feet of surface area on a cylindrical vat with an open top that has a diameter of 2′ 7″ and a height of 20′ 4″.
    a. 170.263 $ft.^2$
12. A circle has an area of 94.5 $ft.^2$ Calculate the diameter of the circle.
    a. 10.97 ft.

Self-Test C-1.4: Use Formulas to Calculate Volumes

Complete Self-Test C-1.4 and check your answers.

1. Find the volume of a warehouse that is 12 ft. high, 85 ft. long and 35 ft. wide.

Volume = _____ $ft.^3$

2. Find the volume of a 12-ft. high tank having a diameter of 6 ft.

Volume = _____ $ft.^3$

3. Find the volume of a $9\text{ m} \times 3.9\text{ m} \times 4.1\text{ m}$ storage shed.

Volume = _____ m^3

4. What is the volume of a glycol storage tank that is 3.8 m long and 2.7 m in diameter?

Volume = _____ m^3

5. How many cubic metres of earth would be required to backfill a trench 32 m long, 1.7 m wide and 1.5 m deep?

Volume = _____ m^3

6. How many cubic feet of earth would be removed to create a trench 85′ long, 5′ wide and 5′ deep?

Volume = _____ $ft.^3$

7. If the volume of a holding tank is 864 $ft.^3$ and the height is 9 ft., find the diameter, to the nearest foot.

Diameter = _____ ft.

8. If the volume is 22,372.5 $in.^3$ and the radius is 25 in., find the height, to the nearest inch.

Height = _____ in.

Answer Key: Self-Test C-1.4 is on the other page.

Answer Key: Self-Test C-1.4

1. Find the volume of a warehouse that is 12 ft. high, 85 ft. long and 35 ft. wide.
   a. 35,700 ft.^{3}
2. Find the volume of a 12-ft. high tank having a diameter of 6 ft.
   a. 339.29 ft.^{3}
3. Find the volume of a $9\text{ m} \times 3.9\text{ m} \times 4.1\text{ m}$ storage shed.
   a. 143.91 m^3
4. What is the volume of a glycol storage tank that is 3.8 m long and 2.7 m in diameter?
   a. 21.757 m^3
5. How many cubic metres of earth would be required to backfill a trench 32 m long, 1.7 m wide and 1.5 m deep?
   a. 81.6 m^3
6. How many cubic feet of earth would be removed to create a trench 85′ long, 5′ wide and 5′ deep?
   a. 2,125 ft.^{3}
7. If the volume of a holding tank is 864 ft.^{3} and the height is 9 ft., find the diameter, to the nearest foot.
   a. 11 ft.
8. If the volume is 22,372.5 in.^{3} and the radius is 25 in., find the height, to the nearest inch.
   a. 11″

Self-Test C-1.5: Use Formula to Calculate Capacity

Complete Self-Test C-1.5 and check your answers.

1. How much water, in imperial gallons, will a cylindrical tank hold if it is 12″ in diameter and 43″ in height?

Answer: _____ imp. gal.

2. How many US gallons of water would be required to fill a pool 10 feet in diameter and 2 feet deep?

Answer: _____ US gal.

3. Refer to the horizontal tank in Figure 1 to answer the following questions:

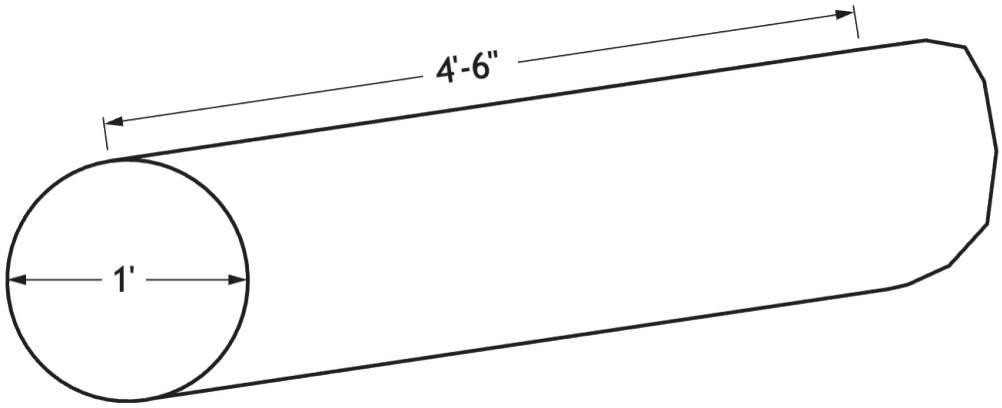


Figure 1 *Illustration for Question 3*

   a. How many imperial gallons would the tank hold when completely full?

Answer: _____ imp. gal.

   b. How many imperial gallons would the tank hold if it were 80% full?

Answer: _____ imp. gal.

   c. How much would the water weigh (lbs.) if the tank were 80% full?

Answer: _____ lbs.

4. A cooling tower basin is 6 m long (20 ft.), 3 m wide (10 ft.) and 450 mm (18 in.) deep.
   a. How many litres would the basin hold when completely full?

Answer: _____ L

b. How many US gallons would the basin hold if it were 75% full?

Answer: _____ US gal.

c. What would the water weigh (lb.) if the basin were 60% full?

Answer: _____ lb.

d. If the manufacturer required a 40:1 ratio of water to corrosion inhibiter added to the basin, how many imperial gallons of inhibitor would be required if the basin were completely full?

Answer: _____ imp. gal.

5. The capacity of the pipe and tank shown in Figure 2 is

Answer: _____ L

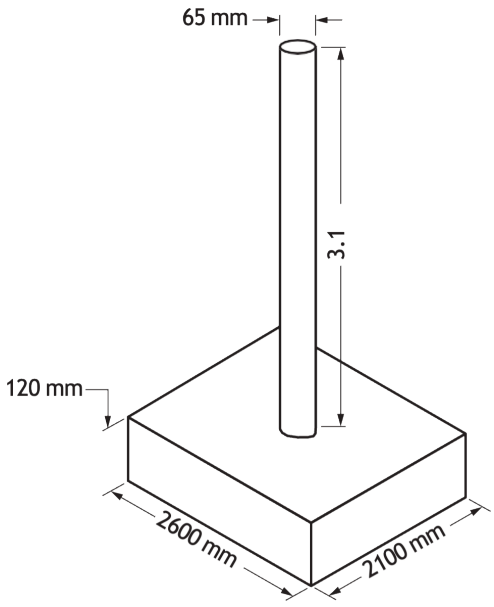


Figure 2 *Illustration for question* 5

6. After 4,000 US gallons of water were added to a large water tank that was already filled to $\frac{3}{4}$ of its capacity, the tank was then at $\frac{4}{5}$ of its capacity. How many US gallons of water does the tank hold when filled to capacity?

Answer: _____ US gal.

Answer Key: Self-Test C-1.5 is on the other page.

Answer Key: Self-Test C-1.5

1. How much water, in imperial gallons, will a cylindrical tank hold if it is 12″ in diameter and 43″ in height?
    a. 17.56 imp. gal
2. How many US gallons of water would be required to fill a pool 10 feet in diameter and 2 feet deep?
    a. 1,174.96 US gal
3. Refer to the horizontal tank in Figure 1 to answer the following questions:
    a. How many imperial gallons would the tank hold when completely full?
        i. 22.05 imp. gal.
    b. How many imperial gallons would the tank hold if it were 80% full?
        i. 17.64 imp. gal.
    c. How much would the water weigh (lbs.) if the tank were 80% full?
        1. 176.43 lb.

4. A cooling tower basin is 6 m long (20 ft.), 3 m wide (10 ft.) and 450 mm (18 in.) deep.
    a. How many litres would the basin hold when completely full?
        i. 8,100 L
    b. How many US gallons would the basin hold if it were 75% full?
        i. 1,683 US gal.
    c. What would the water weigh (lb.) if the basin were 60% full?
        i. 11,232 lb.
    d. If the manufacturer required a 40:1 ratio of water to corrosion inhibiter added to the basin, how many imperial gallons of inhibitor would be required if the basin were completely full?
        i. 46.8 imp. gal

5. The capacity of the pipe and tank shown in Figure 2 is
    a. 665 L

6. After 4,000 US gallons of water were added to a large water tank that was already filled to $\frac{3}{4}$ of its capacity, the tank was then at $\frac{4}{5}$ of its capacity. How many US gallons of water does the tank hold when filled to capacity?
    a. 80,000 US gal.

Self-Test C-1.6.1: Perform Conversions

Complete Self-Test C-1.6.1 and check your answers.

1. Give the prefix that relates each of the following numbers to the standard unit:

a. 1,000 times = _____ d. 1 of 100 = _____

b. 1 of 10 = _____ e. 100 times = _____

c. 1 of 1,000 = _____ f. 10 times = _____

2. Convert to the length unit indicated:

a. 4 m = _____ dm l. 48 cm = _____ in.

b. 39″ = _____ m m. 67 cm = _____ in.

c. 78″ = _____ m n. 266 cm = _____ in.

d. 9 m = _____ in. o. 58 km = _____ hm

e. 120 m = _____ yards p. 5.5″ = _____ cm

f. 0.25 km = _____ hm q. 12 m = _____ in.

g. 8.5 cm = _____ mm r. 8 m = _____ mm

h. 11 ft. = _____ cm s. 58 km = _____ m

i. 6 m = _____ in. t. 0.25 km = _____ m

j. 4″ = _____ mm u. 10.25 hm = _____ cm

k. 5.08 cm = _____ in. v. 2 km = _____ mm

3. Convert to the area unit indicated:

a. 77 m2 = _____ $ft.^2$ f. 43 acres = _____ hectares

b. 1,180 mm^2 = _____ $in.^2$ g. 74 $yd.^2$ = _____ m^2

c. 610 $miles^2$ = _____ km^2 h. 21 cm^2 = _____ $in.^2$

d. 123 km^2 = _____ $miles^2$ i. 39 hectares = _____ acres

e. 894 $in.^2$ = _____ cm^2 j. 44.6 $in.^2$ = _____ mm^2

4. Convert to the volume unit indicated:

a. 411 m^3 = _____ $yd.^3$ e. 345 $ft.^3$ = _____ m^3

b. 8,507 $in.^3$ = _____ cm^3 f. 91 cm^3 = _____ $in.^3$

c. 12 cm^3 = _____ $in.^3$ g. 8,507 m^3 = _____ $ft.^3$

d. 542 $yd.^3$ = _____ m^3 h. 8 $in.^3$ = _____ mm^3

5. Convert to the weight unit indicated:

a. 6 oz. = _____ grams e. 3,234 kg = _____ tons

b. 15 grams = _____ grains f. 50 lb. = _____ kilograms

c. 411 kg = _____ lb. g. 10 lb. = _____ grams

d. 4,239 grams = _____ lb. h. 39 grams = _____ ounces

6. Convert to the capacity unit indicated:

a. 9 L = _____ US gal. f. 10 imp. gal. = _____ litres

b. 1,593 mL = _____ imp. pints g. 15 L = _____ imp. pints

c. 2.36 L = _____ imp. gal. h. 534 $in.^3$ = _____ litres

d. 6 L = _____ US pints i. 5 imp. pints = _____ litres

e. 12 US gal. = _____ litres j. 8 L = _____ $in.^3$

Answer Key: Self-Test C-1.6.1 is on the other page.

Answer Key: Self-Test C-1.6.1

1. Give the prefix that relates each of the following numbers to the standard unit
    a. kilo
    b. deci
    c. milli
    d. centi
    e. hecto
    f. deca
2. Convert to the length unit indicated
    a. 40 dm
    b. 0.99 m
    c. 1.98 m
    d. 354.33 in.
    e. 131.28 yards
    f. 2.5 hm
    g. 85 mm
    h. 335.28 cm
    i. 236.23 in.
    j. 101.6 mm
    k. 2 in.
    l. 18.9 in.
    m. 26.38 in.
    n. 104.72 in.
    o. 580 hm
    p. 13.97 cm
    q. 472.46 in.
    r. 8,000 mm
    s. 58,000 m
    t. 250 m
    u. 102,500 cm
    v. 2,000,000 mm
3. Convert to the area unit indicated
    a. 828.52 $ft.^2$
    b. 1.829 $in.^2$
    c. 1,579.29 km^2
    d. 47.49 $miles^2$
    e. 5,768.1 cm^2
    f. 17.4 $hectares^2$
    g. 61.87 m^2
    h. 3.255 $in.^2$
    i. 96.37 $acres^2$
    j. 28,774 mm^2
4. Convert to the volume unit indicated
    a. 537.59 $yd.^3$

b. 139,429.73^3
c. 0.732 in.^{3}
d. 414.4 m^3
e. 9.77 m^3
f. 5.55 in.^{3}
g. 300,424.7 ft.^{3}
h. 131,096.5 mm^3

5. Convert to the weight unit indicated

a. 170.1 grams
b. 231 grains
c. 906.26 lb.
d. 9.35 lb.
e. 3.183 tons
f. 22.68 kilograms
g. 4,536 grams
h. 1.38 ounces

6. Convert to the capacity unit indicated

a. 2.38 US gal.
b. 2.8 imp. pints
c. 0.52 imp. gal.
d. 12.68 US pints
e. 45.42 L
f. 45.46 L
g. 26.4 imp. pints
h. 8.75 L
i. 2.84 L
j. 488.24 in.^{3}

Self-Test C-1.6.2: Perform Conversions

Complete Self-Test C-1.6.2 and check your answers.

1. Convert the following heat energy values to the units indicated:

a. 256 J = _____ calories

b. 78,000 J = _____ kWh

c. 450,000 J = _____ BTU

d. 1 kWh = _____ J

e. 45 kWh = _____ BTU

f. 6,750 BTU = _____ J

g. 875,000 BTU = _____ kWh

h. 9,540 J = _____ calories

i. 145,000 J = _____ kWh

j. 1,250,600 J = _____ BTU

k. 0.6 kWh = _____ J

l. 61.5 kWh = _____ BTU

m. 100 kWh = _____ BTU

n. 750,000 BTU = _____ kWh

2. Convert the following temperatures to the values indicated:

°F	°R	°C	K
580			
	10		
		−35	
			5,543
−310			
	3,668		
		622	
			300

3. Convert the following pressures to the values indicated:

Pressure Units	psi	kPa	Inches of Hg	Inches of H_20	Atmospheres
1 psi =	18.7				
1 kPa =		263			
1 in. of Hg =			49.8		
1 in. of H_2O =				66.9	
1 atmosphere =					3.4

Answer Key: Self-Test C-1.6.2 is on the other page.

Answer Key: Self-Test C-1.6.2

1. Convert the following heat energy values to the units indicated:
    a. 61.13 calories
    b. 0.0217 kWh
    c. 426.52 BTU
    d. 3,600,000 J
    e. 153,540 BTU
    f. 7,121,250 J
    g. 256.45 kWh
    h. 2,278.15 calories
    i. 0.0403 kWh
    j. 1,185.34 BTU
    k. 2,160,000 J
    l. 209,838 BTU
    m. 341,200 BTU
    n. 219.81 kWh
2. Convert the following temperatures to the values indicated:

°F	°R	°C	K
580	1,040	304.4	577.4
-450	10	-267.8	5.2
-31	429	−35	238
9,518	9,978	5,270	5,543
−310	150	-190	83
3,208	3,668	1,764.4	2,037.4
1,151.6	1,611.6	622	895
80.6	540.6	27	300

3. Convert the following pressures to the values indicated:

Pressure Units	psi	kPa	Inches of Hg	Inches of H_20	Atmospheres
1 psi =	18.7	128.9365	38.0732	517.616	1.27
1 kPa =	38.135	263	77.585	1,055.945	2.595547
1 in. of Hg =	24.4518	168.6228	49.8	677.28	1.664316
1 in. of H_2O =	2.4084	16.6581	4.920	66.9	0.16444
1 atmosphere =	50.082	344.505	101.728	1,383.46	3.4

Self-Test C-1.7.1: Calculate Piping Measurements

Complete Self-Test C-1.7.1 and check your answers.

1. Solve for the end-to-end lengths for the pieces indicated in Figure 16 (to the nearest $\frac{1}{8}$„). $1\frac{1}{4}$„ pipe – screwed fittings (malleable iron class 150):

A: _____ C: _____

B: _____ D: _____

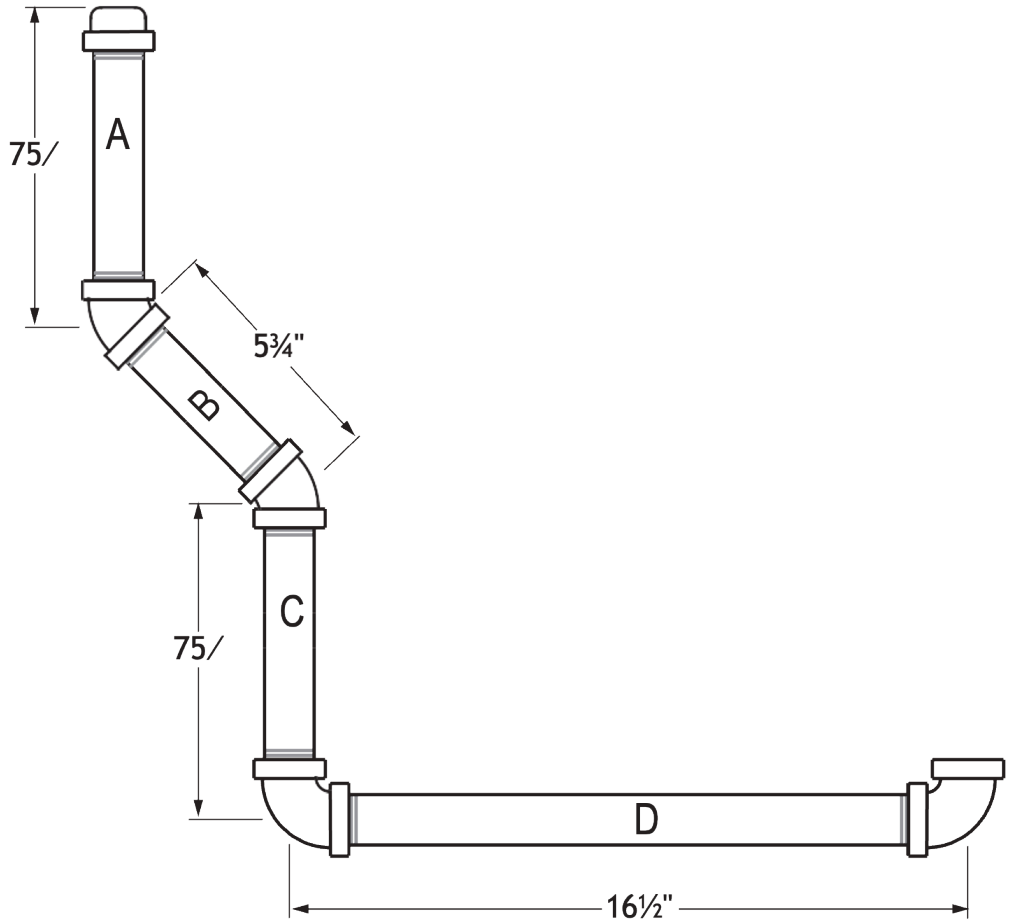


Figure 16 *Illustration for Question 1*

2. Solve for the end-to-end lengths for the pieces indicated in Figure 17 (to the nearest $\frac{1}{8}$„). $1\frac{1}{2}$„ pipe—screwed fittings (malleable iron class 150):

A: _____ F: _____

B: _____ G: _____

C: _____ H: _____

D: _____ I: _____

E: _____ J: _____

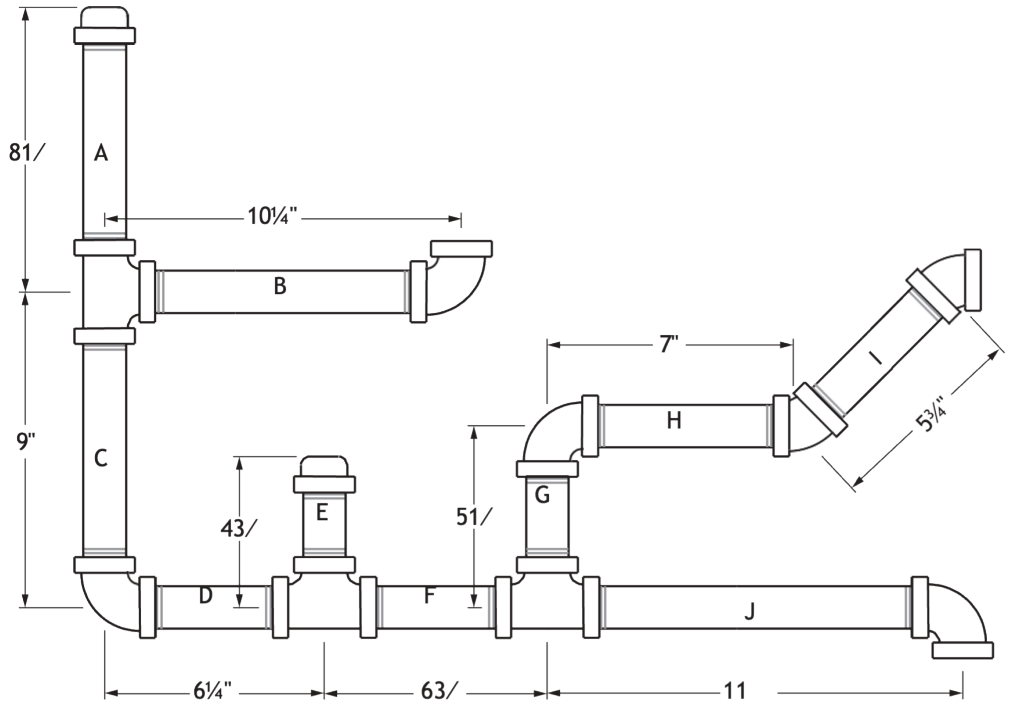


Figure 17 *Illustration for Question 2*

3. Solve for the end-to-end lengths for the pieces indicated in Figure 18 (to the nearest 0.1 mm). 25 mm pipe—screwed fittings (malleable iron class 150):

A: _____ F: _____

B: _____ G: _____

C: _____ H: _____

D: _____ I: _____

E: _____ J: _____

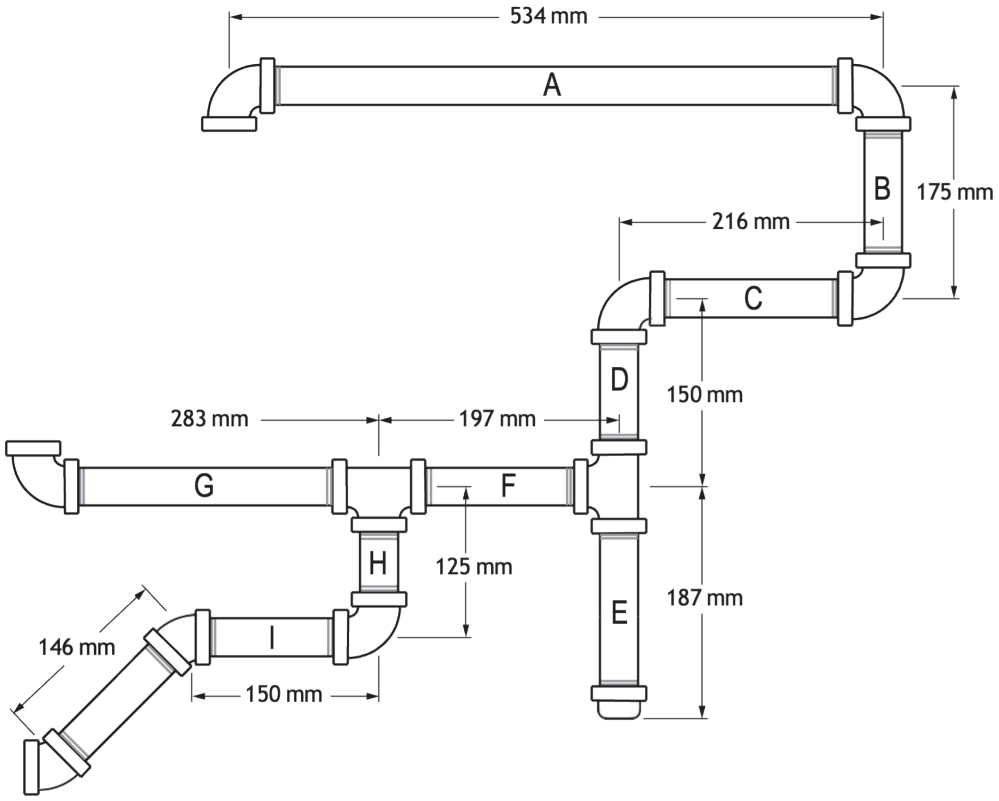


Figure 18 *Illustration for Question 3*

4. Solve for the end-to-end lengths for the pieces indicated in Figure 19 (to the nearest 0.1 mm). 20 mm pipe—screwed fittings (malleable iron class 150):

A: _____ E: _____

B: _____ F: _____

C: _____ G: _____

D: _____ H: _____

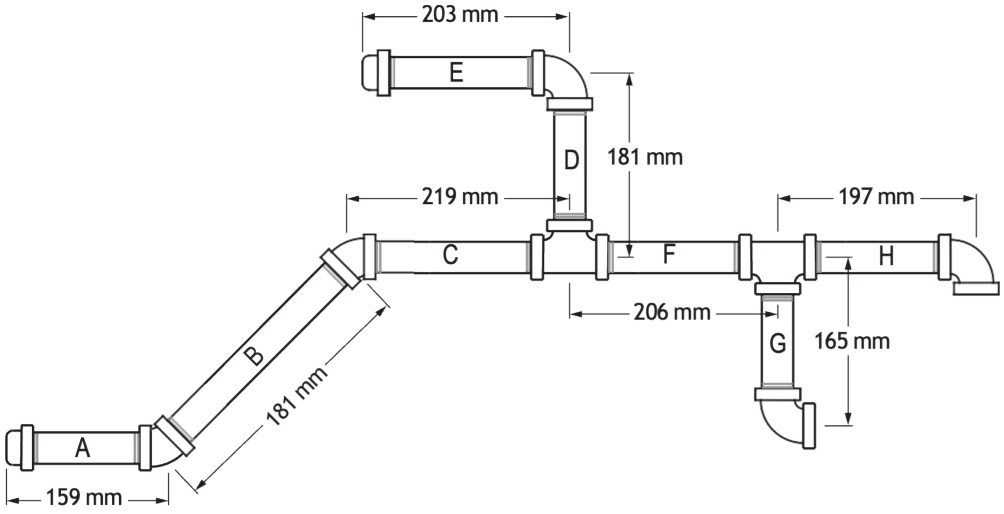


Figure 19 *Illustration for Question 4*

5. Solve for the end-to-end lengths for the pieces indicated in Figure 20 (to the nearest $\frac{1}{8}$″). 2″ pipe—butt-weld fittings—long radius 90° ell, c/w $\frac{1}{8}$″ gap:

A: _____ F: _____

B: _____ G: _____

C: _____ H: _____

D: _____ I: _____

E: _____ J: _____

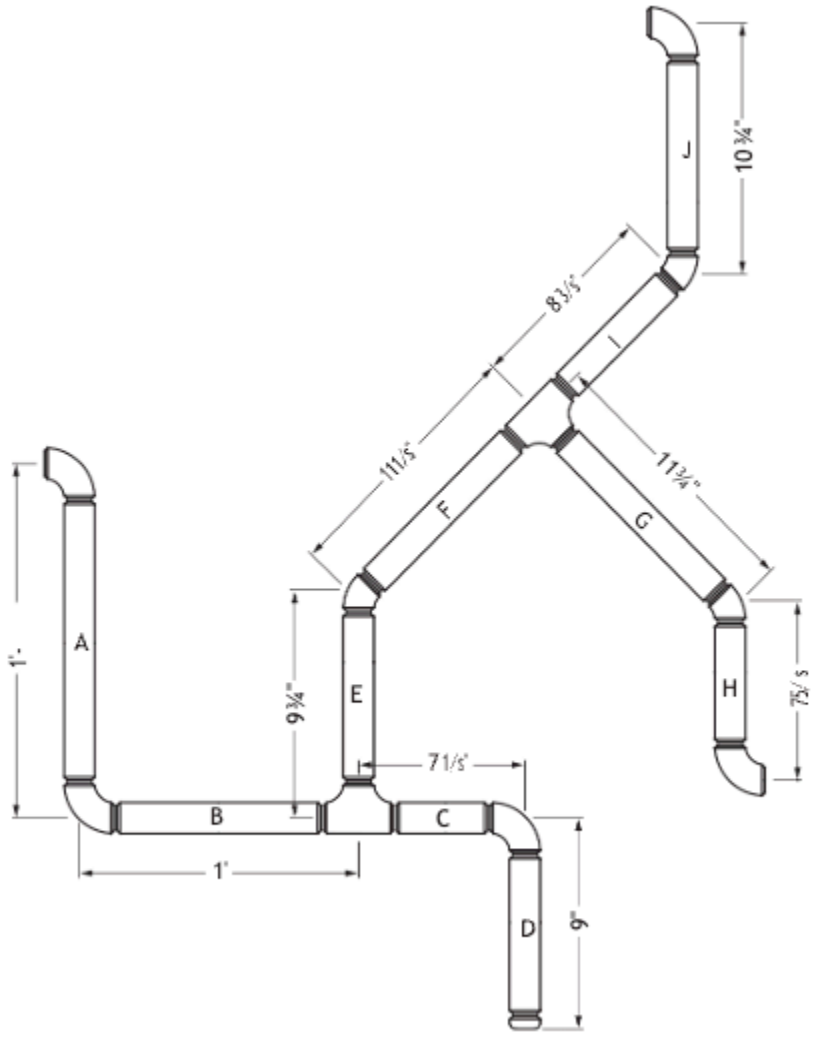


Figure 20 *Illustration for Question 5*

6. Solve for the end-to-end lengths for the pieces indicated in Figure 21 (to the nearest 0.1 mm). 15 mm pipe—butt weld fittings—long radius 90° ell, c/w 3 mm gap:

A: _____ F: _____

B: _____ G: _____

C: _____ H: _____

D: _____ I: _____

E: _____

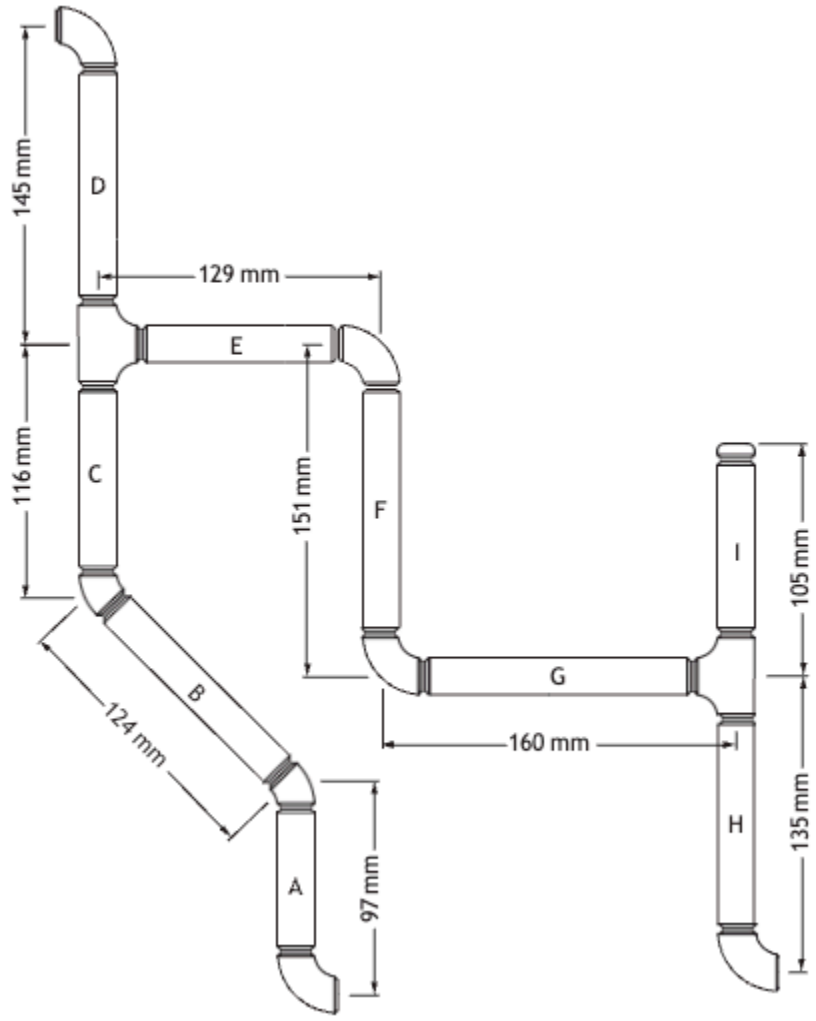


Figure 21 *Illustration for Question 6*

7. Solve for the end-to-end lengths for the pieces indicated in Figure 22 (to the nearest $\frac{1}{8}$″). 1″ pipe—socket-weld fittings—3000# sched. 80 (c/w $\frac{1}{16}$″ gap, included in FA table values):

A: _____ E: _____

B: _____ F: _____

C: _____ G: _____

D: _____ H: _____

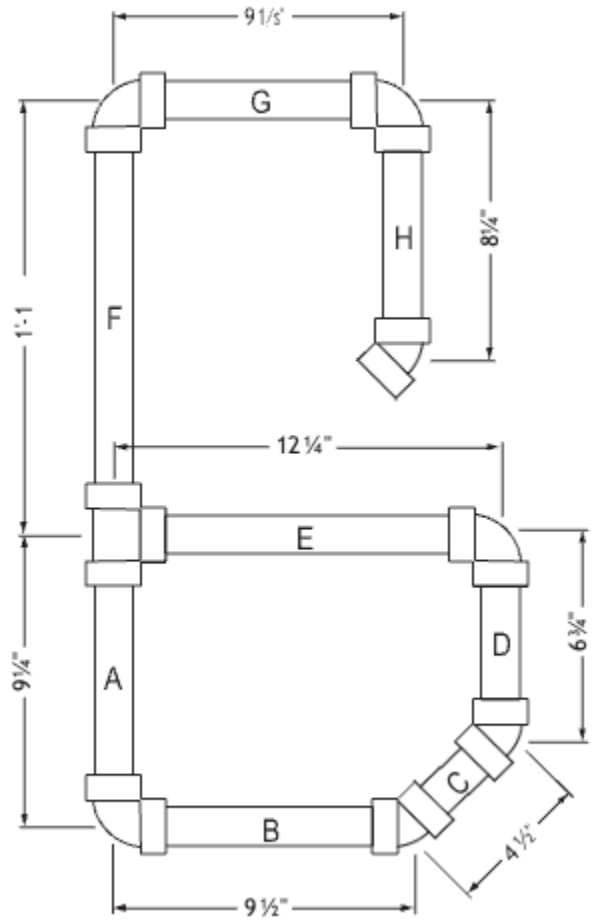


Figure 22 *Illustration for Question 7*

8. Solve for the end-to-end lengths for the pieces indicated in Figure 23 (to the nearest 0.1 mm). 50 mm pipe—socket weld fittings—6000# sched. 160 (c/w 1.6 mm gap, included in FA table values):

A: _____ H: _____

B: _____ I: _____

C: _____ J: _____

D: _____ K: _____

E: _____ L: _____

F: _____ M: _____

G: _____

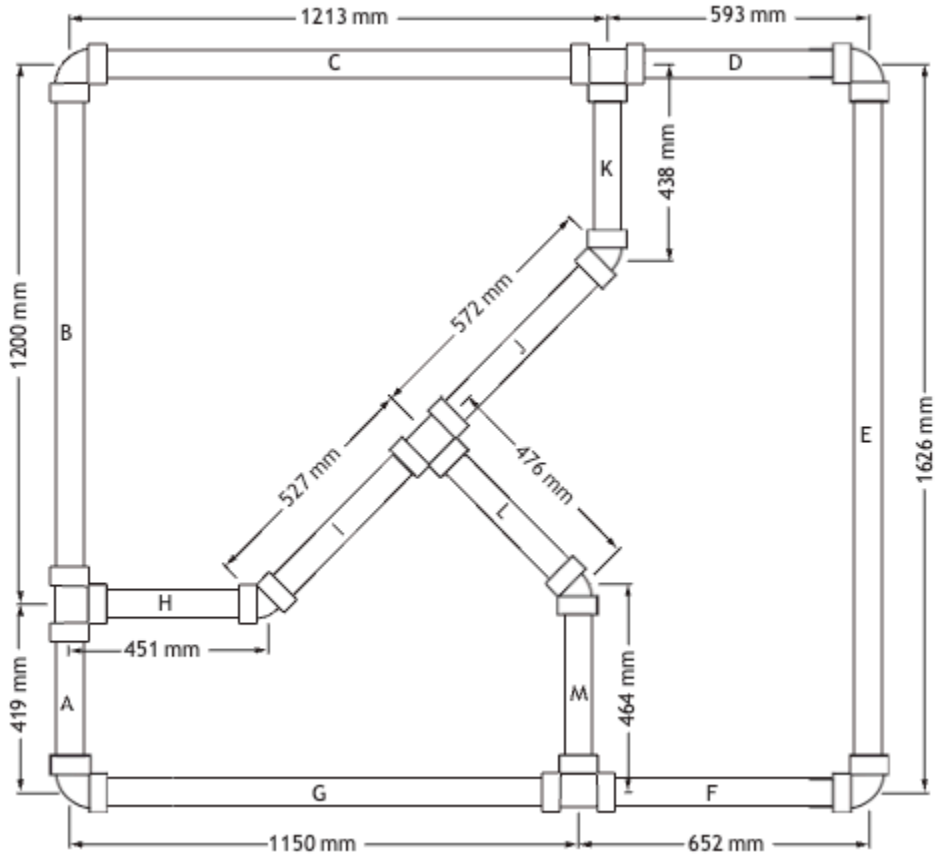


Figure 23 *Illustration for Question 8*

Answer Key: Self-Test C-1.7.1 is on the other page.

Answer Key: Self-Test C-1.7.1

1. Solve for the end-to-end lengths for the pieces indicated in Figure 16 (to the nearest $\frac{1}{8}$"). $1\frac{1}{4}$" pipe – screwed fittings (malleable iron class 150):

   A. $6\frac{3}{8}$"

   B. $4\frac{1}{2}$"

   C. $5\frac{7}{8}$"

   D. $14\frac{3}{8}$"

2. Solve for the end-to-end lengths for the pieces indicated in Figure 17 (to the nearest $\frac{1}{8}$"). $1\frac{1}{2}$" pipe—screwed fittings (malleable iron class 150):

   A. $6\frac{1}{4}$"

   B. $7\frac{3}{4}$"

   C. $6\frac{1}{2}$"

   D. $3\frac{3}{4}$"

   E. $2\frac{1}{2}$"

   F. $3\frac{7}{8}$"

   G. $2\frac{5}{8}$"

   H. 5"

   I. $4\frac{1}{4}$"

J. $9\frac{3}{8}$„

3. Solve for the end-to-end lengths for the pieces indicated in Figure 18 (to the nearest 0.1 mm). 25 mm pipe—screwed fittings (malleable iron class 150):

A. 487.2 mm

B. 128.2 mm

C. 169.2 mm

D. 103.2 mm

E. 148.9 mm

F. 150.2 mm

G. 236.2 mm

H. 78.2 mm

I. 112.8 mm

J. 118.4 mm

4. Solve for the end-to-end lengths for the pieces indicated in Figure 19 (to the nearest 0.1 mm). 20 mm pipe—screwed fittings (malleable iron class 150):

A. 134.9 mm

B. 156.6 mm

C. 186.2 mm

D. 139.8 mm

E. 170.5 mm

F. 164.8 mm

G. 123.8 mm

H. 155.8 mm

5. Solve for the end-to-end lengths for the pieces indicated in Figure 20 (to the nearest $\frac{1}{8}$„). 2″ pipe—butt-weld fittings—long radius 90° ell, c/w $\frac{1}{8}$„ gap:

A. $8\frac{7}{8}$„

B. $6\frac{1}{4}$„

C. $1\frac{3}{8}$„

D. $4\frac{1}{4}$"

E. $5\frac{5}{8}$"

F. 7"

G. $7\frac{5}{8}$"

H. 3"

I. $4\frac{1}{4}$"

J. $6\frac{1}{8}$"

6. Solve for the end-to-end lengths for the pieces indicated in Figure 21 (to the nearest 0.1 mm). 15 mm pipe—butt weld fittings—long radius 90° ell, c/w 3 mm gap:

A. 37 mm

B. 86 mm

C. 69 mm

D. 76 mm

E. 60 mm

F. 69 mm

G. 91 mm

H. 66 mm

I. 49 mm

7. Solve for the end-to-end lengths for the pieces indicated in Figure 22 (to the nearest $\frac{1}{8}$"). 1″ pipe—socket-weld fittings—3000# sched. 80 (c/w $\frac{1}{16}$" gap, included in FA table values):

A. $7\frac{1}{2}$"

B. 8"

C. $3\frac{3}{8}$"

D. $5\frac{1}{4}$"

E. $10\frac{1}{2}$"

F. $12\frac{1}{8}$"

G. $7\frac{3}{8}$"

H. $6\frac{3}{4}$"

8. Solve for the end-to-end lengths for the pieces indicated in Figure 23 (to the nearest 0.1 mm). 50 mm pipe—socket weld fittings—6000# sched. 160 (c/w 1.6 mm gap, included in FA table values):

A. 336.7 mm

B. 1,117.7 mm

C. 1,130.7 mm

D. 510.7 mm

E. 1,543.7 mm

F. 569.7 mm

G. 1,067.7 mm

H. 380.9 mm

I. 456.9 mm

J. 501.9 mm

K. 367.9 mm

L. 405.9 mm

M. 393.9 mm

Self-Test C-1.7.2: Calculate Piping Measurements

Complete Self-Test C-1.7.2 and check your answers.

1. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = $\frac{1}{8}$„ per foot

Length = 95 feet

Total fall = _____ in.

2. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = 1%

Length = 125 feet

Total fall = _____ in.

3. Calculate the pipe length:

Total fall = 0.95 feet

Grade = 2%

Length = _____ ft. _____ in.

4. Calculate the pipe length:

Total fall = 11 inches

Grade = $\frac{1}{8}$„ per foot

Length = _____ ft.

5. Calculate the grade in inches per foot:

Total fall = 24 inches

Length = 192 feet

Grade = _____ $\frac{\text{in.}}{\text{ft.}}$

6. Calculate the grade as a percentage:

Total fall = 4.5 feet

Length = 475 feet

Grade = _____ %

7. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = $\frac{1}{8}$" per foot

Length = 130 feet

Total fall = _____ in.

8. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = 0.5%

Length = 445 feet

Total fall = _____ in.

9. Calculate the length:

Total fall = 162 mm

Grade = 1%

Length = _____ m

10. Calculate the length:

Total fall = 18 inches

Grade = 1:133

Length = _____ ft.

11. Calculate the grade in inches per foot:

Total fall = 8 inches

Length = 128 feet

Grade = _____ $\frac{\text{in.}}{\text{ft.}}$

12. Calculate the grade as a percentage:

Total fall = 3 feet

Length = 555 feet

Grade = _____ %

13. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = $\frac{1}{4}$" per foot

Length = 19 feet

Total fall = _____ in.

14. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = 1:50

Length = 95 feet

Total fall = _____ in.

15. Calculate the pipe length:

Total fall = 18″

Grade = 1.5%

Length = _____ ft.

16. Calculate the pipe length:

Total fall = $8\frac{7}{8}$"

Grade = 1:50

Length = _____ ft. _____ in.

17. Calculate the grade in inches per foot:

Total fall = 23″

Length = 184′

Grade = _____ $\frac{\text{in.}}{\text{ft.}}$

18. Calculate the grade as a percentage:

Total fall = $54\frac{3}{4}$„

Length = 456′

Grade = _____ %

19. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = $\frac{1}{16}$„ per foot

Length = 165′

Total fall = _____ in.

20. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

Grade = 1.5%

Length = 325 feet

Total fall = _____ in.

21. Calculate the length:

Total fall = 18″

Grade = 1.04%

Length = _____ ft.

22. Calculate the length:

Total fall = 45″

Grade = $\frac{1}{8}$" per foot

Length = _____ ft.

23. Calculate the grade as a ratio:

Total fall = 9″

Length = 37′ 6″

Grade = _____

24. Calculate the grade as a ratio:

Total fall = 4.66′

Length = 1400′

Grade = _____

25. Convert each measurement to engineer's measurement (3 decimal places):

a. 18′ 6″ = _____ d. 33′ 10″ = _____

b. 15′ 5″ = _____ e. 35′ 11 $\frac{1}{4}$ ″ = _____

c. 32′ 9″ = _____

26. Convert each measurement to builder's measure (nearest $\frac{1}{8}$"):

a. 84.27′ = _____ d. 123.44′ = _____

b. 93.08′ = _____ e. 156.92′ = _____

c. 106.71′ = _____

27. A house construction site has a benchmark of 100.00′, basement floor elevation of 94.20′, first floor elevation of 103.75′ and second floor elevation of 113.00′.

    a. How far below the benchmark is the basement floor?

Answer = _____

    b. How far above the benchmark is the first floor?

Answer = _____

    c. What is the distance from the basement floor to the first floor?

Answer = _____

d. What is the distance from the first floor to the second floor?

Answer = _____

28. The low end of a sanitary building drain has an elevation of 91.55 feet. The grade is $\frac{1}{8}$ inch per foot.

a. What is the elevation of a fitting 10′ upstream of the low point?

Answer = _____

b. What is the elevation of a fitting 25′ upstream of the low point?

Answer = _____

29. Refer to Figure 27 to solve for the unknown values.

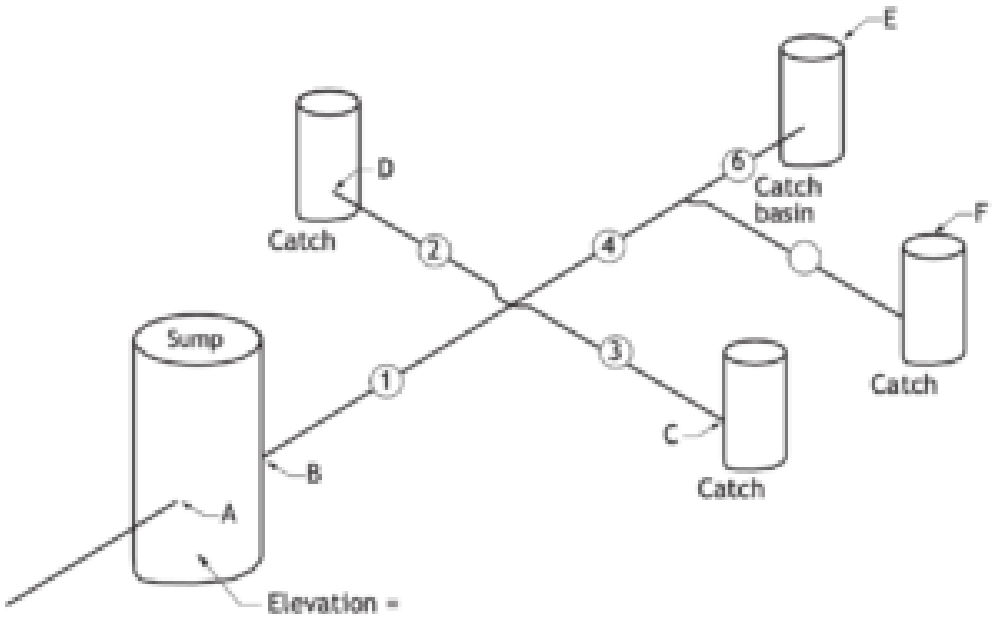


Figure 27 *Illustration for problem 29*

Notes:

- Main line (pipe sections 1 & 4) are 12″ in diameter
- Branch line (pipe sections 2, 3, 5 & 6) are 6″ in diameter

- Grade on all pipe sections is $\frac{\frac{1}{8}\text{"}}{\text{ft.}}$

Sump:

- Liquid depth = 24″
- Inlet is 4″ higher than outlet
- Sump height = 60″

Catch basin:

- Liquid depth = 18″
- Catch basin height = 36″ Pipe lengths:
- Main sections:
    - ▸ Pipe section 1 = 30′
    - ▸ Pipe section 4 = 125′
- Branches:
    - ▸ Pipe section 2 = 75′
    - ▸ Pipe section 3 = 21′
    - ▸ Pipe section 5 = 40′
    - ▸ Pipe section 6 = 64′

The invert level of a pipe is the level taken from the bottom inside of the pipe, as shown.

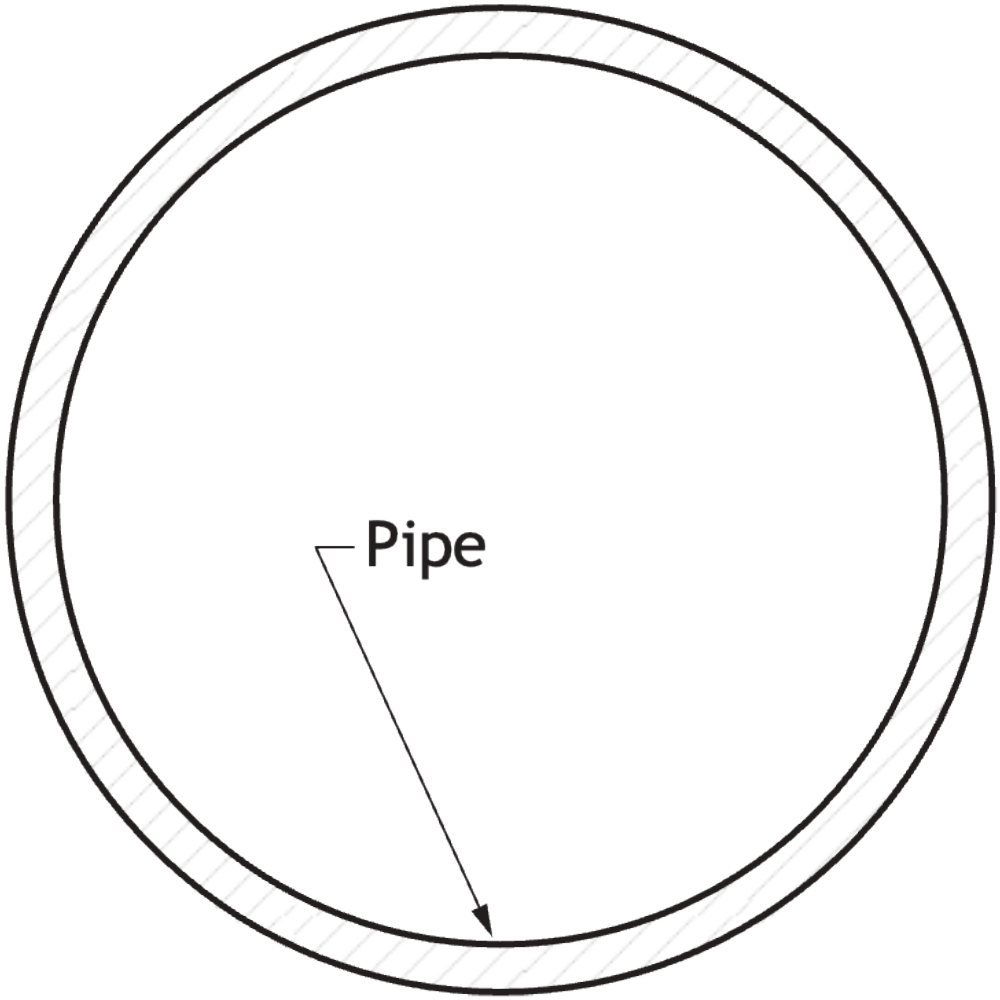


Figure 28 *Pipe invert*

Solve for the following elevations in feet to 3 decimal places:

A. Outlet invert = _____ D. Outlet invert = _____

B. Inlet invert = _____ E. Top elevation = _____

C. Outlet invert = _____ F. Top elevation = _____

Answer Key: Self-Test C-1.7.2 is on the other page.

Answer Key: Self-Test C-1.7.2

1. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

   a. $11\frac{7}{8}$”

2. Calculate the total fall to the nearest $\frac{1}{8}$ inch:

   a. 15”
3. Calculate the pipe length:

   a. 47’ 6”
4. Calculate the pipe length:

   a. 88’
5. Calculate the grade in inches per foot:

   a. $\frac{1}{8}\frac{\text{”}}{\text{ft.}}$
6. Calculate the grade as a percentage:

   a. 0.95%

7. Calculate the total fall to the nearest $\frac{1}{8}$ inch: $16\frac{1}{4}$”

Calculate the total fall to the nearest $\frac{1}{8}$ inch:

a. $26\frac{3}{4}$”

Calculate the length:

a. 16.2 m

Calculate the length:

a. 199.5’

Calculate the grade in inches per foot:

a. $\frac{1}{16}\frac{"}{\text{ft.}}$

Calculate the grade as a percentage:

a. 0.54%

Calculate the total fall to the nearest $\frac{1}{8}$ inch: $4\frac{3}{4}"$ Calculate the total fall to the nearest $\frac{1}{8}$ inch: $22\frac{3}{4}"$

Calculate the pipe length:

a. 100’

Calculate the pipe length:

a. $36'\ 11\frac{3}{4}"$

Calculate the grade in inches per foot:

a. $\frac{1}{8}\frac{"}{\text{ft.}}$

Calculate the grade as a percentage:

a. 1%

Calculate the total fall to the nearest $\frac{1}{8}$ inch: $10\frac{3}{8}"$ Calculate the total fall to the nearest $\frac{1}{8}$ inch: $58\frac{1}{2}"$

Calculate the length:

a. 144.23’

Calculate the length:

a. 360’

Calculate the grade as a ratio:

a. 1:50

Calculate the grade as a ratio:

a. 1:300

Convert each measurement to engineer's measurement (3 decimal places):

a. 18.5'
b. 15.417'
c. 32.75'
d. 33.833'
e. 35.938'

Convert each measurement to builder's measure (nearest $\frac{1}{8}$") 84' $3\frac{1}{4}$" 93' 1" 106' $8\frac{1}{2}$" 123' $5\frac{1}{4}$" 156' 11" A house construction site has a benchmark of 100.00′, basement floor elevation of 94.20′, first floor elevation of 103.75′ and second floor elevation of 113.00′.

a. How far below the benchmark is the basement floor?
    i. 5.8'
b. How far above the benchmark is the first floor?
    i. 3.75'
c. What is the distance from the basement floor to the first floor?
    i. 9.55'
d. What is the distance from the first floor to the second floor?
    i. 9.25'

The low end of a sanitary building drain has an elevation of 91.55 feet. The grade is $\frac{1}{8}$ inch per foot. What is the elevation of a fitting 10′ upstream of the low point? 91.65' What is the elevation of a fitting 25′ upstream of the low point? 91.81' Refer to Figure 27 to solve for the unknown values.

A. 86.000'
B. 86.333'
C. 87.646'
D. 88.771'
E. 92.646'
F. 92.146'

Self-Test C-1.8: Use the Pythagorean Theorem of Right Angles

Complete Self-Test C-1.8 and check your answers.

Calculate the length of the missing side in the following right angle triangles. Round off your answers to two decimal places.

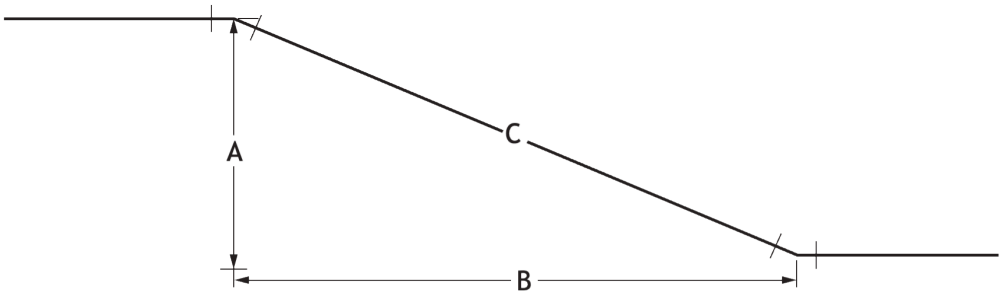


Figure 3 *Illustration for Self-Test 14*

1. Question 1
    a. A = 4.3′
    b. B = 11.25′
    c. C = _____

2. Question 2
    a. A = _____
    b. B = 11.25 m
    c. C = 14.8 m

3. Question 3
    a. A = 750 mm
    b. B = _____
    c. C = 1.8 m

4. Question 4
    a. A = 9′
    b. B = 28′
    c. C = _____

5. Question 5
    a. A = _____
    b. B = 2′ 3″
    c. C = 4′ 9″

6. Question 6
    a. A = 65 mm
    b. B = _____
    c. C = 17 cm

7. Question 7
    a. A = 7′ 6″
    b. B = 2′ 9″
    c. C = _____

8. Question 8
    a. A = _____
    b. B = 9.6 m
    c. C = 12.9 m

9. Question 9
    a. A = _____
    b. B = 7″
    c. C = 3′ 6″

10. Question 10
    a. A = 77 mm
    b. B = _____
    c. C = 104 mm

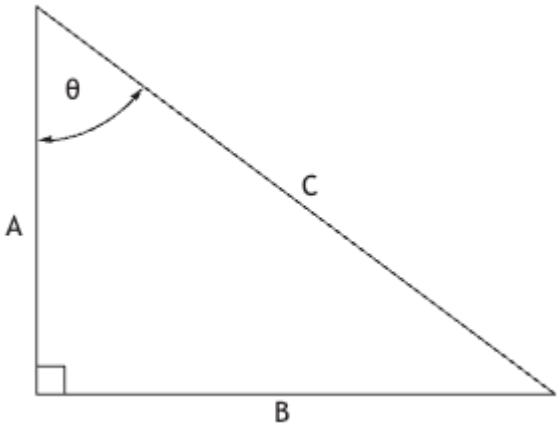
Answer Key: Self-Test C-1.8 is on the other page.

Answer Key: Self-Test C-1.8

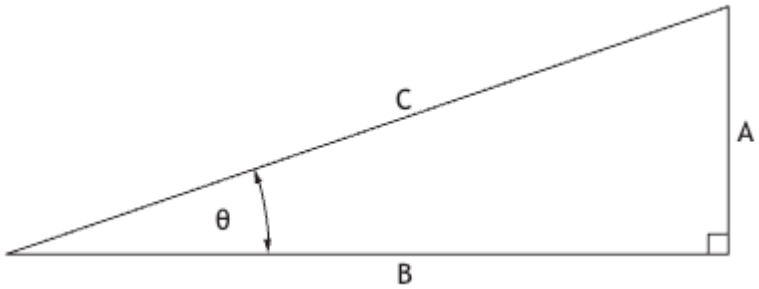
1. Question 1
    a. $\mathrm{C} = \sqrt{4.3^2 + 11.25^2} = 12.04\text{’}$
2. Question 2
    a. $\mathrm{A} = \sqrt{14.8^2 - 11.25^2} = 9.62\ \mathrm{m}$
3. Question 3
    a. $\mathrm{B} = \sqrt{1.8^2 - 0.75^2} = 1.64\ \mathrm{m}$
4. Question 4
    a. $\mathrm{C} = \sqrt{9^2 + 28^2} = 29.41\text{’}$
5. Question 5
    a. $\mathrm{A} = \sqrt{4.75^2 - 2.25^2} = 4.18\text{’}$
6. Question 6
    a. $\mathrm{B} = \sqrt{17^2 - 6.5^2} = 15.71\ \mathrm{cm}$
7. Question 7
    a. $\mathrm{C} = \sqrt{7.5^2 + 2.75^2} = 7.99\text{’}$
8. Question 8
    a. $\mathrm{A} = \sqrt{12.9^2 - 9.6^2} = 8.62\ \mathrm{m}$
9. Question 9
    a. $\mathrm{A} = \sqrt{42^2 - 7^2} = 41.41\text{”}$
10. Question 10
    a. $\mathrm{B} = \sqrt{104^2 - 77^2} = 69.9\ \mathrm{mm}$

Self-Test C-1.9.1: Calculate Offsets Using the Applicable Trigonometric Function

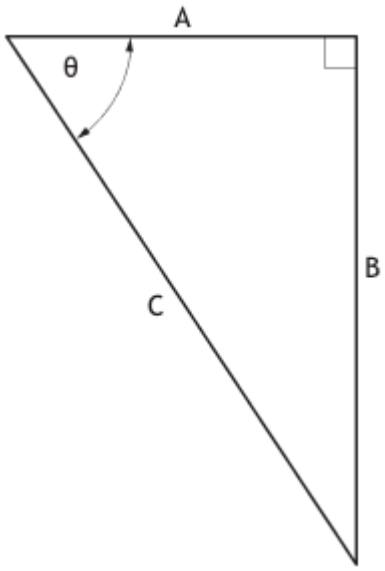
Complete Self-Test C-1.9.1 and check your answers.



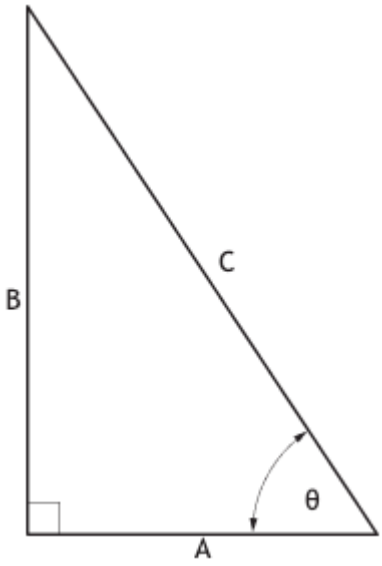
1. Question 1
    a. Adjacent side: _____
    b. Opposite side: _____



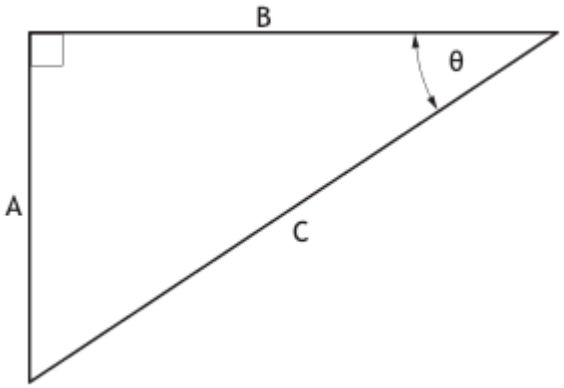
2. Question 2
    a. Adjacent side: _____
    b. Opposite side: _____



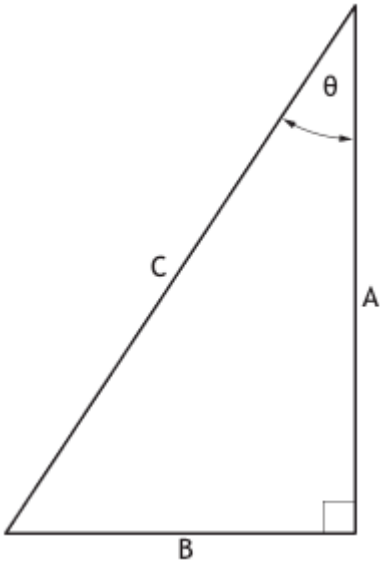
3. Question 3
    a. Adjacent side: _____
    b. Opposite side: _____



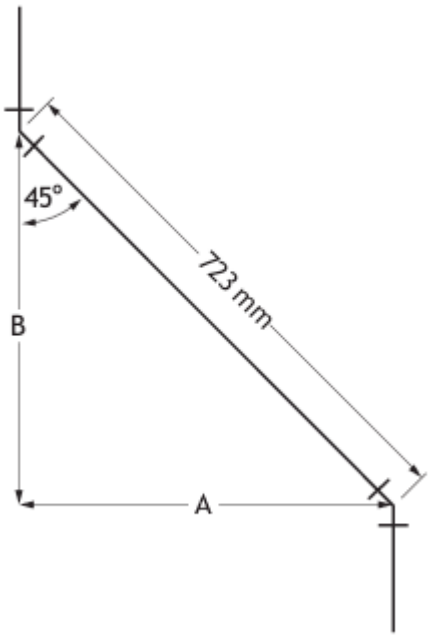
4. Question 4
    a. Adjacent side:
    b. Opposite side:



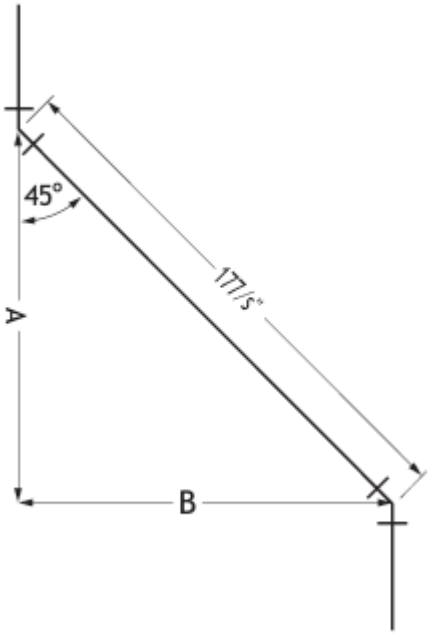
5. Question 5
    a. Adjacent side: _____
    b. Opposite side: _____



6. Question 6
    a. Adjacent side: _____
    b. Opposite side: _____



7. Question 7
    a. Adjacent side: _____
    b. Opposite side: _____



8. Question 8
    a. Adjacent side: _____
    b. Opposite side: _____

Answer Key: Self-Test C-1.9.1 is on the other page.

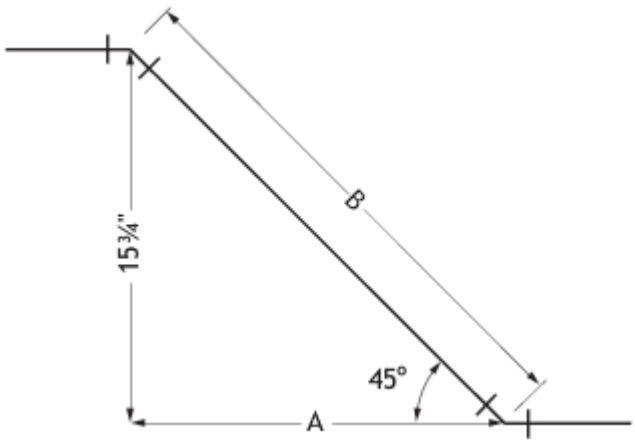
Answer Key: Self-Test C-1.9.1

1. Question 1
    a. Adjacent Side: A
    b. Opposite Side: B
2. Question 2
    a. Adjacent Side: B
    b. Opposite Side: A
3. Question 3
    a. Adjacent Side: A
    b. Opposite Side: B
4. Question 4
    a. Adjacent Side: A
    b. Opposite Side: B
5. Question 5
    a. Adjacent Side: B
    b. Opposite Side: A
6. Question 6
    a. Adjacent Side: A
    b. Opposite Side: B
7. Question 7
    a. Adjacent Side: B
    b. Opposite Side: A
8. Question 8
    a. Adjacent Side: A
    b. Opposite Side: B

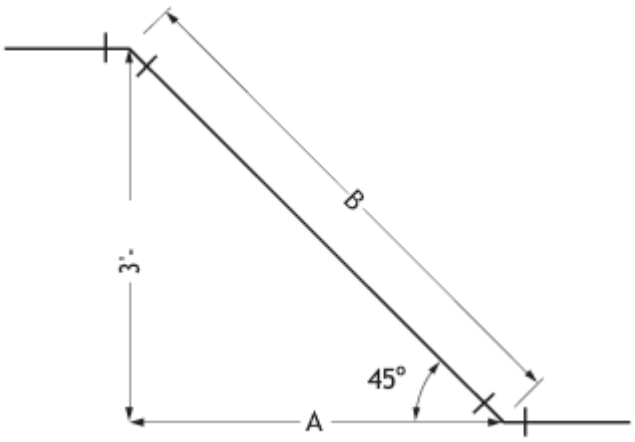
Self-Test C-1.9.2: Calculate Offsets Using the Applicable Trigonometric Function

Complete Self-Test C-1.9.2 and check your answers.

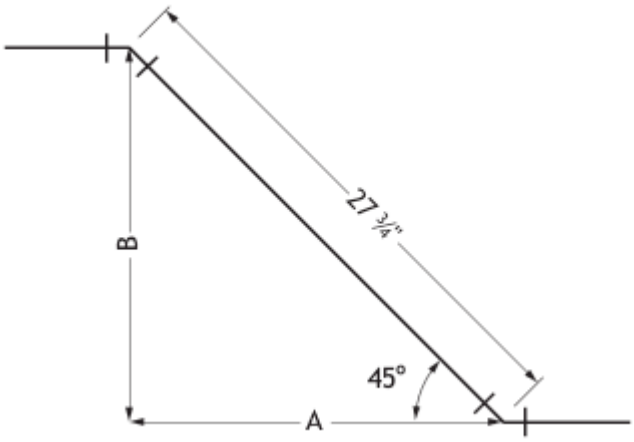
Using trigonometry, solve for the unknown lengths for the following 45° piping offsets. Express your answers to the nearest $\frac{1}{8}$" or 0.1 mm, as required.



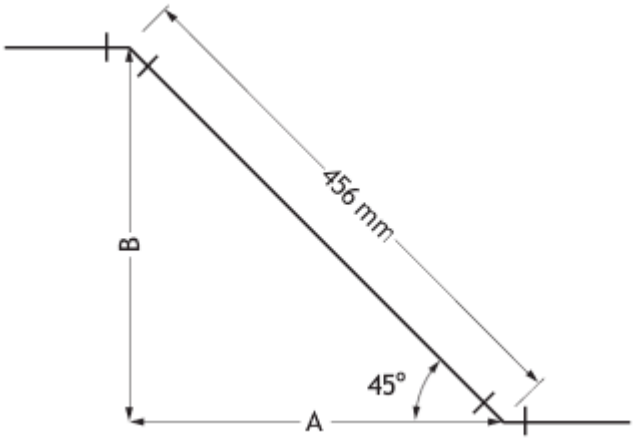
1. Question 1
    a. A = _____
    b. B = _____



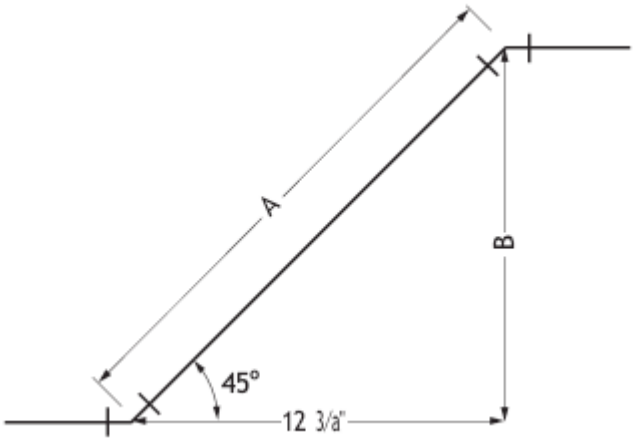
2. Question 2
    a. A = _____
    b. B = _____



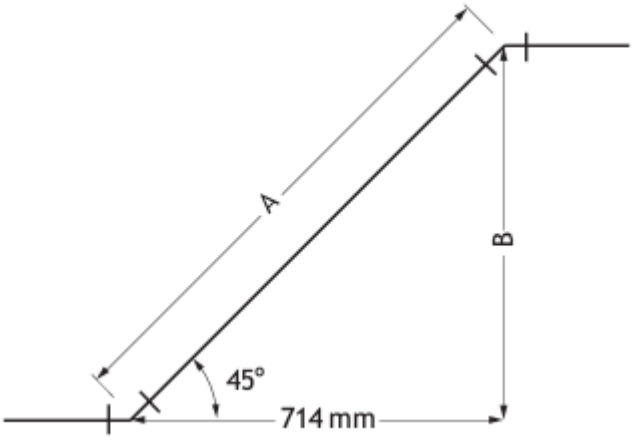
3. Question 3
    a. A = _____
    b. B = _____



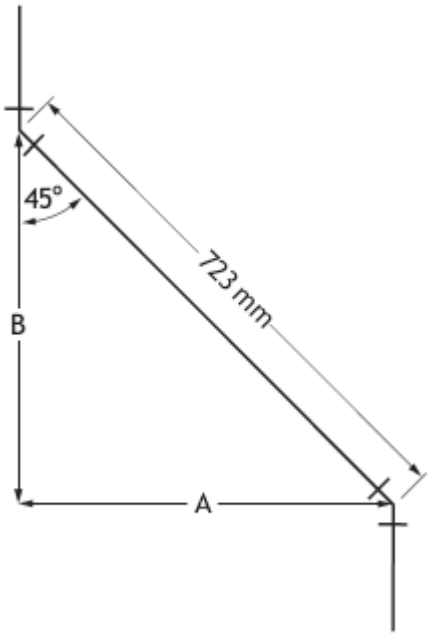
4. Question 4
    a. A = _____
    b. B = _____



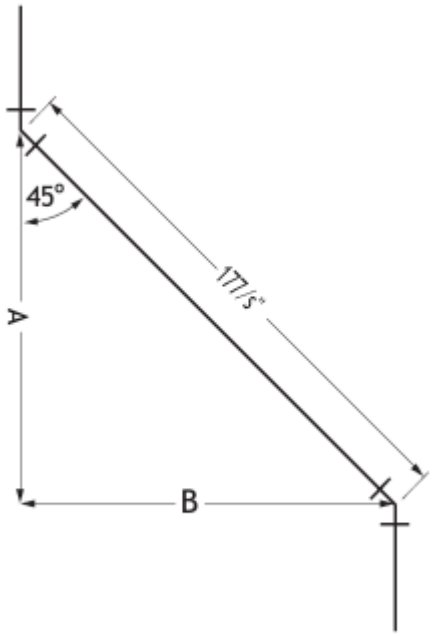
5. Question 5
    a. A = _____
    b. B = _____



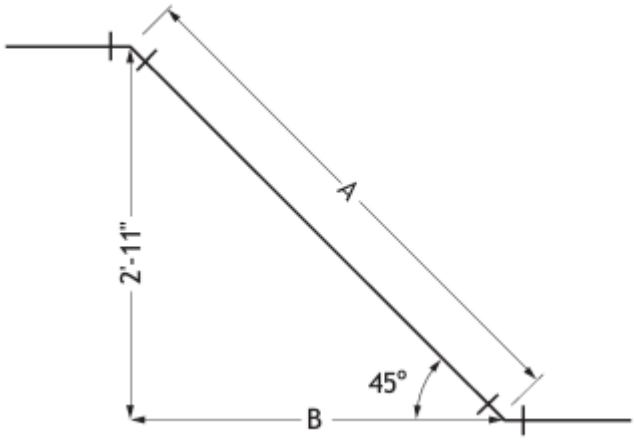
6. Question 6
    a. A = _____
    b. B = _____



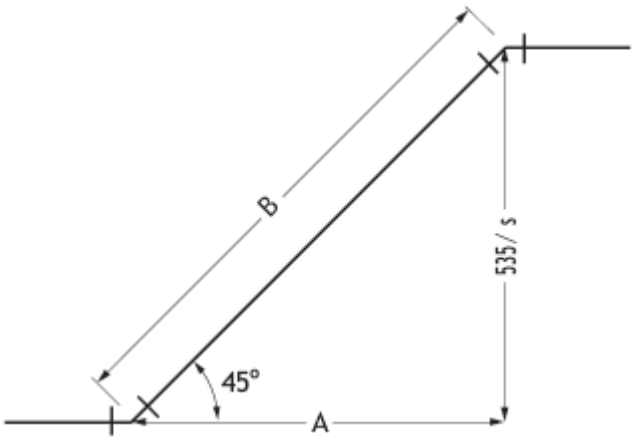
7. Question 7
    a. A = _____
    b. B = _____



8. Question 8
    a. A = _____
    b. B = _____



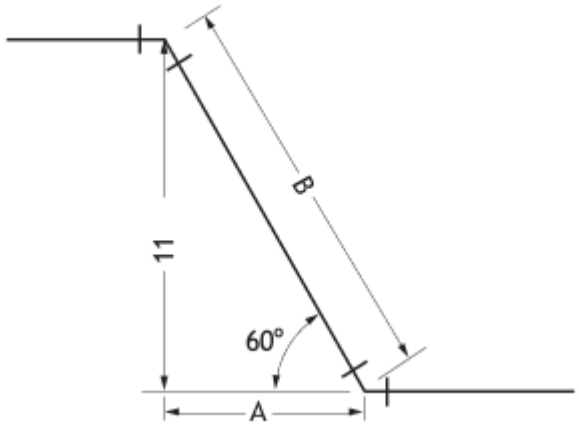
9. Question 9
    a. A = _____
    b. B = _____



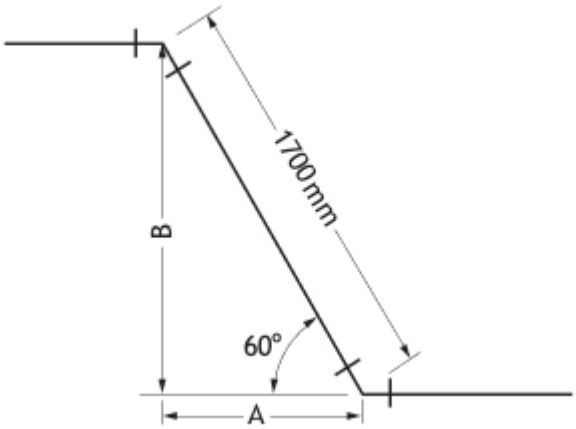
10. Question 10
    a. A = _____
    b. B = _____

image

Using trigonometry, solve for the unknown lengths for the following 60° piping offsets. Express your answers to the nearest $\frac{1}{8}$", or 0.1 mm, as required.



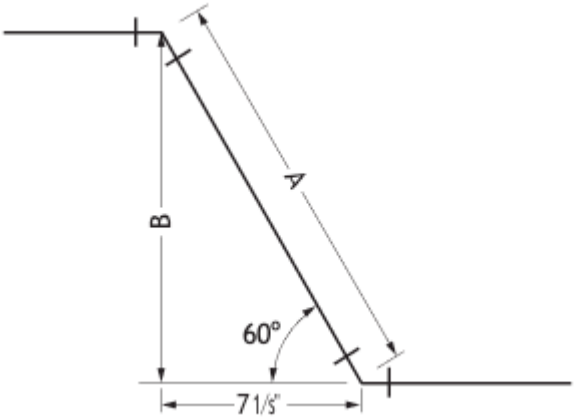
11. Question 11
    a. A = _____
    b. B = _____



12. Question 12

    a. A = _____

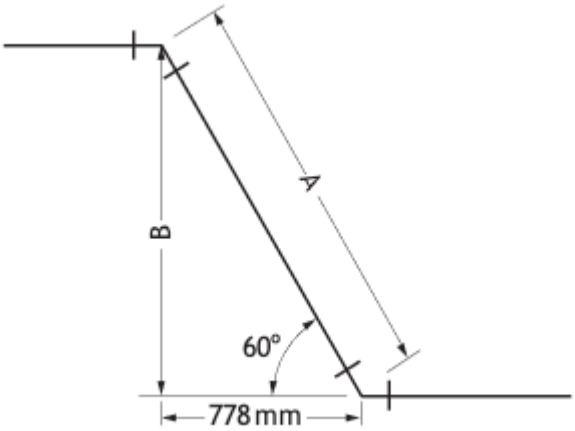
    b. B = _____



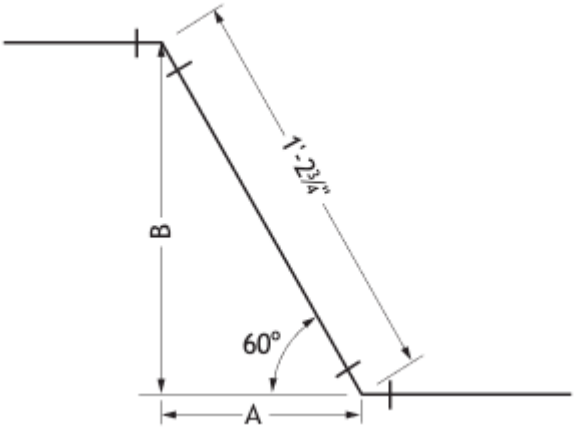
13. Question 13

    a. A = _____

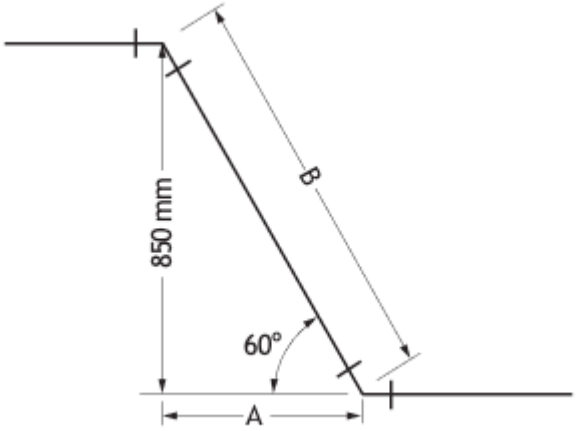
    b. B = _____



14. Question 14
    a. A = _____
    b. B = _____

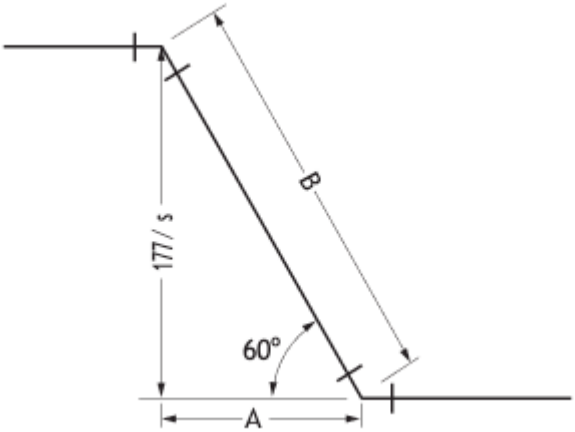


15. Question 15
    a. A = _____
    b. B = _____



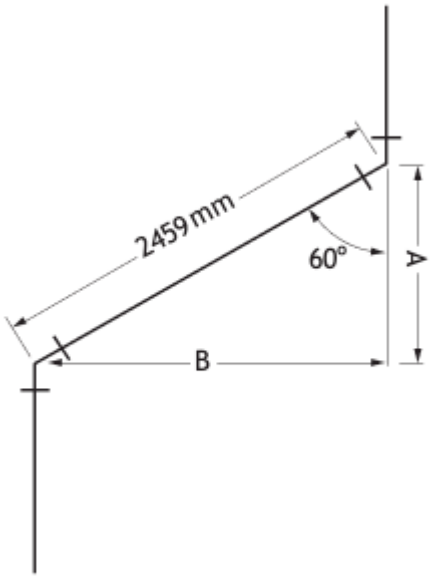
16. Question 16

    a. A = _____
    b. B = _____



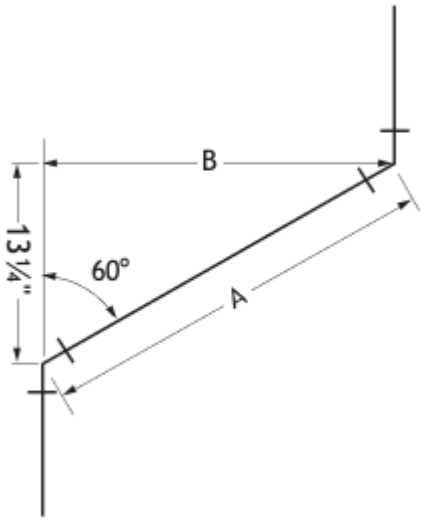
17. Question 17

a. A = _____
b. B = _____

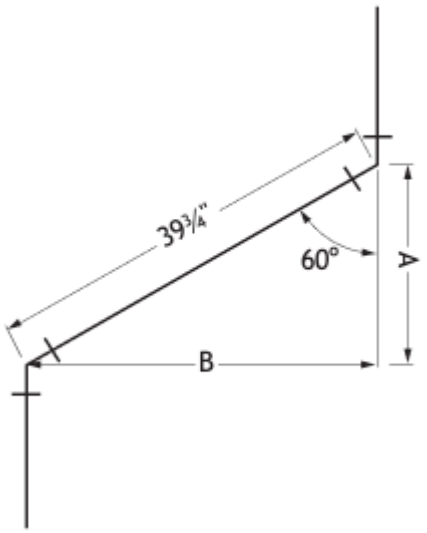


18. Question 18

a. A = _____
b. B = _____



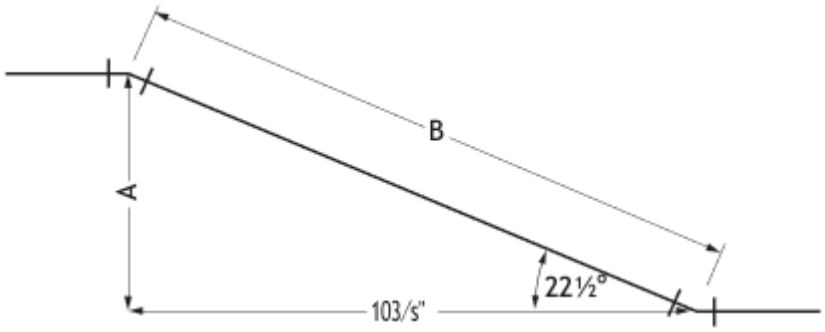
19. Question 19
    a. A = _____
    b. B = _____



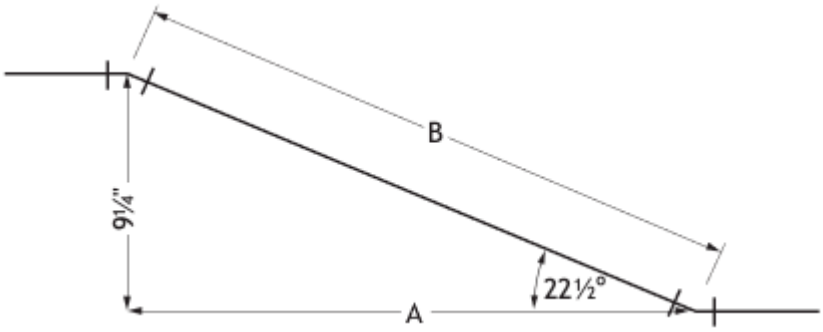
20. Question 20
    a. A = _____
    b. B = _____

image

Using trigonometry, solve for the unknown lengths for the following $22\frac{1}{2}$° piping offsets. Express your answers to the nearest $\frac{1}{8}$" or 0.1 mm, as required.

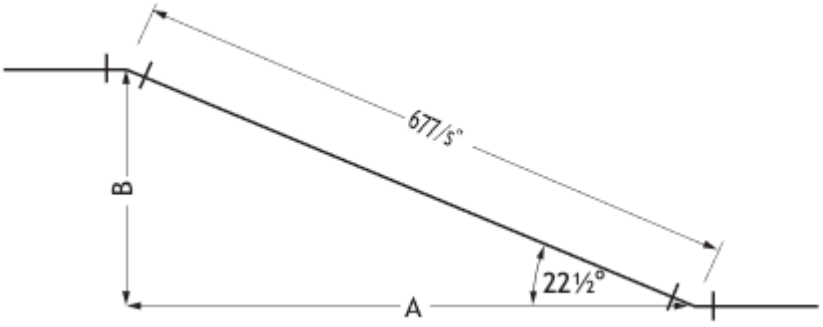


21. Question 21
    a. A = _____
    b. B = _____



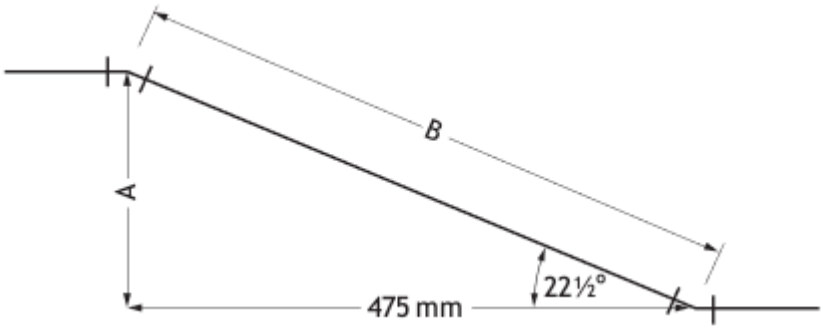
22. Question 22

    a. A = _____
    b. B = _____



23. Question 23

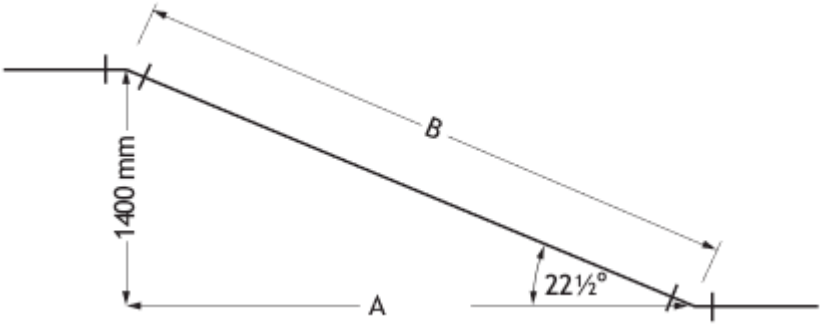
    a. A = _____
    b. B = _____



24. Question 24

    a. A = _____

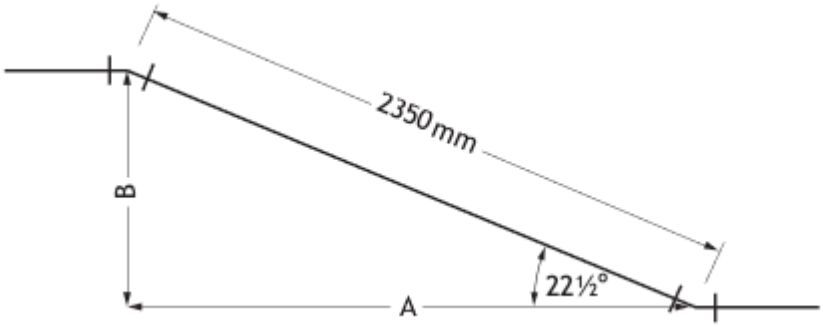
    b. B = _____



25. Question 25

    a. A = _____

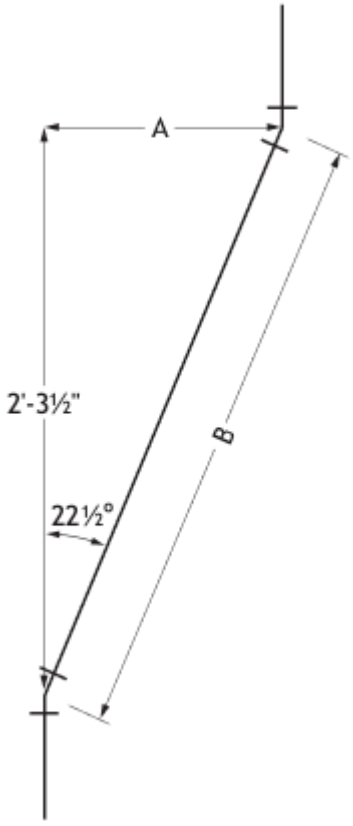
    b. B = _____



26. Question 26

    a. A = _____

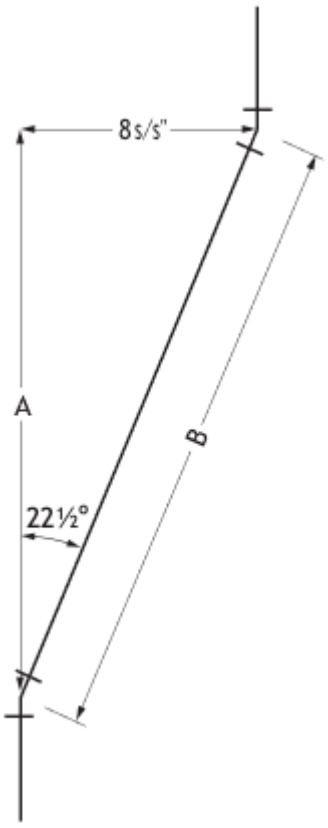
    b. B = _____



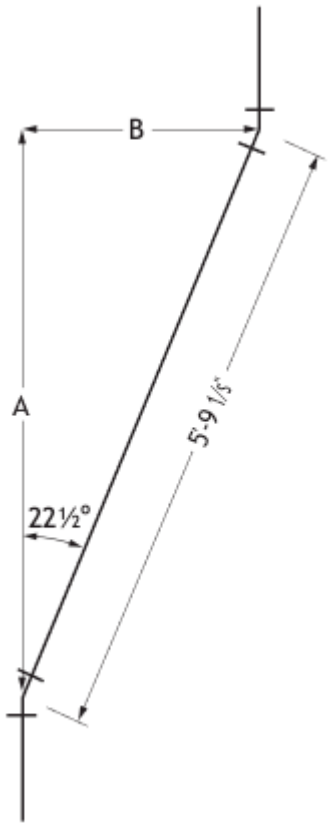
27. Question 27

    a. A = _____

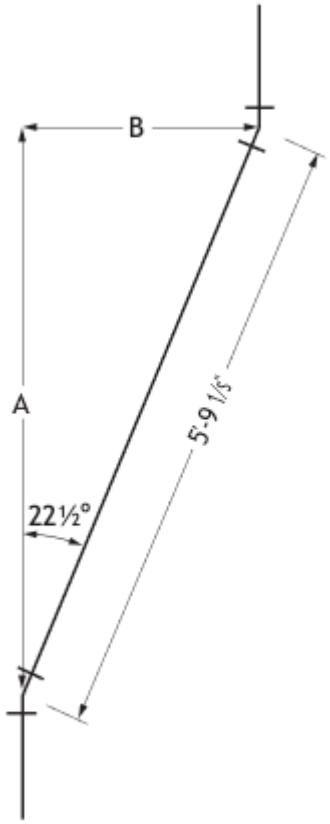
    b. B = _____



28. Question 28
    a. A = _____
    b. B = _____



29. Question 29
    a. A = _____
    b. B = _____



30. Question 30

    a. A = _____
    b. B = _____

image

Answer Key: Self-Test C-1.9.2 is on the other page.

Answer Key: Self-Test C-1.9.2

1. Question 1
   a. A = $15\frac{3}{4}$"
   b. B = $22\frac{1}{4}$"
2. Question 2
   a. A = $45\frac{1}{8}$"
   b. B = $63\frac{3}{4}$"
3. Question 3
   a. A = $19\frac{5}{8}$"
   b. B = $19\frac{5}{8}$"
4. Question 4
   a. A = 322.5 mm
   b. B = 322.5 mm
5. Question 5
   a. A = $17\frac{1}{2}$"
   b. B = $12\frac{3}{8}$"
6. Question 6
   a. A = $1,009.6$ mm
   b. B = 714 mm
7. Question 7
   a. A = 511.2 mm
   b. B = 511.2 mm
8. Question 8
   a. A = $12\frac{5}{8}$"

b. B = $12\frac{5}{8}$”

9. Question 9

a. A = $49\frac{1}{2}$”

b. B = 35”

10. Question 10

a. A = $53\frac{5}{8}$”

b. B = $75\frac{7}{8}$”

11. Question 11

a. A = $6\frac{7}{8}$”

b. B = $13\frac{3}{4}$”

12. Question 12

a. A = 850 mm

b. B = $1,472.2$ mm

13. Question 13

a. A = $14\frac{1}{4}$”

b. B = $12\frac{3}{8}$”

14. Question 14

a. A = $1,556$ mm

b. B = $1,347.5$ mm

15. Question 15

a. A = $7\frac{3}{8}$”

b. B = $12\frac{3}{4}$”

16. Question 16

a. A = 490.7 mm

b. B = 981.5 mm

17. Question 17

a. A = $10\frac{3}{8}$”

b. B = $20\frac{5}{8}$”

18. Question 18

a. A = $1,229.5 \text{ mm}$

b. B = $2,129.6 \text{ mm}$

19. Question 19

a. A = $26\frac{1}{2}$”

b. B = 23”

20. Question 20

a. A = $19\frac{7}{8}$”

b. B = $34\frac{3}{8}$”

21. Question 21

a. A = $4\frac{1}{4}$”

b. B = $11\frac{1}{4}$”

22. Question 22

a. A = $22\frac{3}{8}$”

b. B = $24\frac{1}{8}$”

23. Question 23

a. A = $62\frac{3}{4}$”

b. B = 26”

24. Question 24

a. A = 196.8 mm

b. B = 514.1 mm

25. Question 25

a. A = $3,379.9 \text{ mm}$

b. B = $3,658.4 \text{ mm}$

26. Question 26

a. A = $2,171.1 \text{ mm}$

b. B = 899.3 mm

27. Question 27

a. A = $11\frac{3}{8}$”

b. B = $29\frac{3}{4}$”

28. Question 28

a. A = $20\frac{7}{8}$”

b. B = $22\frac{1}{2}$”

29. Question 29

a. A = $63\frac{7}{8}$”

b. B = $26\frac{1}{2}$”

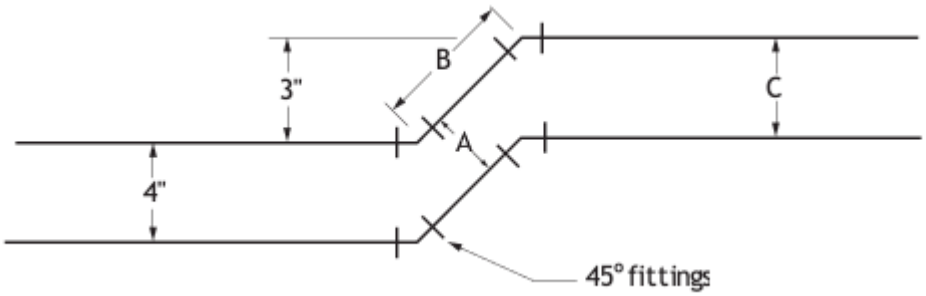
30. Question 30

a. A = 475.8 mm

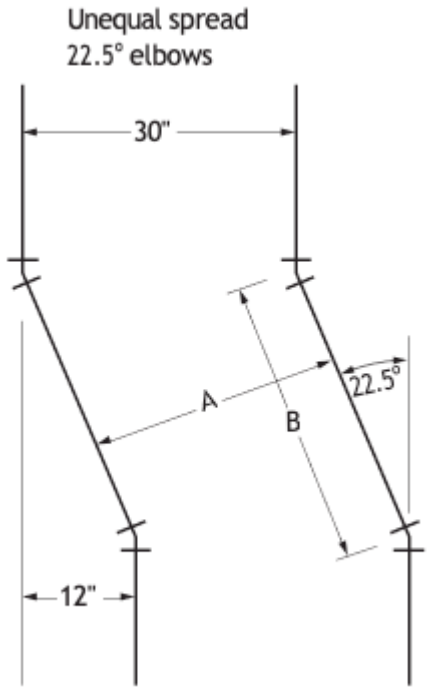
b. B = 197.1 mm

Self-Test C-1.10.1: Calculate Required Measurements for Piping Offsets

Complete Self-Test C-1.10.1 and check your answers.

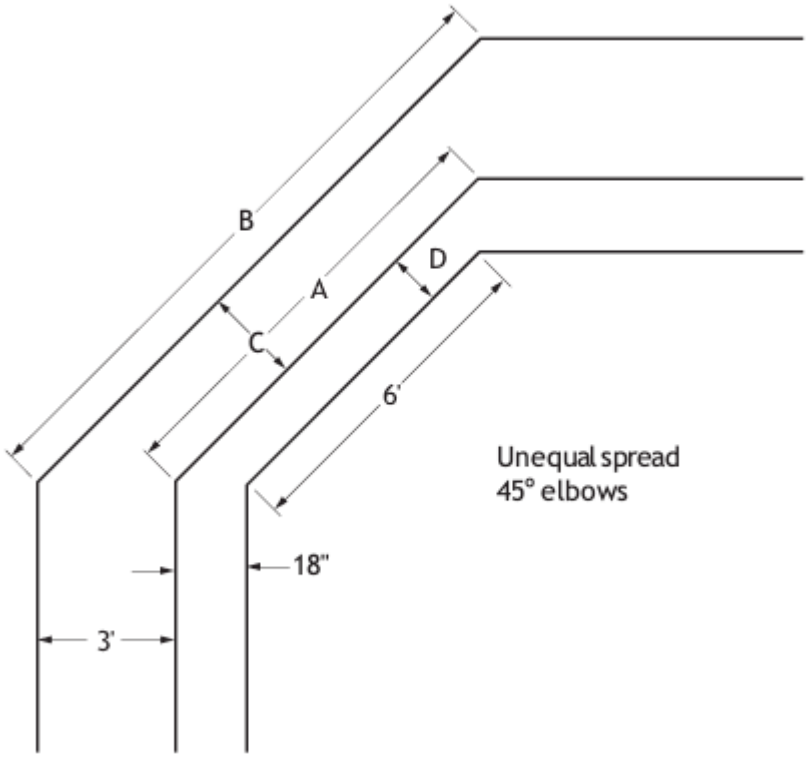


1. Question 1
    a. A = _____
    b. B = _____
    c. C = _____



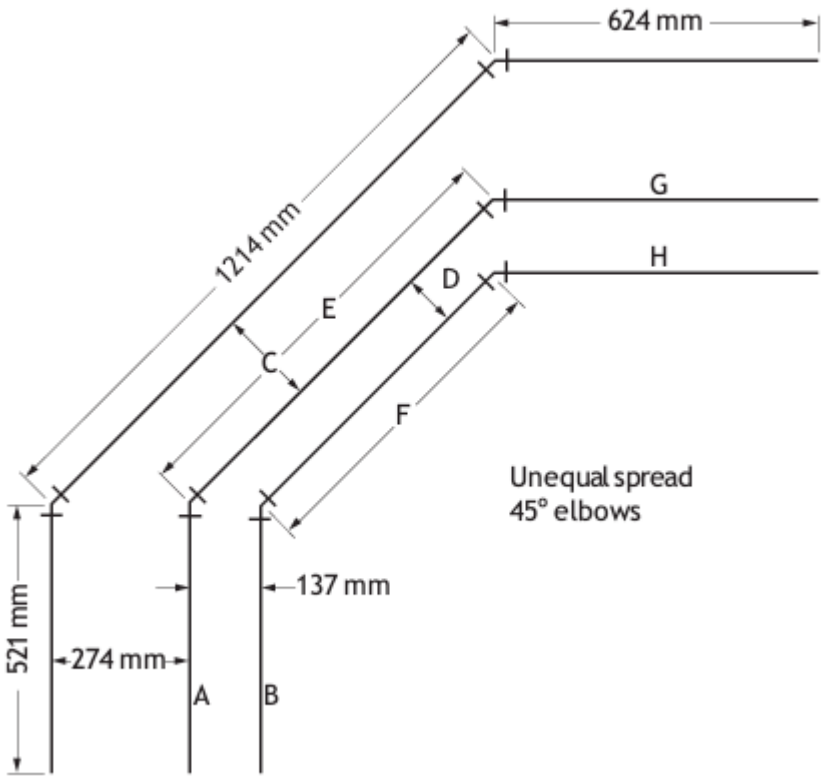
2. Question 2

a. A = _____
b. B = _____



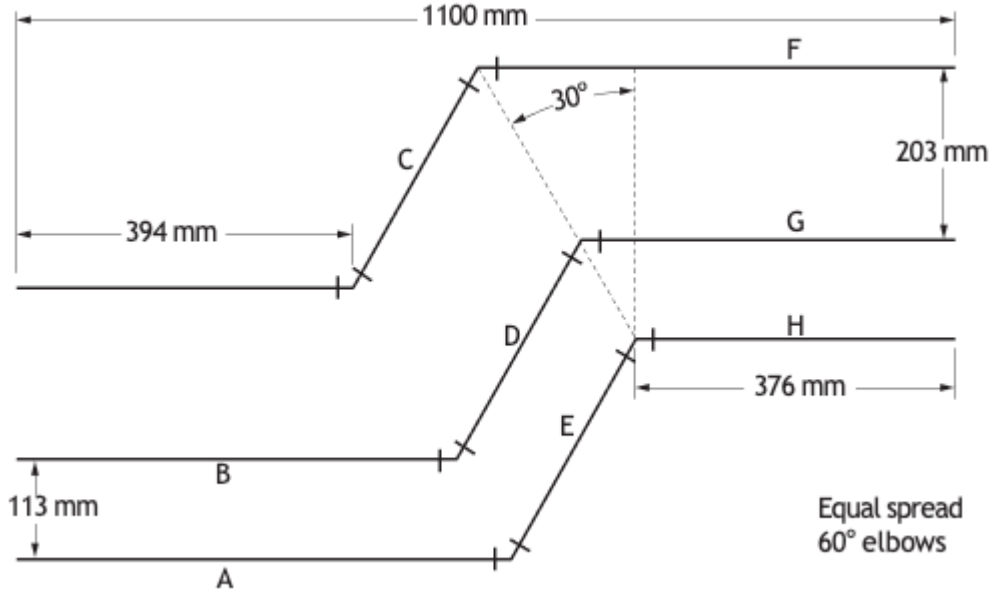
3. Question 3

a. A = _____
b. B = _____
c. C = _____
d. D = _____

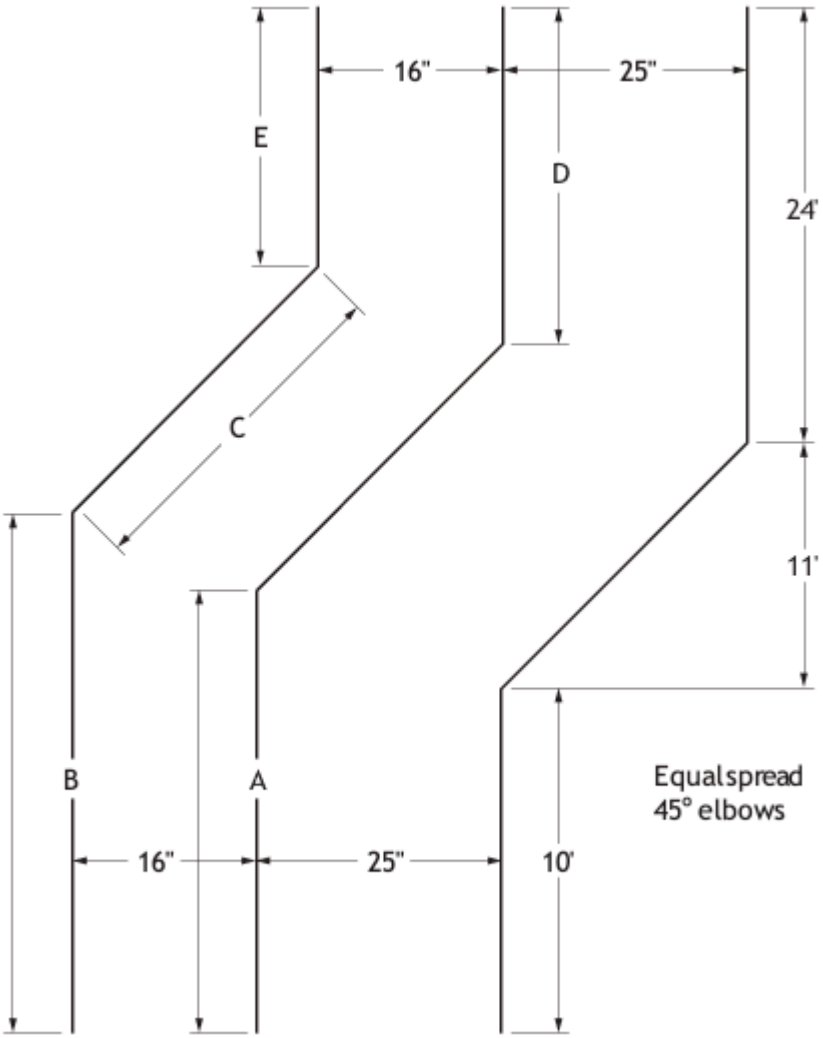


4. Question 4

   a. A = _____
   b. B = _____
   c. C = _____
   d. D = _____
   e. E = _____
   f. F = _____
   g. G = _____
   h. H = _____

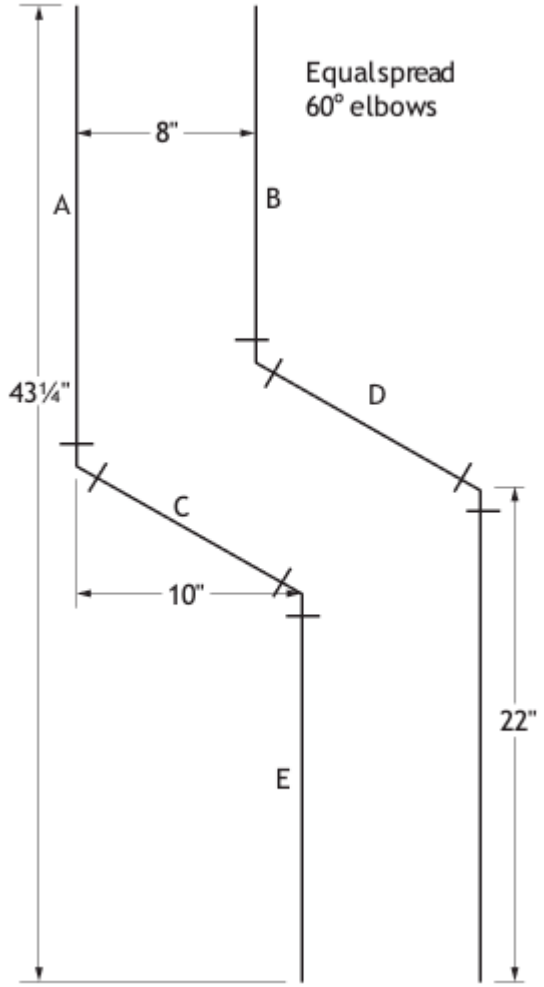


5. Question 5
    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____
    f. F = _____
    g. G = _____
    h. H = _____



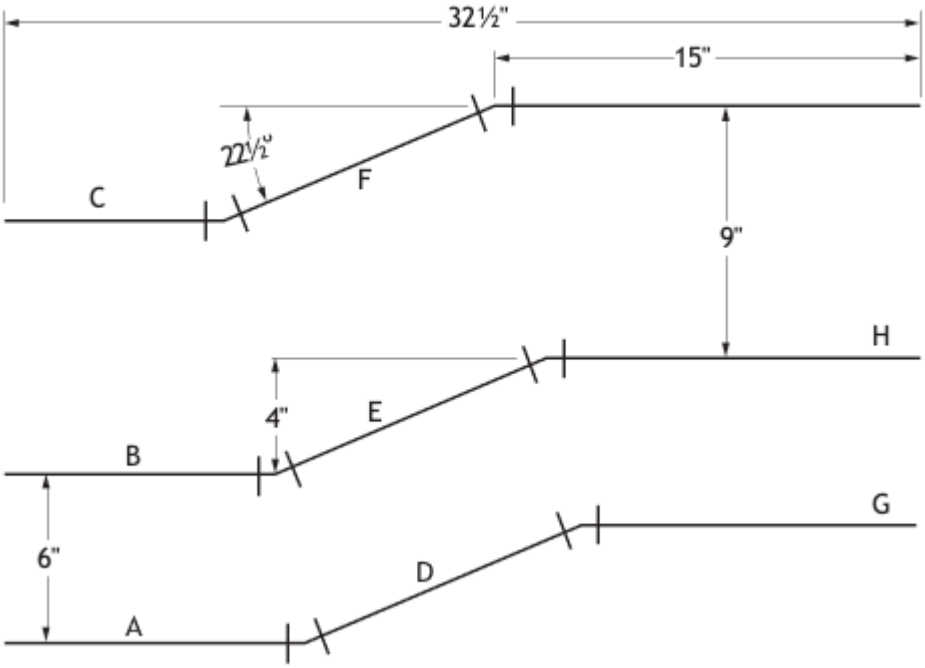
6. Question 6

   a. A = _____
   b. B = _____
   c. C = _____
   d. D = _____
   e. E = _____

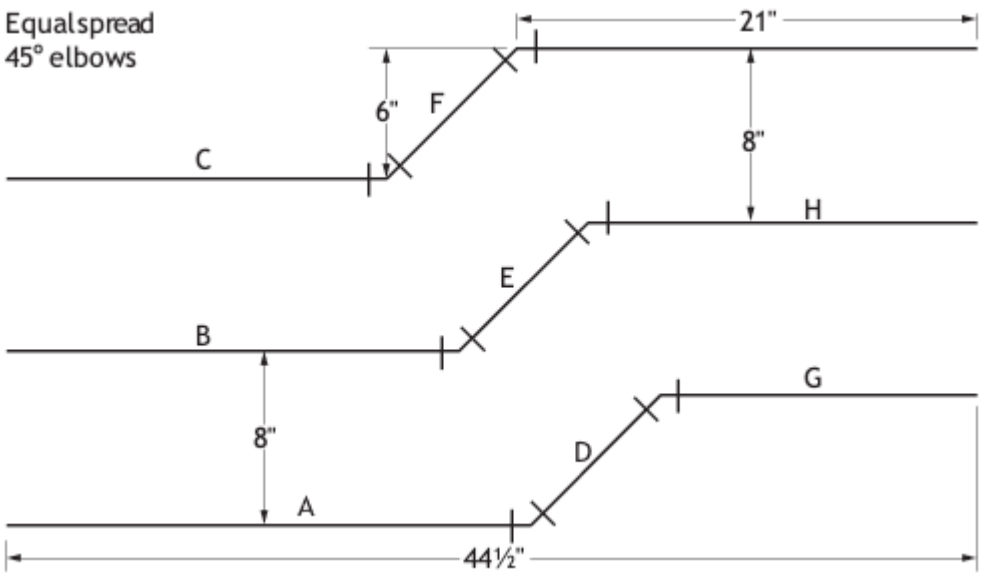


7. Question 7
    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____

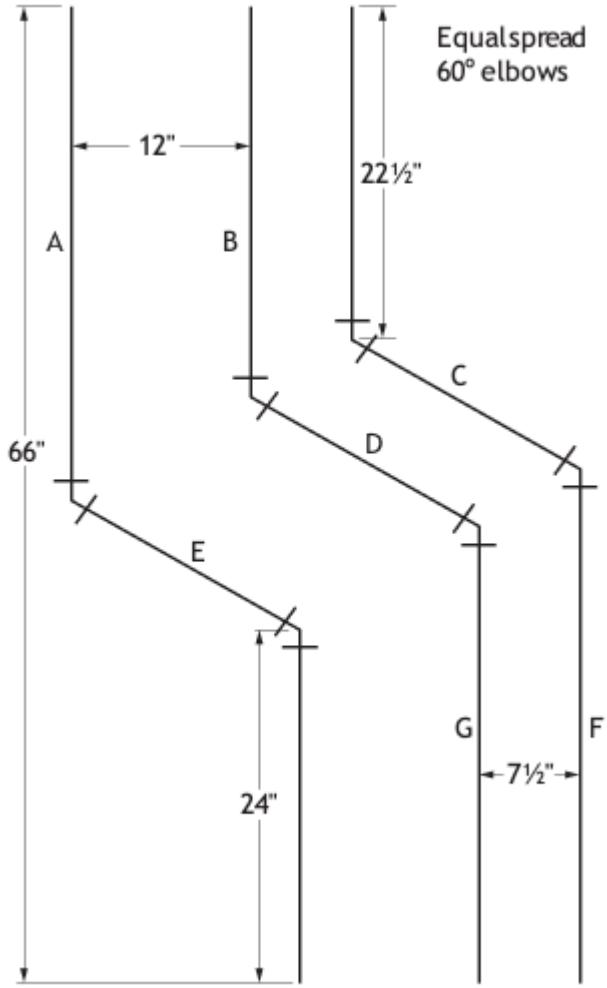
Equal spread 22½° elbows



8. Question 8
    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____
    f. F = _____
    g. G = _____
    h. H = _____

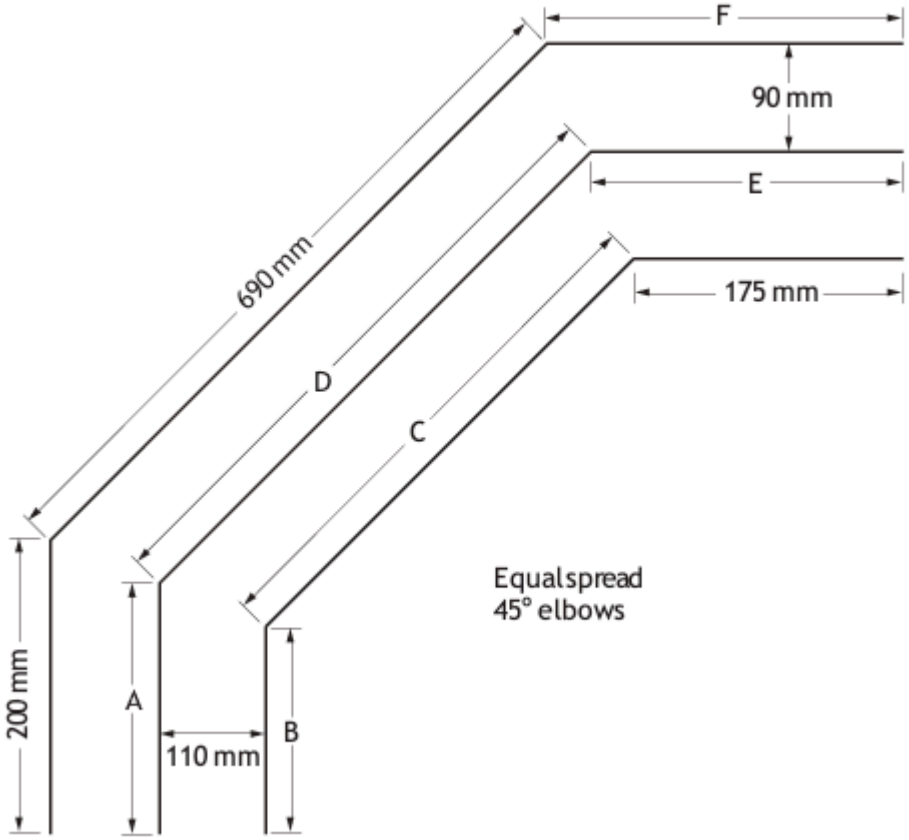


9. Question 9
    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____
    f. F = _____
    g. G = _____
    h. H = _____



10. Question 10

    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____
    f. F = _____
    g. G = _____



11. Question 11

    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____
    f. F = _____

Answer Key: Self-Test C-1.10.1 is on the other page.

Answer Key: Self-Test C-1.10.1

1. Question 1
    a. A = $2\frac{7}{8}$”
    b. B = $4\frac{1}{4}$”
    c. C = 4”
2. Question 2
    a. A = $27\frac{3}{4}$”
    b. B = $31\frac{3}{8}$”
3. Question 3
    a. A = $97\frac{1}{2}$”
    b. B = $148\frac{1}{2}$”
    c. C = $25\frac{1}{2}$”
    d. D = $12\frac{3}{4}$”
4. Question 4
    a. A = 521 mm
    b. B = 521 mm
    c. C = 193.8 mm
    d. D = 96.9 mm
    e. E = 826.4 mm
    f. F = 632.6 mm
    g. G = 624 mm
    h. H = 624 mm
5. Question 5
    a. A = 576.4 mm

b. B = 511.2 mm
c. C = 295.2 mm
d. D = 295.2 mm
e. E = 295.2 mm
f. F = 558.4 mm
g. G = 441.2 mm
h. H = 376 mm

6. Question 6

a. A = $130\frac{3}{8}$"
b. B = $136\frac{7}{8}$"
c. C = $186\frac{1}{2}$"
d. D = $277\frac{5}{8}$"
e. E = $271\frac{1}{8}$"

7. Question 7

a. A = $20\frac{1}{8}$"
b. B = $15\frac{1}{2}$"
c. C = $11\frac{1}{2}$"
d. D = $11\frac{1}{2}$"
e. E = $17\frac{3}{8}$"

8. Question 8

a. A = $10\frac{3}{4}$"
b. B = $9\frac{1}{2}$"

c. C = $7\frac{3}{4}$"

d. D = $10\frac{1}{2}$"

e. E = $10\frac{1}{2}$"

f. F = $10\frac{1}{2}$"

g. G = $14\frac{3}{8}$"

h. H = $17\frac{5}{8}$"

9. Question 9

a. A = $24\frac{1}{4}$"

b. B = $20\frac{7}{8}$"

c. C = $17\frac{1}{2}$"

d. D = $8\frac{1}{2}$"

e. E = $8\frac{1}{2}$"

f. F = $8\frac{1}{2}$"

g. G = $14\frac{3}{8}$"

h. H = $17\frac{5}{8}$"

10. Question 10

a. A = $33\frac{3}{4}$"

b. B = $26\frac{7}{8}$"

c. C = $16\frac{1}{2}$”

d. D = $16\frac{1}{2}$”

e. E = $16\frac{1}{2}$”

f. F = $35\frac{1}{4}$”

g. G = $30\frac{7}{8}$”

11. Question 11

a. A = 162.7 mm

b. B = 117.2 mm

c. C = 524.3 mm

d. D = 615.4 mm

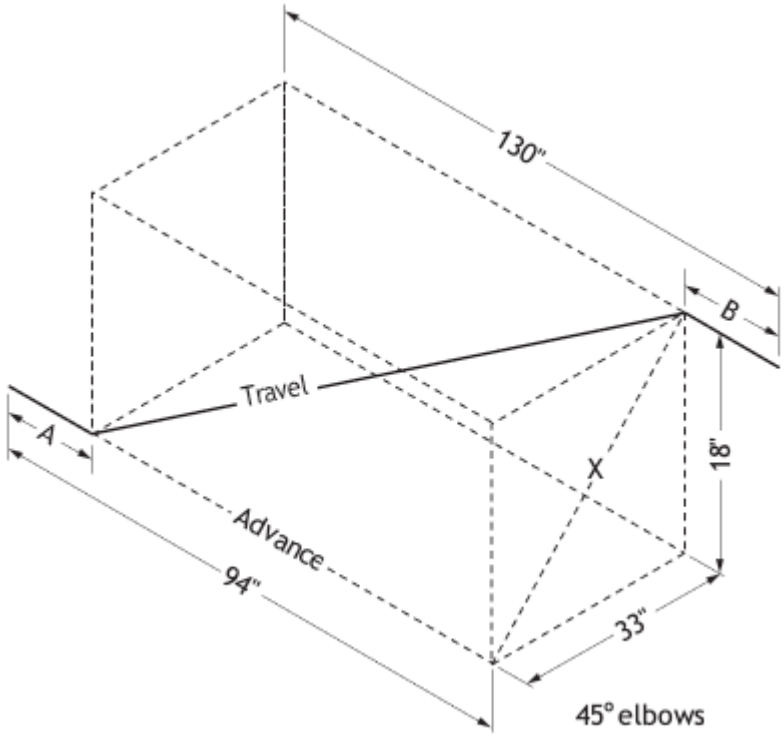
e. E = 220.6 mm

f. F = 257.8 mm

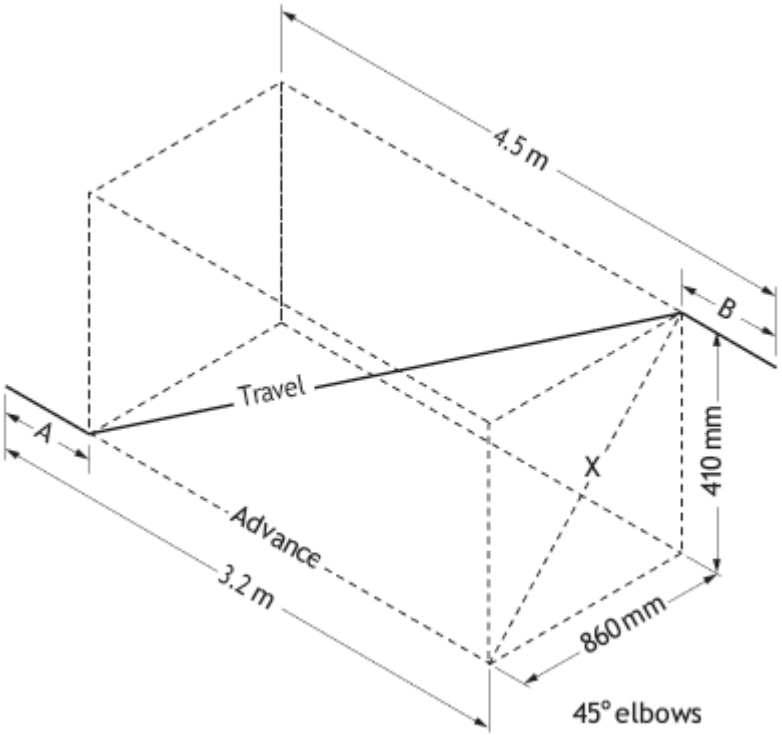
Self-Test C-1.10.2: Calculate Required Measurements for Piping Offsets

Complete Self-Test C-1.10.2 and check your answers.

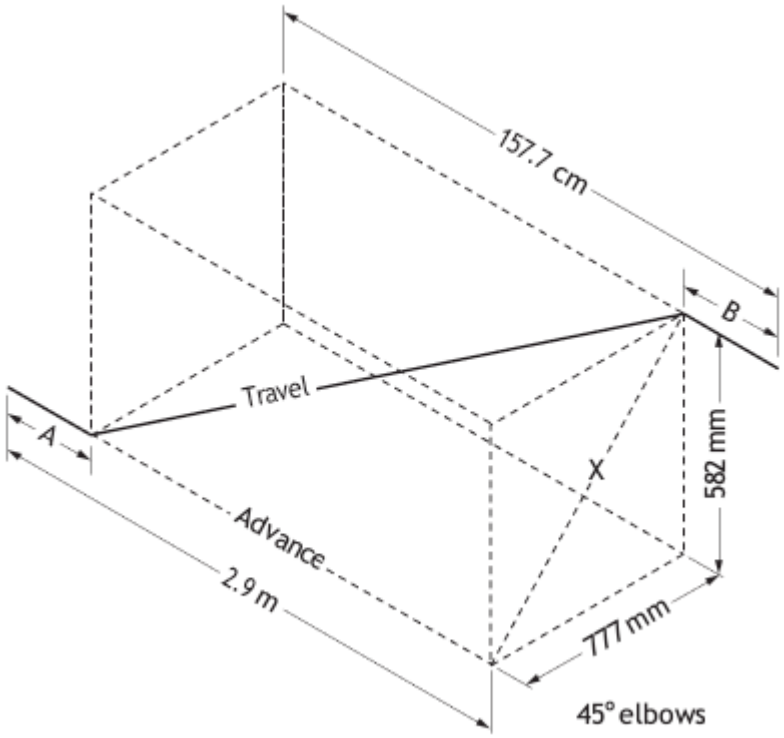
Solve for the lengths indicated. Express your answers to the nearest $\frac{1}{8}$", or $\frac{1}{10}$ mm, as required.



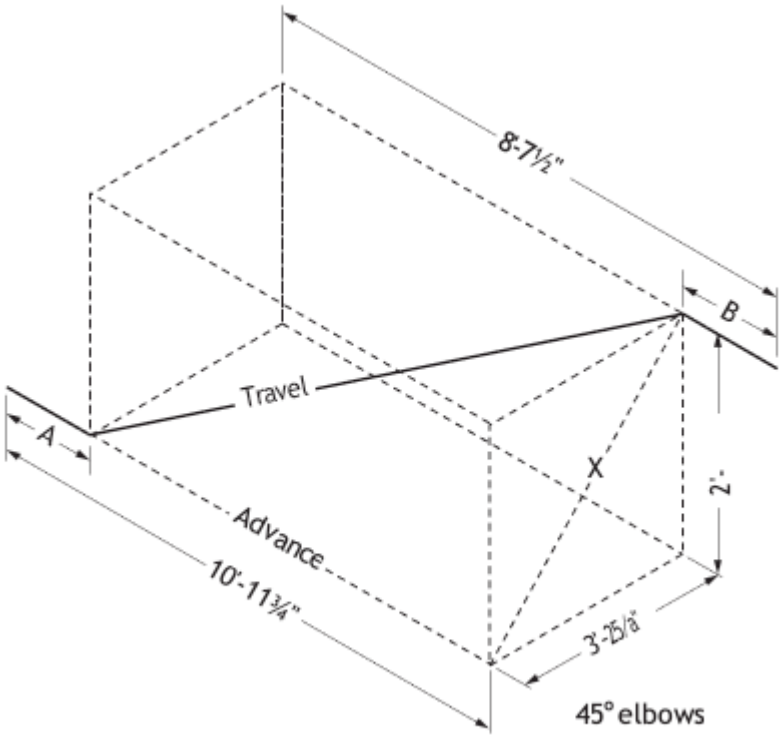
1. Question 1
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



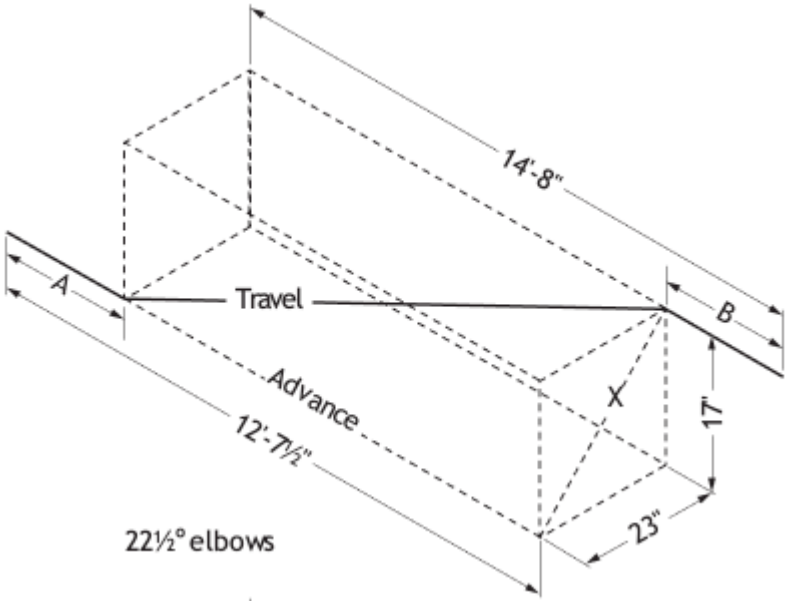
2. Question 2
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



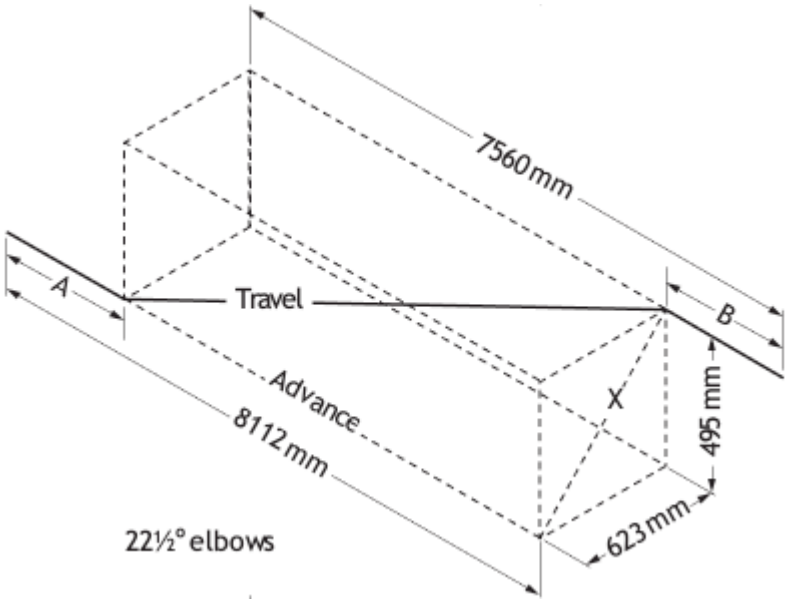
3. Question 3
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



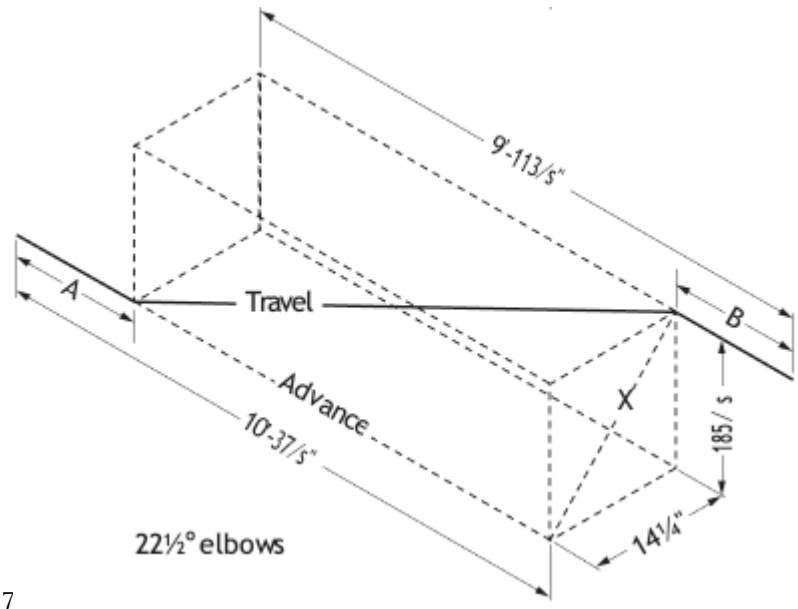
4. Question 4
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



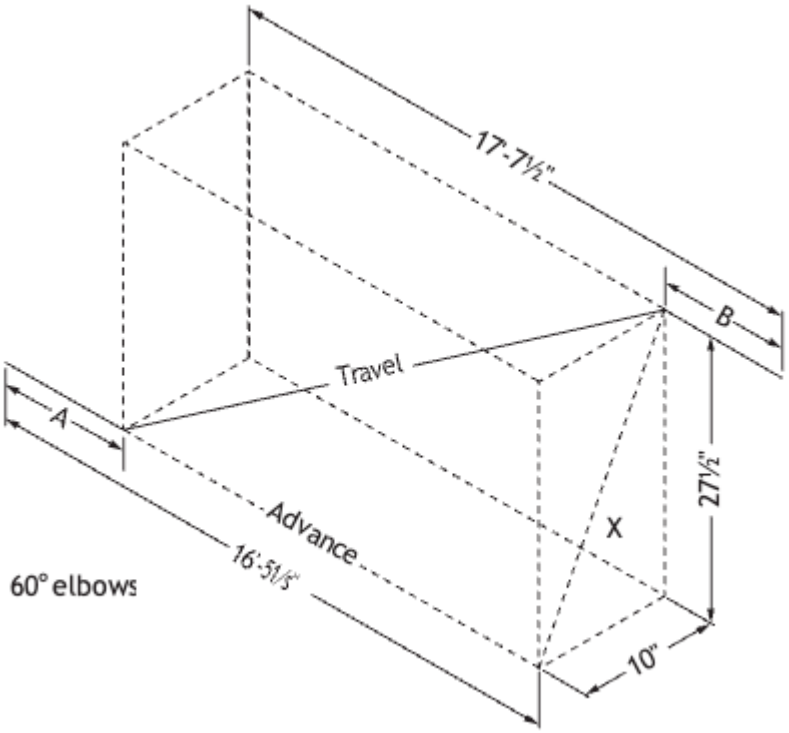
5. Question 5
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



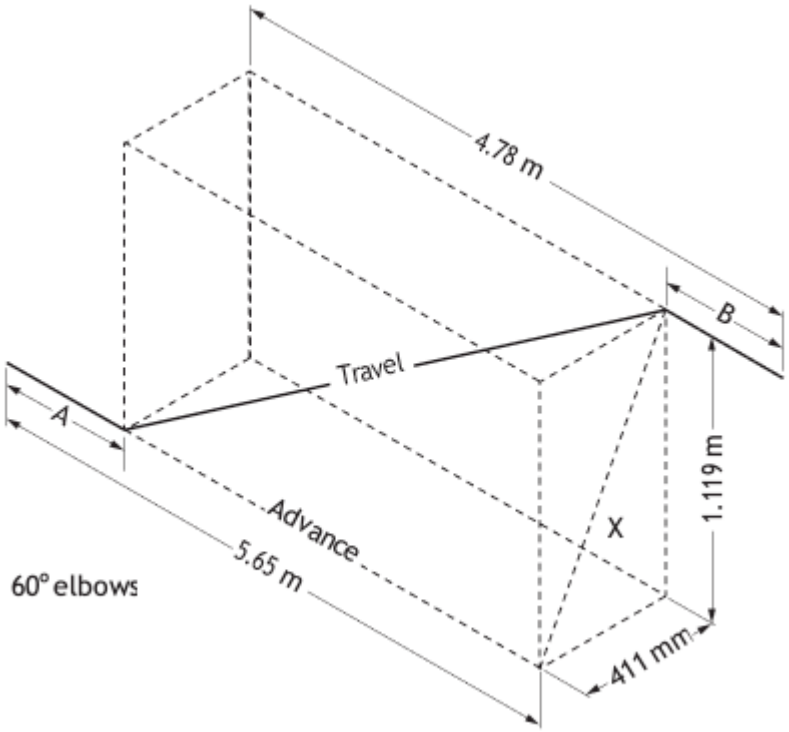
6. Question 6
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



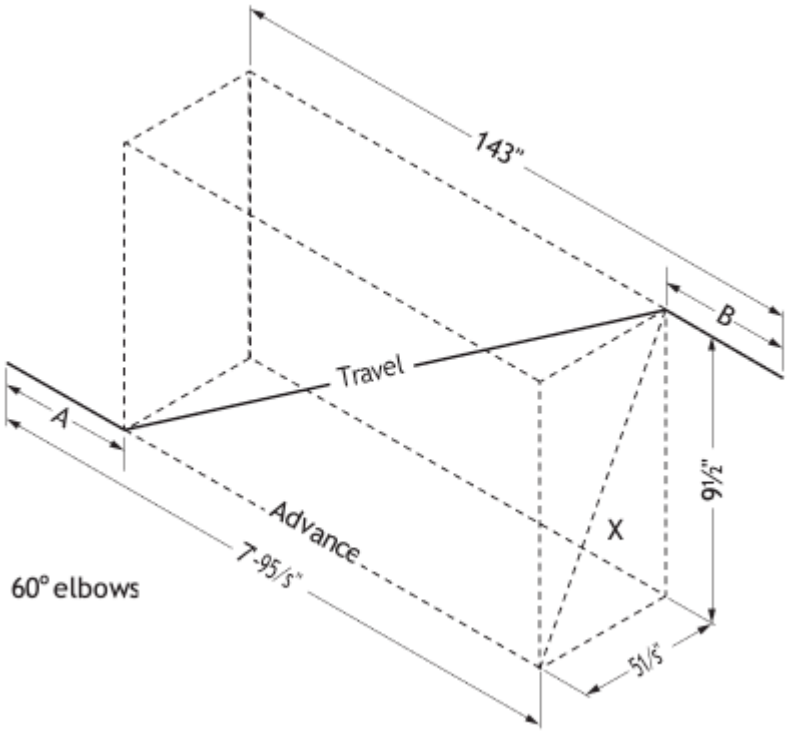
7. Question 7
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



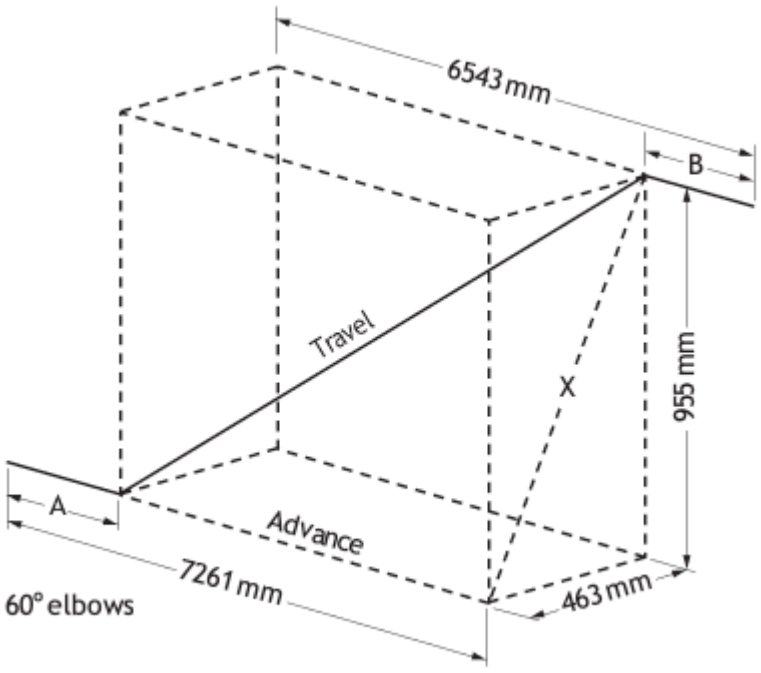
8. Question 8
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



9. Question 9
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____

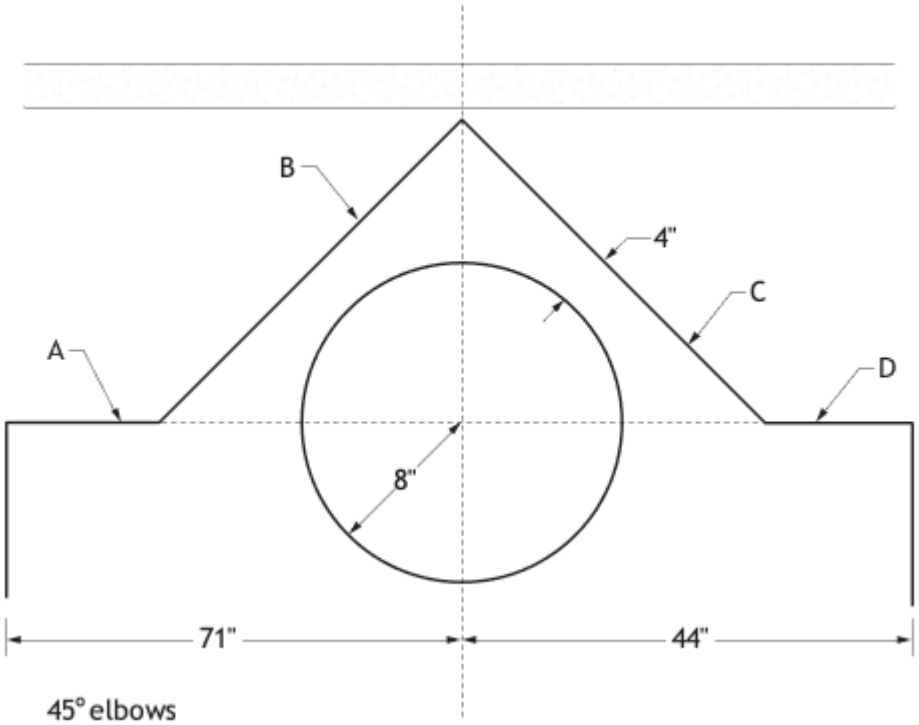


10. Question 10
    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



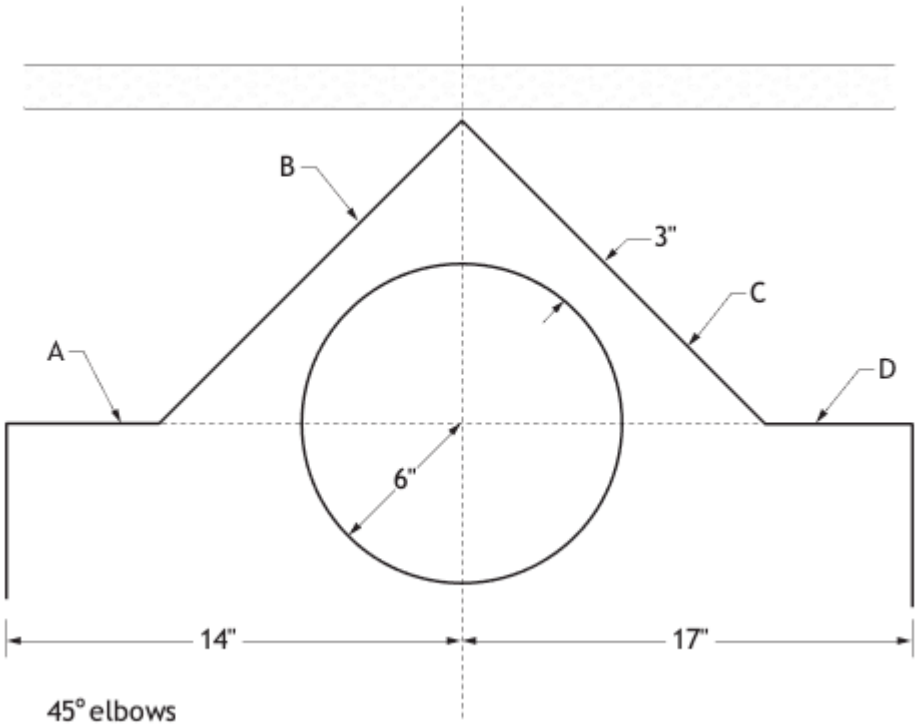
11. Question 11

    a. True offset (X) = _____
    b. Advance = _____
    c. Travel = _____
    d. A = _____
    e. B = _____



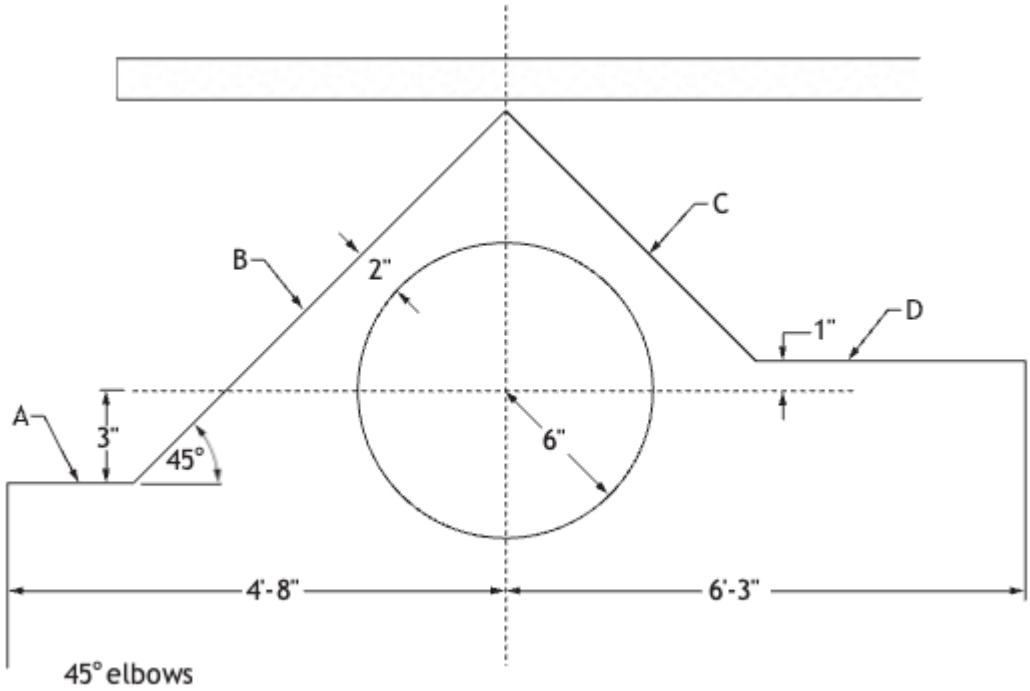
12. Question 12

    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____



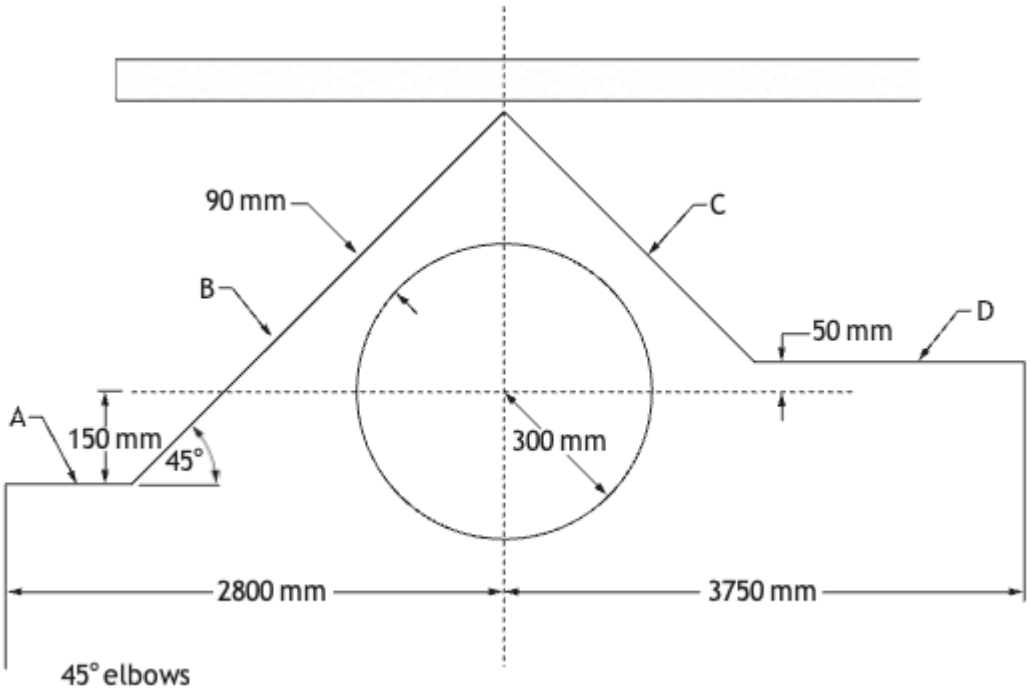
13. Question 13

    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____

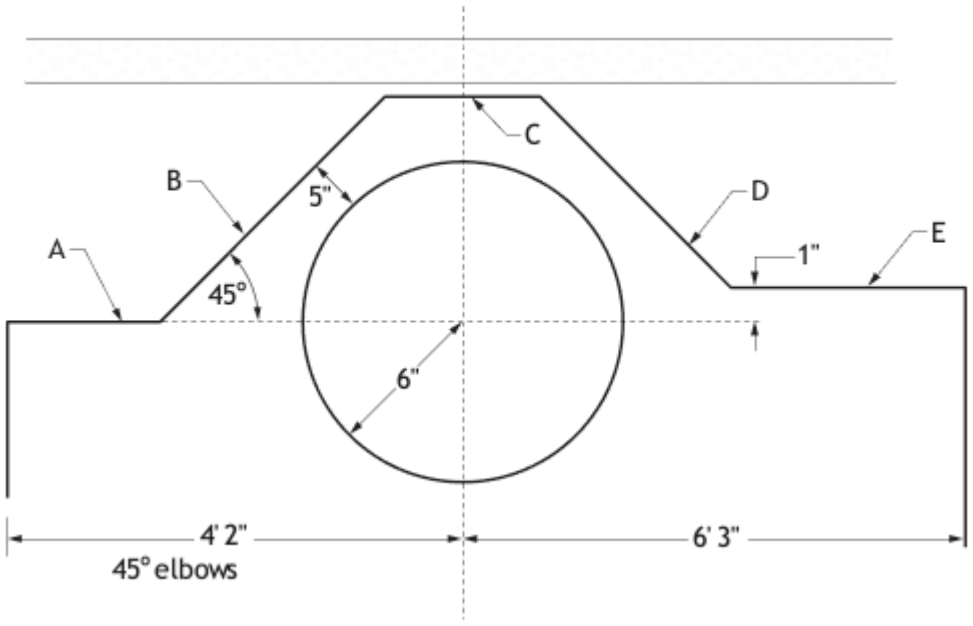


14. Question 14

    a. A = ____
    b. B = ____
    c. C = ____
    d. D = ____

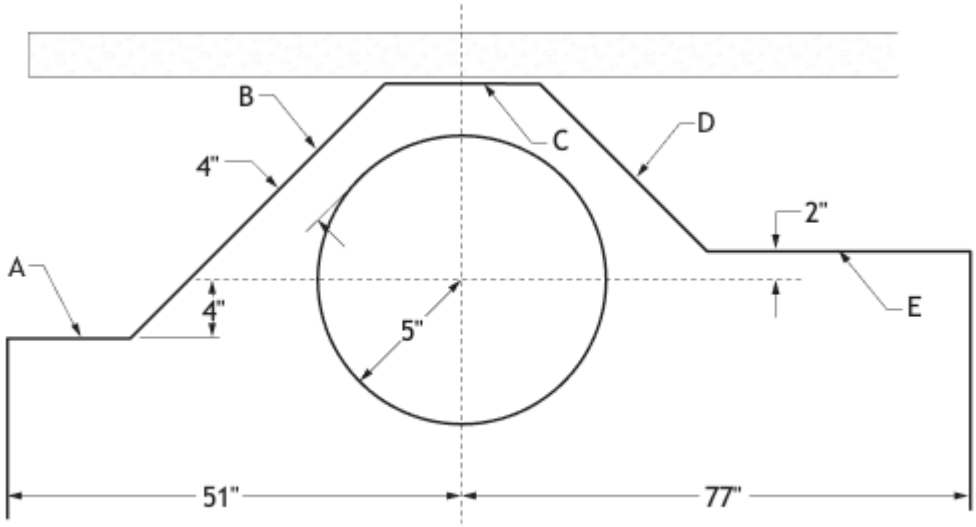


15. Question 15
    a. A = ____
    b. B = ____
    c. C = ____
    d. D = ____



16. Question 16

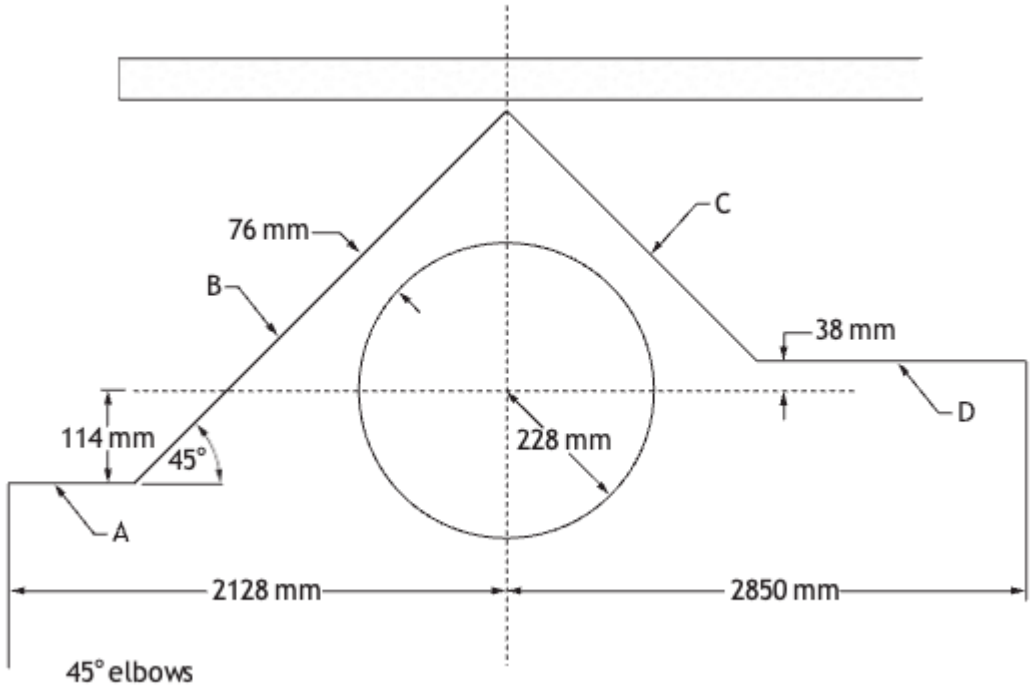
    a. A = _____
    b. B = _____
    c. C = _____
    d. D = _____
    e. E = _____



45° elbows

17. Question 17

a. A = _____
b. B = _____
c. C = _____
d. D = _____
e. E = _____



18. Question 18

    a. A = ____
    b. B = ____
    c. C = ____
    d. D = ____

Answer Key: Self-Test C-1.10.2 is on the other page.

Answer Key: Self-Test C-1.10.2

1. Question 1
    a. True offset (X) = $37\frac{5}{8}$”
    b. Advance = $37\frac{5}{8}$”
    c. Travel = $53\frac{1}{8}$”
    d. A = $56\frac{3}{8}$”
    e. B = $92\frac{3}{8}$”
2. Question 2
    a. True offset (X) = 952.7 mm
    b. Advance = 952.7 mm
    c. Travel = $1,347.1 \text{ mm}$
    d. A = $2,247.3 \text{ mm}$
    e. B = $3,547.3 \text{ mm}$
3. Question 3
    a. True offset (X) = 970.8 mm
    b. Advance = 970.8 mm
    c. Travel = $1,372.7 \text{ mm}$
    d. A = $1,929.2 \text{ mm}$
    e. B = 606.2 mm
4. Question 4
    a. True offset (X) = $43\frac{7}{8}$”
    b. Advance = $43\frac{7}{8}$”
    c. Travel = 67”
    d. A = $84\frac{3}{8}$”

e. B = $56\frac{1}{8}$"

5. Question 5

   a. True offset (X) = $28\frac{5}{8}$"

   b. Advance = $69\frac{1}{8}$"

   c. Travel = $74\frac{3}{4}$"

   d. A = $82\frac{3}{8}$"

   e. B = $106\frac{7}{8}$"

6. Question 6

   a. True offset (X) = 795.7 mm

   b. Advance = $1,921\text{ mm}$

   c. Travel = $2,079.3\text{ mm}$

   d. A = $6,191\text{ mm}$

   e. B = $5,639\text{ mm}$

7. Question 7

   a. True offset (X) = $23\frac{1}{2}$"

   b. Advance = $56\frac{3}{4}$"

   c. Travel = $61\frac{3}{8}$"

   d. A = $67\frac{1}{8}$"

   e. B = $62\frac{5}{8}$"

8. Question 8

   a. True offset (X) = $29\frac{1}{4}$"

b. Advance = $16\frac{7}{8}$”

c. Travel = $33\frac{3}{4}$”

d. A = $180\frac{1}{4}$”

e. B = $194\frac{5}{8}$”

9. Question 9

a. True offset (X) = $1,192.1$ mm

b. Advance = 688.3 mm

c. Travel = $1,376.5$ mm

d. A = $4,961.7$ mm

e. B = $4,091.7$ mm

10. Question 10

a. True offset (X) = $10\frac{3}{4}$”

b. Advance = $6\frac{1}{4}$”

c. Travel = $12\frac{1}{2}$”

d. A = $87\frac{3}{8}$”

e. B = $136\frac{1}{4}$”

11. Question 11

a. True offset (X) = $1,061.3$ mm

b. Advance = 612.7 mm

c. Travel = $1,225.5$ mm

d. A = $6,648.3$ mm

e. B = $5,930.3$ mm

12. Question 12

a. A = 54”

b. B = 24”

c. C = 24”

d. D = 27”

13. Question 13

a. A = $1\frac{1}{4}$”

b. B = 18”

c. C = 18”

d. D = $4\frac{1}{4}$”

14. Question 14

a. A = $41\frac{3}{4}$”

b. B = $20\frac{1}{4}$”

c. C = $14\frac{5}{8}$”

d. D = $64\frac{3}{4}$”

15. Question 15

a. A = $2,098.5$ mm

b. B = 992.1 mm

c. C = 709.3 mm

d. D = $3,248.5$ mm

16. Question 16

a. A = $34\frac{1}{2}$”

b. B = $15\frac{1}{2}$”

c. C = $9\frac{1}{8}$”

d. D = $14\frac{1}{8}$”

e. E = $60\frac{1}{2}$"

17. Question 17

a. A = $34\frac{1}{4}$"

b. B = $18\frac{3}{8}$"

c. C = $7\frac{1}{2}$"

d. D = $9\frac{7}{8}$"

e. E = $66\frac{1}{4}$"

18. Question 18

a. A = $1,584.1$ mm

b. B = 769.2 mm

c. C = 554.3 mm

d. D = $2,458.1$ mm

Self-Test C-1.11: Define the Properties of Matter

Complete Self-Test C-1.11 and check your answers.

1. A mixture is chemically combined molecules of different matter.
   a. true
   b. false
2. True or False. Calcium carbonate is classified as a compound.
   a. true
   b. false
3. True or false. All matter is made of elements.
   a. true
   b. false
4. Anything that occupies space and has mass can be classified as

Answer: _____

5. The number of different forms or states in which matter exists is
   a. one
   b. two
   c. three
   d. five
6. The ratio of an object's mass to its _____ is called the density of the object.
7. A block of ice weighs 2,208 g and has a volume of 2,400 cm^3. Find the density of the ice.

Answer: _____ $\frac{g}{cm^3}$

8. A piece of insulation has a density of 2 $\frac{g}{cm^3}$. It has a volume of 420 cm^3. What is the mass of the insulation?

Answer: _____ g

9. A stone weighs 440 g. The density of the stone is 2,200 $\frac{g}{cm^3}$. What is the volume of the stone?

Answer: _____ cm^3

10. Magnesium has a density of 174 $\frac{g}{cm^3}$. A bar of magnesium has a volume of 12 cm^3. What is the mass of the magnesium bar?

Answer: _____ kg

11. A plywood plank measures $1\text{ cm} \times 8\text{ cm} \times 90\text{ cm}$ and weighs 396 g.

    a. What is the volume of the plank?

Answer: _____ cm^3

    b. What is the density of the plank?

Answer: _____ $\frac{\text{g}}{\text{cm}^3}$

12. Copper is supplied in a rectangular block with dimensions of $10\text{ cm} \times 8\text{ cm} \times 5\text{ cm}$. The density of the block is 8.9 $\frac{\text{g}}{\text{cm}^3}$. What is the mass of the block?

Answer: _____ kg

13. The density of water is given as 62.4 $\frac{\text{lb.}}{\text{ft.}^3}$ What is the weight of a 12-ft.^3 volume of water?

Answer: _____ lb.

14. A block of solid copper weighs 119,880 lb. The density of copper is 555.0 $\frac{\text{lb.}}{\text{ft.}^3}$. What is the volume of the block of copper?

Answer: _____ ft.^3

15. A container, $4\text{ in.} \times 3\text{ in.} \times 7\text{ in.}$, is filled with water. Given that the density of water is 0.0361 $\frac{\text{lb.}}{\text{in.}^3}$, what is the weight of the water in the container, to the nearest pound?

Answer: _____ lb.

16. Air has a density of 0.0807 $\frac{\text{lb.}}{\text{ft.}^3}$; butane has a density of 0.162 $\frac{\text{lb.}}{\text{ft.}^3}$ How many times denser than air is butane?

Answer: _____

17. What would be the volume of 22 lb. of water, given its density of 62.4 $\frac{\text{lb.}}{\text{ft.}^3}$?

Answer: _____ ft.^3

18. The density of porcelain is 2,403 $\frac{\text{kg}}{\text{m}^3}$. What would be the mass of 0.75 m^3 of porcelain?

Answer: _____ kg

19. Three cubic feet of liquid propane weighs 95.47 lb. What is its density?

Answer: _____ $\frac{\text{lb.}}{\text{ft.}^3}$

20. When an external force tries to stretch a body, the body is said to be under the stress of
    a. tension
    b. compression
    c. torque
    d. shear
21. A material that can be drawn into permanent wires is said to have high
    a. conductivity
    b. elasticity
    c. ductility
    d. malleability
22. The maximum force a solid can withstand without becoming permanently deformed is called its
    a. ultimate strength
    b. Brinell number
    c. elasticity
    d. elastic limit
23. Elasticity is the ability to
    a. stretch and maintain the new shape
    b. stretch and return to the original shape
    c. be pounded into thin sheets
    d. resist a force that is trying to pierce an object
24. The attractive force between two dissimilar materials is known as

Answer: _____

25. The attractive force between two similar materials is known as

Answer: _____

26. What term is used to describe the ability of a material to transfer energy from one place to another?

Answer: _____

27. An insulation material with a high R-value would have a _____ thermal conductivity value.
28. What term describes the forces that oppose the flow of electrical current in a conductor?

Answer: _____

29. What is the unit used to measure the opposition to current flow in a conductor?

Answer: _____

Answer Key: Self-Test C-1.11 is on the other page.

Answer Key: Self-Test C-1.11

1. A mixture is chemically combined molecules of different matter.
    a. false
2. True or False. Calcium carbonate is classified as a compound.
    a. true
3. True or false. All matter is made of elements.
    a. true
4. Anything that occupies space and has mass can be classified as
    a. matter
5. The number of different forms or states in which matter exists is
    a. C
6. The ratio of an object's mass to its volume is called the density of the object.
7. A block of ice weighs 2,208 g and has a volume of 2,400 cm^3. Find the density of the ice.
    a. 0.92 $\frac{g}{cm^3}$
8. A piece of insulation has a density of 2 $\frac{g}{cm^3}$. It has a volume of 420 cm^3. What is the mass of the insulation?
    a. 840 g
9. A stone weighs 440 g. The density of the stone is 2,200 $\frac{g}{cm^3}$. What is the volume of the stone?
    a. 0.2 cm^3
10. Magnesium has a density of 174 $\frac{g}{cm^3}$. A bar of magnesium has a volume of 12 cm^3. What is the mass of the magnesium bar?
    a. 2.088 kg
11. A plywood plank measures $1\text{ cm} \times 8\text{ cm} \times 90\text{ cm}$ and weighs 396 g.
    a. What is the volume of the plank?
        i. 720 cm^3
    b. What is the density of the plank?
        i. 0.55 $\frac{g}{cm^3}$
12. Copper is supplied in a rectangular block with dimensions of $10\text{ cm} \times 8\text{ cm} \times 5\text{ cm}$. The density of the

block is 8.9 $\frac{g}{cm^3}$. What is the mass of the block?

a. 3.56 kg

13. The density of water is given as 62.4 $\frac{lb.}{ft.^3}$ What is the weight of a 12-ft.^{3} volume of water?

a. 748.8 lb.

14. A block of solid copper weighs 119,880 lb. The density of copper is 555.0 $\frac{lb.}{ft.^3}$. What is the volume of the block of copper?

a. 216 ft.^{3}

15. A container, $4 \text{ in.} \times 3 \text{ in.} 7 \text{ in.}$, is filled with water. Given that the density of water is 0.0361 $\frac{lb.}{in.^3}$, what is the weight of the water in the container, to the nearest pound?

a. 3 lb.

16. Air has a density of 0.0807 $\frac{lb.}{ft.^3}$; butane has a density of 0.162 $\frac{lb.}{ft.^3}$ How many times denser than air is butane?

a. 2

17. What would be the volume of 22 lb. of water, given its density of 62.4 $\frac{lb.}{ft.^3}$?

a. 0.35 ft.^{3}

18. The density of porcelain is 2403 $\frac{kg}{m^3}$. What would be the mass of 0.75 m^3 of porcelain?

a. 1,802.25 kg

19. Three cubic feet of liquid propane weighs 95.47 lb. What is its density?

a. 31.82 $\frac{lb.}{ft.^3}$

20. When an external force tries to stretch a body, the body is said to be under the stress of

a. A

21. A material that can be drawn into permanent wires is said to have high

a. C

22. The maximum force a solid can withstand without becoming permanently deformed is called its

a. D

23. Elasticity is the ability to

a. B

24. The attractive force between two dissimilar materials is known as

a. adhesion

25. The attractive force between two similar materials is known as

a. cohesion

26. What term is used to describe the ability of a material to transfer energy from one place to another?
    a. conductivity
27. An insulation material with a high R-value would have a low thermal conductivity value.
28. What term describes the forces that oppose the flow of electrical current in a conductor?
    a. resistance
29. What is the unit used to measure the opposition to current flow in a conductor?
    a. ohm

Self-Test C-1.12: Use Pascal's Theory of Pressure and Force

Complete Self-Test C-1.12 and check your answers.

1. A piping apprentice accidentally strikes a pipe with the end of a pickaxe while trying to expose a gas line. If the pickaxe strikes with a force of 2,000 N and the end of the pickaxe measures 0.02 m by 0.01 m, how much pressure was placed on the pipe by the pickaxe?

Answer: _____ MPa

2. A carpenter hammers a nail with a force of 45 N with every stroke. The head of the nail has a surface area of 0.002 m^2. How much pressure is exerted on the nail head with each stroke?

Answer: _____ kPa

3. A box has a weight of 480 lb., and the bottom of the box is 12 $in.^2$ What is the pressure the box exerts on the floor?

Answer: _____ psi

4. A heating boiler weighs 2,400 newtons and has a base that is 4 metres by $\frac{1}{2}$ metre. What is the pressure the boiler exerts on the floor?

Answer: _____ kPa

5. What is the weight of an object that has a base that is 14.5 square inches and that exerts a pressure of 21 pounds per square inch?

Answer: _____ lb.

6. What does a car weigh if its tires cover an area of 4.3 square feet and each tire exerts a pressure of 975 pounds per square foot on the ground?

Answer: _____ lb.

7. To pop a balloon, you stab it with a pencil. If the area of the pencil tip is 0.001 $in.^2$ and the pressure applied by the pencil to the balloon is 10 $\frac{\text{lb.}}{\text{in.}^2}$, how hard (what force) must you push on the pencil to make the balloon pop?

Answer: _____ lb.

8. A round rod weighs 38 lb. If the rod is stood on end so it pushes down on the floor with a pressure of 12.66 $\frac{\text{lb.}}{\text{in.}^2}$,

how many square inches is the end of the rod?

Answer: _____ $in.^2$

9. If the inside of a container has a surface area of 20 $in.^2$, what will be the pressure on each square inch of the container if 117.6 pounds of force are applied to the container?

Answer: _____ psi

10. The pressure of a nail was measured at 350 Pa. What force is exerted by the nail if the surface area is 0.13 m^2?

Answer: _____ N

11. The pressure in a boiler is 20 kPa. If the area of one end of the shell is 0.6 m^2, what is the force on that end?

Answer: _____ N

12. A student exerts a force of 304 N on a gas syringe. The pressure gauge reads a pressure of 40 kPa. What is the cross-sectional area of the plunger of the syringe?

Answer: _____ m^2

13. A pressure cooker has a pressure of 1,013,250 Pa inside. The lid has an area of 0.2 m^2. What is the force on the lid?

Answer: _____ N

14. A water main is directed around a sharp 90-degree bend. The force produced is equal to 1,750 lb. The soil engineer's report says that the sandy soil in the area will only withstand 12 psi before it may compact. How much area must a thrust block cover in order to comply with the soils report?

Answer: _____ $in.^2$

15. What would be the pressure exerted by four feet of water depth?

Answer: _____ psi

16. What would be the pressure exerted by 7.5 m of water depth?

Answer: _____ kPa

17. What height of water is required to exert a pressure of 47 psi?

Answer: _____ ft.

18. What height of water is required to exert a pressure of 0.0361 $\frac{lb.}{in.^2}$?

Answer: _____ in.

19. What height of water is required to exert a pressure of 231.52 kPa?

Answer: _____ m

20. How much pressure would a column of mercury 14 inches high exert?

Answer: _____ psi

21. What would be the pressure at the bottom of a pipe full of water that is 10″ in diameter and is 15′ high?

Answer: _____ psi

22. What would be the psi at the bottom of a tank full of water $25' \text{ long} \times 15' \text{ wide} \times 8'' \text{ deep}$?

Answer: _____ psi

23. What would be the height of a water column needed to produce a pressure of 12.8 psi in a 6″ pipe?

Answer: _____ ft.

24. What would be the total force on the bottom of a tank full of water that is $4' \text{ long} \times 6' \text{ wide} \times 26'' \text{ high}$?

Answer: _____ lb.

25. What would be the total force at the bottom of a 4″ soil or waste stack 16′ high?

Answer: _____ lb.

Answer Key: Self-Test C-1.12 is on the other page.

Answer Key: Self-Test C-1.12

1. A piping apprentice accidentally strikes a pipe with the end of a pickaxe while trying to expose a gas line. If the pickaxe strikes with a force of 2,000 N and the end of the pickaxe measures 0.02 m by 0.01 m, how much pressure was placed on the pipe by the pickaxe?
   a. 10 MPa

2. A carpenter hammers a nail with a force of 45 N with every stroke. The head of the nail has a surface area of 0.002 m^2. How much pressure is exerted on the nail head with each stroke?
   a. 22.5 kPa

3. A box has a weight of 480 lb., and the bottom of the box is 12 $in.^2$ What is the pressure the box exerts on the floor?
   a. 40 psi

4. A heating boiler weighs 2,400 newtons and has a base that is 4 metres by $\frac{1}{2}$ metre. What is the pressure the boiler exerts on the floor?
   a. 1.2 kPa

5. What is the weight of an object that has a base that is 14.5 square inches and that exerts a pressure of 21 pounds per square inch?
   a. 304.5 lb.

6. What does a car weigh if its tires cover an area of 4.3 square feet and each tire exerts a pressure of 975 pounds per square foot on the ground?
   a. 4,192.5lb.

7. To pop a balloon, you stab it with a pencil. If the area of the pencil tip is 0.001 $in.^2$ and the pressure applied by the pencil to the balloon is 10 $\frac{\text{lb.}}{\text{in.}^2}$, how hard (what force) must you push on the pencil to make the balloon pop?
   a. 0.01 lb.

8. A round rod weighs 38 lb. If the rod is stood on end so it pushes down on the floor with a pressure of 12.66 $\frac{\text{lb.}}{\text{in.}^2}$, how many square inches is the end of the rod?
   a. 3 $in.^2$

9. If the inside of a container has a surface area of 20 $in.^2$, what will be the pressure on each square inch of the container if 117.6 pounds of force are applied to the container?
   a. 5.88 psi

10. The pressure of a nail was measured at 350 Pa. What force is exerted by the nail if the surface area is 0.13 m^2?

a. 45.5 N

11. The pressure in a boiler is 20 kPa. If the area of one end of the shell is 0.6 m^2, what is the force on that end?
    a. 12,000 N

12. A student exerts a force of 304 N on a gas syringe. The pressure gauge reads a pressure of 40 kPa. What is the cross-sectional area of the plunger of the syringe?
    a. 0.0076 m^2

13. A pressure cooker has a pressure of 1,013,250 Pa inside. The lid has an area of 0.2 m^2. What is the force on the lid?
    a. 202,650 N

14. A water main is directed around a sharp 90-degree bend. The force produced is equal to 1,750 lb. The soil engineer's report says that the sandy soil in the area will only withstand 12 psi before it may compact. How much area must a thrust block cover in order to comply with the soils report?
    a. 145.8 $in.^2$

15. What would be the pressure exerted by four feet of water depth?
    a. 1.732 psi

16. What would be the pressure exerted by 7.5 m of water depth?
    a. 73.58 kPa

17. What height of water is required to exert a pressure of 47 psi?
    a. 108.55 ft.

18. What height of water is required to exert a pressure of 0.0361 $\frac{\text{lb.}}{\text{in.}^2}$?
    a. 1 in.

19. What height of water is required to exert a pressure of 231.52 kPa?
    a. 23.6 m

20. How much pressure would a column of mercury 14 inches high exert?
    a. 6.874 psi

21. What would be the pressure at the bottom of a pipe full of water that is 10″ in diameter and is 15′ high?
    a. 6.495 psi

22. What would be the psi at the bottom of a tank full of water $25\text{'} \text{ long} \times 15\text{'} \text{ wide} \times 8\text{''} \text{ deep}$?
    a. 0.29 psi

23. What would be the height of a water column needed to produce a pressure of 12.8 psi in a 6″ pipe?
    a. 29.6 ft.

24. What would be the total force on the bottom of a tank full of water that is $4' \text{ long} \times 6' \text{ wide} \times 26'' \text{ high}$?

    a. 3,245 lb.

25. What would be the total force at the bottom of a 4″ soil or waste stack 16′ high?

    a. 87 lb.

Self-Test C-1.13: Use Archimedes' Principles of Displacement and Floatation

Complete Self-Test C-1.13 and check your answers.

1. A block of gold and a block of wood both have the same volume. If they are both submerged in water, which has the higher buoyant force?

Answer: _____

2. A 100-cm^3 block of lead that weighs 11 N is submerged in water. One cm^3 of water weighs 0.0098 N.
    a. What volume of water does the lead displace?

Answer: _____ cm^3

    b. How much does that volume of water weigh?

Answer: _____ N

    c. What is the buoyant force on the lead?

Answer: _____ N

    d. Will the lead block sink or float in the water?

Answer: _____

3. The same 100-cm^3 lead block is submerged in a container of mercury. One cm^3 of mercury weighs 0.13 N.
    a. What volume of mercury is displaced?

Answer: _____ cm^3

    b. How much does that volume of displaced mercury weigh?

Answer: _____ N

    c. What is the buoyant force on the lead?

Answer: _____ N

    d. Will the lead block sink or float in the mercury?

Answer: _____

4. An iron anchor weighs 250 pounds in air and has a density of 480 $\frac{\text{lb.}}{\text{ft.}^3}$ If it is immersed in seawater that has a density of 64 $\frac{\text{lb.}}{\text{ft.}^3}$, how much force would be required to lift it while it is immersed?

Answer: _____ lb.

5. An aluminum bar weighs 82 pounds in air. How much force is required to lift the bar while it is immersed in gasoline? The density of aluminum is 170 $\frac{\text{lb.}}{\text{ft.}^3}$, and the density of gasoline is 42 $\frac{\text{lb.}}{\text{ft.}^3}$

Answer: _____ lb.

6. What would be the relative density of steel if the density is 491 $\frac{\text{lb.}}{\text{ft.}^3}$?

Answer: _____

7. What would be the buoyant force on an object under water, whose volume is 0.35 m^3 (12.36 $ft.^3$)? Show you answer in both unit classifications.

Answer: _____ N or _____ lb.

8. If a substance has a density of 54.3 $\frac{\text{lb.}}{\text{ft.}^3}$, what is its relative density?

Answer: _____

9. If an object has a relative density of 3.1 and weighs 290 lb., how much volume will it occupy?

Answer: _____ $ft.^3$

10. A rock has a specific weight of 2.6. On dry land it weighs 77 pounds. How much will its apparent weight be when it is submerged in water?

Answer: _____ lb.

11. If the specific weight of a substance is 4.9, what is its density in $\frac{\text{lb.}}{\text{ft.}^3}$?

Answer: _____ $\frac{\text{lb.}}{\text{ft.}^3}$

12. A piece of iron alloy weighs 8.5 lb. in air and 7.2 lb. in water. What is its specific gravity?

Answer: SG =_____

13. The most common method of finding the specific gravity of liquids is with the use of a hydrometer. Explain the principle of operation of the hydrometer.

Answer: _____

_____

_____

_____

14. What is the reason that density is always expressed in units such as $\frac{\text{lb.}}{\text{ft.}^3}$, while specific gravity has no units?

Answer: _____

_____

_____

_____

15. What is the weight of 3.4 cubic feet of iron with a density of 455 $\frac{\text{lb.}}{\text{ft.}^3}$?

Answer: _____ lb.

16. If a square object with an SG of 0.58 is placed in a vessel of fresh water, what percentage of the object will be showing above the water line?

Answer: _____ %

17. Six pounds of argon occupy 43 ft.^3. What is its density?

Answer: _____ $\frac{\text{lb.}}{\text{ft.}^3}$

18. The density of a certain material is 406 $\frac{\text{lb.}}{\text{ft.}^3}$. What would the density be in $\frac{\text{lb.}}{\text{in.}^3}$?

Answer: _____ $\frac{\text{lb.}}{\text{in.}^3}$

19. What would be the density of a piece of steel in $\frac{\text{lb.}}{\text{ft.}^3}$, if 5.46 cubic inches weighs 1 lb.?

Answer: _____ $\frac{\text{lb.}}{\text{ft.}^3}$

20. The density of brass is 0.283 $\frac{\text{lb.}}{\text{in.}^3}$. Find the volume of a piece of brass that weighs 475 lb.

Answer: _____ ft.^3

Answer Key: Self-Test C-1.13 is on the other page.

Answer Key: Self-Test C-1.13

1. A block of gold and a block of wood both have the same volume. If they are both submerged in water, which has the higher buoyant force?
    a. They are equal
2. A 100-cm^3 block of lead that weighs 11 N is submerged in water. One cm^3 of water weighs 0.0098 N.
    a. What volume of water does the lead displace?
        i. 100 cm^3
    b. How much does that volume of water weigh?
        i. 0.98 N
    c. What is the buoyant force on the lead?
        i. 0.98 N
    d. Will the lead block sink or float in the water?
        i. sink
3. The same 100-cm^3 lead block is submerged in a container of mercury. One cm^3 of mercury weighs 0.13 N.
    a. What volume of mercury is displaced?
        i. 85 cm^3
    b. How much does that volume of displaced mercury weigh?
        i. 11 N
    c. What is the buoyant force on the lead?
        i. 11 N
    d. Will the lead block sink or float in the mercury?
        i. float

4. An iron anchor weighs 250 pounds in air and has a density of 480 $\frac{\text{lb.}}{\text{ft.}^3}$ If it is immersed in seawater that has a density of 64 $\frac{\text{lb.}}{\text{ft.}^3}$, how much force would be required to lift it while it is immersed?
    1. 216.67 lb.
5. An aluminum bar weighs 82 pounds in air. How much force is required to lift the bar while it is immersed in gasoline? The density of aluminum is 170 $\frac{\text{lb.}}{\text{ft.}^3}$, and the density of gasoline is 42 $\frac{\text{lb.}}{\text{ft.}^3}$
    a. 61.7 lb.
6. What would be the relative density of steel if the density is 491 $\frac{\text{lb.}}{\text{ft.}^3}$?
    a. 7.87
7. What would be the buoyant force on an object under water, whose volume is 0.35 m^3 (12.36 $ft.^3$)? Show you answer in both unit classifications.
    a. 3,430 N or 771 lb.

8. If a substance has a density of 54.3 $\frac{\text{lb.}}{\text{ft.}^3}$, what is its relative density?

    a. 0.87

9. If an object has a relative density of 3.1 and weighs 290 lb., how much volume will it occupy?

    a. 1.5 ft.^3

10. A rock has a specific weight of 2.6. On dry land it weighs 77 pounds. How much will its apparent weight be when it is submerged in water?

    a. 47.38 lb.

11. If the specific weight of a substance is 4.9, what is its density in $\frac{\text{lb.}}{\text{ft.}^3}$?

    a. 305.76 $\frac{\text{lb.}}{\text{ft.}^3}$

12. A piece of iron alloy weighs 8.5 lb. in air and 7.2 lb. in water. What is its specific gravity?

    a. SG = 6.54

13. The most common method of finding the specific gravity of liquids is with the use of a hydrometer. Explain the principle of operation of the hydrometer.

    a. A solid suspended in a fluid will be buoyed up by a force equal to the weight of the fluid displaced by thesubmerged part of the suspended solid. Thus, the lower the density of the substance, the farther the hydrometer will sink.

14. What is the reason that density is always expressed in units such as $\frac{\text{lb.}}{\text{ft.}^3}$, while specific gravity has no units?

    a. Specific gravity is a ratio of the densities, compared to water.

15. What is the weight of 3.4 cubic feet of iron with a density of 455 $\frac{\text{lb.}}{\text{ft.}^3}$?

    a. 1,547 lb.

16. If a square object with an SG of 0.58 is placed in a vessel of fresh water, what percentage of the object will be showing above the water line?

    a. 42%

17. Six pounds of argon occupy 43 ft.^3 What is its density?

    a. 0.1395 $\frac{\text{lb.}}{\text{ft.}^3}$

18. The density of a certain material is 406 $\frac{\text{lb.}}{\text{ft.}^3}$ What would the density be in $\frac{\text{lb.}}{\text{ft.}^3}$?

    a. 0.235 $\frac{\text{lb.}}{\text{in.}^3}$

19. What would be the density of a piece of steel in $\frac{\text{lb.}}{\text{ft.}^3}$, if 5.46 cubic inches weighs 1 lb.?

a. 316.48 $\frac{\text{lb.}}{\text{ft.}^3}$

20. The density of brass is 0.283 $\frac{\text{lb.}}{\text{in.}^3}$ Find the volume of a piece of brass that weighs 475 lb.

a. 0.97 ft.^3

Self-Test C-1.14: Define Mechanical Advantages as It Relates to Fluid Power

Complete Self-Test C-1.14 and check your answers.

1. What would be the output force of a hydraulic press that has an MA of 70 and an input force of 140 N?

Answer: _____ N

2. If the small piston on a hydraulic jack has a diameter of 3 in., what is its area?

Answer: _____ $in.^2$

3. What is the pressure in pounds per square inch if 100 pounds of force are applied to a hydraulic system's piston with an area of 2 $in.^2$?

Answer: _____ psi

4. What is the pressure in kPa if 700 N of force is applied to a hydraulic system's piston with an area of 52 cm^2?

Answer: _____ kPa

5. What is the force exerted by a hydraulic piston that has an area of 3 $in.^2$ and a 50 psi fluid pressure?

Answer: _____ lb.

6. What is the force exerted by a hydraulic piston that has an area of 18 cm^2 and a 411 kPa fluid pressure?

Answer: _____ N

7. If the small piston on a hydraulic lift has an area of 2 $in.^2$ and 50 lb. of force are applied to it, what would the area of the larger piston have to be to produce 500 lb. of force?

Answer: _____ $in.^2$

8. Complete the following table referring to a hydraulic jack. Show the required values and the proper units.

Small piston force	Small piston diameter	Small piston area	Small piston travel distance	Fluid pressure	Large piston diameter	Large piston area	Large piston travel distance	Force exerted by large piston	Mechanical advantage
25 lb.	2.5 in.				7.5 in.		7 in.		
44 lb.	3.7 in.		14 in.			73 $in.^2$			
78 lb.	5.5 in.						12 in.		14
2,375 N	8 cm		1.8 m					9,449 N	
1,850 N		40 cm^2			27.64 cm		70 mm		15
						6,120 cm^2	113 mm	10,770 N	34

Answer Key: Self-Test C-1.14 is on the other page.

Answer Key: Self-Test C-1.14

1. What would be the output force of a hydraulic press that has an MA of 70 and an input force of 140 N?
   a. 9,800 N
2. If the small piston on a hydraulic jack has a diameter of 3 in., what is its area?
   a. 7.07 $in.^2$
3. What is the pressure in pounds per square inch if 100 pounds of force are applied to a hydraulic system's piston with an area of 2 $in.^2$?
   a. 50 psi
4. What is the pressure in kPa if 700 N of force is applied to a hydraulic system's piston with an area of 52 cm^2?
   a. 134.61 kPa
5. What is the force exerted by a hydraulic piston that has an area of 3 $in.^2$ and a 50 psi fluid pressure?
   a. 150 lb.
6. What is the force exerted by a hydraulic piston that has an area of 18 cm^2 and a 411 kPa fluid pressure?
   a. 740.54 N
7. If the small piston on a hydraulic lift has an area of 2 $in.^2$ and 50 lb. of force are applied to it, what would the area of the larger piston have to be to produce 500 lb. of force?
   a. 20 $in.^2$
8. Complete the following table referring to a hydraulic jack. Show the required values and the proper units.

Small piston force	**Small piston diameter**	**Small piston area**	**Small piston travel distance**	**Fluid pressure**	**Large piston diameter**	**Large piston area**	**Large piston travel distance**	**Force exerted by large piston**	**Mechanical advantage**
25 lb.	2.5 in.	4.9 cm^2	63 in.	5.1 psi	7.5 in.	44.18 $in.^2$	7 in.	225.32 lb.	9
44 lb.	3.7 in.	10.75 cm^2	14 in.	4.09 psi	9.64 in.	73 $in.^2$	2.06 in.	298.57 lb.	6.79
78 lb.	5.5 in.	23.76 cm^2	168 in.	3.28 psi	20.56 in.	332.64 $in.^2$	12 in.	1,092 lb.	14
2,375 N	8 cm	50.27 cm^2	1.8 m	472.45 kPa	15.96 cm	200 cm^2	452 mm	9,449 N	3.98
1,850 N	7.14 cm	40 cm^2	1.05 m	462.5 kPa	27.64 cm	600 cm^2	70 mm	693.8 N	15
316.8 N	15.12 cm	180 cm^2	3.84 m	17.6 kPa	88.27 cm	6,120 cm^2	113 mm	10,770 N	34

Self-Test C-1.15: Describe Factors that Affect Fluid Flow in a Piping System

Complete Self-Test C-1.15 and check your answers.

1. Generally speaking, what two types of flow are possible in a piping system?
    a. _____
    b. _____
2. What term is used to describe a liquid's internal resistance to flow?

Answer: _____

3. When fluid velocity is low, _____ flow usually results.
4. When fluid velocity is high, _____ flow usually results.
5. Another name for laminar flow is _____ flow.
6. List the six factors that govern the pressure drop due to friction in a piping system.
    a. _____
    b. _____
    c. _____
    d. _____
    e. _____
    f. _____
7. When fluid velocity is low, _____ static pressure results.
8. When fluid velocity is high, _____ static pressure results.

Answer Key: Self-Test C-1.15 is on the other page.

Answer Key: Self-Test C-1.15

1. Generally speaking, what two types of flow are possible in a piping system?
    a. laminar
    b. turbulent
2. What term is used to describe a liquid's internal resistance to flow?
    a. viscosity
3. When fluid velocity is low, laminar flow usually results.
4. When fluid velocity is high, turbulent flow usually results.
5. Another name for laminar flow is streamline flow.
6. List the six factors that govern the pressure drop due to friction in a piping system.
    a. viscosity of liquid
    b. length of pipe
    c. velocity of flow
    d. size and type of pipe
    e. number and type of fittings and valves
    f. number and degree of bends
7. When fluid velocity is low, high static pressure results.
8. When fluid velocity is high, low static pressure results.

Self-Test C-1.16: Describe Factors that Affect Gas Volumes and Pressures

Complete Self-Test C-1.16 and check your answers.

1. The gas law that states "a volume of a gas varies inversely to the absolute pressure, provided the absolute temperature remains constant" is known by what name?

Answer: _____

2. When the absolute pressure remains the same and the absolute temperature of a gas decreases, does the volume increase or decrease?

Answer: _____

3. A standard 1.5-$ft.^3$ nitrogen cylinder at 2,200 psig is at 60°F. How many $ft.^3$ of volume will the nitrogen occupy at 50 psig if there is no change in temperature?

Answer: _____ $ft.^3$

4. If the pressure remains constant and the Kelvin temperature of a gas is doubled, the volume of the gas will increase by what factor?

Answer: _____

5. A balloon has a volume of 2.5 m^3 on a day when the temperature is 30°C. If the temperature at night falls to 10°C, what will be the volume of the balloon if the pressure remains constant?

Answer: _____ m^3

6. A 6.5-$ft.^3$ sample of nitrogen under a pressure of 26 psig is heated from 77°F to 186°F. What is the new volume if the pressure increased to 32 psig?

Answer: _____ $ft.^3$

7. Assuming no change in pressure, what is the new temperature (K) when 2 L of gas at 20°C are cooled and contract to 1 L?

Answer: _____ K

8. A standard nitrogen cylinder has a volume of 1.5 $ft.^3$ at 2,200 psig at 60°F. What is the new gauge pressure if the cylinder is heated to 130°F?

Answer: _____ psig

9. A natural gas piping system has an internal volume of 12 m^3 and is pressurized with nitrogen to 1,050 kPa at an ambient temperature of 25°C. The next day, the ambient temperature is 10°C. Assuming the nitrogen is now at 10°C

and there are no leaks in the system, what is the new gauge reading?

Answer: _____ kPa

10. Which gas law states "the absolute pressure of a gas varies directly with the absolute temperature, provided that the volume of the gas remains constant"?

Answer: _____

11. An air compressor inlet receives 410 $ft.^3$ of standard air and charges it to 129 psig. What is the volume of the compressor tank?

Answer: _____ $ft.^3$

12. An air compressor has a tank that holds 27 $ft.^3$ while at a pressure of 69 psig. How many $ft.^3$ of standard air would it take to fill the tank?

Answer: _____ $ft.^3$

13. A helium balloon has a pressure of 6 psig and a volume of 0.85 $ft.^3$. The balloon were compressed to a volume of 0.25 $ft.^3$ before it ruptured. What was the pressure of the helium in the balloon when it popped?

Answer: _____ psig

14. A vessel with a pressure of 106 psig has an air volume of 45 $ft.^3$. Calculate the volume if the air was compressed to a pressure of 201 psig.

Answer: _____ $ft.^3$

15. A 17-m^3 air sample is pressurized to 100 kPa at a temperature of –14°C. The air is heated and the volume expands to 25.5 m^3 at a pressure of 120 kPa. What is the temperature (°C) of the air in order to cause this change in conditions?

Answer: _____ °C

16. A pressure tank for a well pump contains 0.2 m^3 of air at 150 kPa of gauge pressure. What is the new air volume when at 400 kPa gauge pressure?

Answer: _____ m^3

17. A hydrogen balloon has a pressure of 16 psig and a volume of 15,000 $ft.^3$. Calculate the required amount of hydrogen (at atmospheric pressure) needed to fill the balloon.

Answer: _____ $ft.^3$

18. A captive argon sample is measured with a volume of 41 m^3, a temperature of 39°C and a pressure of 500 kPa. The argon is heated to a point where the conditions change so that the temperature is now 60°C and the volume is now 62 m^3. What pressure (kPa) must the argon be in order to cause the new conditions?

Answer: _____ kPa

19. The pressure of a gas in a container is 22 psig at 19°F. The gas is heated until the gauge pressure reaches 82 psig. What temperature is the gas when the pressure gauge reaches 82 psig?

Answer: _____ °F

20. The pressure of a gas in a container is 87 psig at 140°F. What will the new gauge pressure be when the gas in the container is cooled to –27°F?

Answer: _____ psig

Answer Key: Self-Test C-1.16 is on the other page.

Answer Key: Self-Test C-1.16

1. The gas law that states "a volume of a gas varies inversely to the absolute pressure, provided the absolute temperature remains constant" is known by what name?
    a. Boyle's Law
2. When the absolute pressure remains the same and the absolute temperature of a gas decreases, does the volume increase or decrease?
    a. decrease
3. A standard 1.5-ft.^{3} nitrogen cylinder at 2,200 psig is at 60°F. How many ft.^{3} of volume will the nitrogen occupy at 50 psig if there is no change in temperature?
    a. 51.3 ft.^{3}
4. If the pressure remains constant and the Kelvin temperature of a gas is doubled, the volume of the gas will increase by what factor?
    a. 2
5. A balloon has a volume of 2.5 m^3 on a day when the temperature is 30°C. If the temperature at night falls to 10°C, what will be the volume of the balloon if the pressure remains constant?
    a. 2.33 m^3
6. A 6.5-ft.^{3} sample of nitrogen under a pressure of 26 psig is heated from 77°F to 186°F. What is the new volume if the pressure increased to 32 psig?
    a. 6.84 ft.^{3}
7. Assuming no change in pressure, what is the new temperature (K) when 2 L of gas at 20°C are cooled and contract to 1 L?
    a. 146.5 K
8. A standard nitrogen cylinder has a volume of 1.5 ft.^{3} at 2200 psig at 60°F. What is the new gauge pressure if the cylinder is heated to 130°F?
    a. 2,498.1 psig
9. A natural gas piping system has an internal volume of 12 m^3 and is pressurized with nitrogen to 1,050 kPa at an ambient temperature of 25°C. The next day, the ambient temperature is 10°C. Assuming the nitrogen is now at 10°C and there are no leaks in the system, what is the new gauge reading?
    a. 992 kPa
10. Which gas law states "the absolute pressure of a gas varies directly with the absolute temperature, provided that the volume of the gas remains constant"?
    a. Charles Law
11. An air compressor inlet receives 410 ft.^{3} of standard air and charges it to 129 psig. What is the volume of the compressor tank?
    a. 42.01 ft.^{3}
12. An air compressor has a tank that holds 27 ft.^{3} while at a pressure of 69 psig. How many ft.^{3} of standard air would it take to fill the tank?
    a. 153.48 ft.^{3}
13. A helium balloon has a pressure of 6 psig and a volume of 0.85 ft.^{3}. The balloon were compressed to a volume of 0.25 ft.^{3} before it ruptured. What was the pressure of the helium in the balloon when it popped?
    a. 55.75 psig

14. A vessel with a pressure of 106 psig has an air volume of 45 $ft.^3$. Calculate the volume if the air was compressed to a pressure of 201 psig.
    a. 25.18 $ft.^3$
15. A 17-m^3 air sample is pressurized to 100 kPa at a temperature of –14°C. The air is heated and the volume expands to 25.5 m^3 at a pressure of 120 kPa. What is the temperature (°C) of the air in order to cause this change in conditions?
    a. 154.1 °C
16. A pressure tank for a well pump contains 0.2 m^3 of air at 150 kPa of gauge pressure. What is the new air volume when at 400 kPa gauge pressure?
    a. 0.1 m^3
17. A hydrogen balloon has a pressure of 16 psig and a volume of 15,000 $ft.^3$ Calculate the required amount of hydrogen (at atmospheric pressure) needed to fill the balloon.
    a. 31,326.53 $ft.^3$
18. A captive argon sample is measured with a volume of 41 m^3, a temperature of 39°C and a pressure of 500 kPa. The argon is heated to a point where the conditions change so that the temperature is now 60°C and the volume is now 62 m^3. What pressure (kPa) must the argon be in order to cause the new conditions?
    a. 323.1 kPa
19. The pressure of a gas in a container is 22 psig at 19°F. The gas is heated until the gauge pressure reaches 82 psig. What temperature is the gas when the pressure gauge reaches 82 psig?
    a. 802.1 °F
20. The pressure of a gas in a container is 87 psig at 140°F. What will the new gauge pressure be when the gas in the container is cooled to –27°F?
    a. 58.69 psig

Self-Test C-1.17: Calculate the Expansion and Contraction of Various Piping Materials Due to Heating and Cooling

Complete Self-Test C-1.17 and check your answers.

1. The coefficient of linear expansion is the increase in unit of measure for one degree increase in heat.
   a. True
   b. False
2. The coefficient of linear contraction is the decrease in unit of measure for one degree decrease in heat.
   a. True
   b. False
3. How much linear expansion would occur if a 58′ stainless steel pipe installed at –18°F were heated to 250°F?

Answer: _____ in.

4. An 18.5-m length of PVC pipe was installed in a commercial building. If the pipe underwent a temperature change of +22°C, what increase in length would it experience?

Answer: _____ mm

5. A 45′ length of CPVC pipe was installed in a commercial building when the ambient temperature was 65°F. If the pipe were put into service transporting a chilled brine and were cooled to 5°F, what would be its new length?

Answer: _____ ft. _____ in.

6. A 3-in. carbon steel steam pipe is 40 m long and is 10°C. at the time of installation. How much linear expansion can be expected when the temperature is raised to 150°C (steam)?

Answer: _____ mm

7. A 3-in. copper hot water supply line is installed at a temperature of 32°F. When the line is put into use, the temperature of the hot water will be 160°F. The total length of the line at the time of installation is 69 feet 4 inches. What will its new length be?

Answer: _____ ft. _____ in.

8. A 2-in. ABS drain line, 60 ft. in length, is installed in a building under construction. There are no doors or windows installed at this point of construction. The time of year is midwinter and the temperature is 5°F. After the building is completed, the temperature will rise to 92°F. How much linear expansion will occur in the 2-in. pipe?

Answer: _____ in.

9. A hot water heating system is installed with $1\frac{1}{4}$-in. carbon steel wall fin convector. One particular run is 30 m long. The fin temperature at the time of installation was 15°C. At peak heating season, the pipe temperature rises to 82°C. How much linear expansion must be allowed for on the wall fin installation?

Answer: _____ mm

10. A 26-m copper chilled water line is installed in a building. The temperature at time of installation is 29.5°C. After the pipe is put in service, cold water running in the pipe is 3°C. How much contraction should we allow for?

Answer: _____ mm

Transpose the linear expansion formula to solve the following questions:

11. A stainless steel pipe is installed in a brewery. The pipe temperature at time of installation was 62°F. During the brewing process the pipe reached a temperature of 210°F and increased $1' \frac{11}{2}"$. How long was the pipe when it was installed?

Answer: _____ ft.

12. A PVC pipe is installed in a fertilizer plant. The pipe temperature at time of installation was 11°C. During the process, the pipe reached a temperature of 70°C and increased 18 mm in length. How long was the pipe when it was installed?

Answer: _____ m

13. A cast iron stack 128′ long is installed in January when the temperature is –18°F. During final inspection, the stack is $\frac{3}{8}"$ longer. What was the temperature of the building when the inspection took place?

Answer: _____ °F

14. A 77′ polypropylene pipe is installed in a geothermal header. At the time of installation, the temperature of the pipe was 50°F. During the process, the fluid it contains has a temperature of 120°F. When heated, the pipe becomes $\frac{15}{16}$ in. longer than at the time of installation. What is the coefficient of linear expansion of the polypropylene pipe? Give your answer to the accuracy of seven (7) decimal places.

Answer: _____ CLE

Answer Key: Self-Test C-1.17 is on the other page.

Answer Key: Self-Test C-1.17

1. The coefficient of linear expansion is the increase in unit of measure for one degree increase in heat.
   a. True
2. The coefficient of linear contraction is the decrease in unit of measure for one degree decrease in heat.
   a. True
3. How much linear expansion would occur if a 58′ stainless steel pipe installed at –18°F were heated to 250°F?
   a. $1\frac{7}{8}$ in.
4. An 18.5-m length of PVC pipe was installed in a commercial building. If the pipe underwent a temperature change of +22°C, what increase in length would it experience?
   a. 20.5 mm
5. A 45′ length of CPVC pipe was installed in a commercial building when the ambient temperature was 65°F. If the pipe were put into service transporting a chilled brine and were cooled to 5°F, what would be its new length?
   a. 44 ft. $10\frac{9}{16}$ in.
6. A 3-in. carbon steel steam pipe is 40 m long and is 10°C. at the time of installation. How much linear expansion can be expected when the temperature is raised to 150°C (steam)?
   a. 65.52 mm
7. A 3-in. copper hot water supply line is installed at a temperature of 32°F. When the line is put into use, the temperature of the hot water will be 160°F. The total length of the line at the time of installation is 69 feet 4 inches. What will its new length be?
   a. 69 ft. 5 in.
8. A 2-in. ABS drain line, 60 ft. in length, is installed in a building under construction. There are no doors or windows installed at this point of construction. The time of year is midwinter and the temperature is 5°F. After the building is completed, the temperature will rise to 92°F. How much linear expansion will occur in the 2-in. pipe?
   a. $2\frac{3}{16}$ in.
9. A hot water heating system is installed with $1\frac{1}{4}$-in. carbon steel wall fin convector. One particular run is 30 m long. The fin temperature at the time of installation was 15°C. At peak heating season, the pipe temperature rises to 82°C. How much linear expansion must be allowed for on the wall fin installation?
   a. 23.5 mm
10. A 26-m copper chilled water line is installed in a building. The temperature at time of installation is 29.5°C. After the pipe is put in service, cold water running in the pipe is 3°C. How much contraction should we allow for?
    a. 11.6 mm

Transpose the linear expansion formula to solve the following questions:

11. A stainless steel pipe is installed in a brewery. The pipe temperature at time of installation was 62°F. During the

brewing process the pipe reached a temperature of 210°F and increased $1' \frac{11}{2}"$. How long was the pipe when it was installed?

a. 767.8 ft.

12. A PVC pipe is installed in a fertilizer plant. The pipe temperature at time of installation was 11°C. During the process, the pipe reached a temperature of 70°C and increased 18 mm in length. How long was the pipe when it was installed?

a. 6.05 m

13. A cast iron stack 128′ long is installed in January when the temperature is –18°F. During final inspection, the stack is $\frac{3}{8}"$ longer. What was the temperature of the building when the inspection took place?

a. 23.4 °F

14. A 77′ polypropylene pipe is installed in a geothermal header. At the time of installation, the temperature of the pipe was 50°F. During the process, the fluid it contains has a temperature of 120°F. When heated, the pipe becomes $\frac{15}{16}$ in. longer than at the time of installation. What is the coefficient of linear expansion of the polypropylene pipe? Give your answer to the accuracy of seven (7) decimal places.

a. 0.0000145 CLE

Self-Test C-1.18: Define Methods of Heat Transfer

Complete Self-Test C-1.18 and check your answers.

1. As hot coffee is stirred with a spoon, the spoon gets hot due to

Answer: _____

2. A chair is placed several feet from a fire in a fireplace. The fireplace has a glass screen. The side of the chair facing the fireplace gets warm because of

Answer: _____

3. A certain type of decorative lamp contains coloured liquids. These liquids form globs that break off and rise to the top of the liquid. The globs rise due to

Answer: _____

4. Near the ceiling of a room, the air is warmer. The warm air rises because of

Answer: _____

5. A college student holds the back of his hand near an iron to see if it is hot. Heat is transferred to his hand by

Answer: _____

6. A heater is placed under one corner of a waterbed mattress. Warm water moves throughout the mattress because of

Answer: _____

7. A certain type of stainless steel cookware has a layer of copper applied to the bottom to help it heat evenly. The copper transfers heat to the pan by

Answer: _____

8. In a swimming pool, the water near the surface is slightly warmer. The warm water rises because of

Answer: _____

9. One end of a copper tube is placed in a torch flame. Small pieces of flux placed along the tube melt at a progressively further distance from the flame. Heat is transferred through the tube by

Answer: _____

10. A house burns down. On the house across the street, all of the vinyl siding is twisted and warped by the heat. The heat was transferred across the street by

Answer: _____

11. Warm air over the beach rises while cooler dense air from the ocean rushes in due to

Answer: _____

12. A huge rock at the provincial park gets so hot during the day that you can't sit on it because of

Answer: _____

13. You lie on that same rock at night so that you can keep warm by

Answer: _____

14. A fireman feels a door, which is hot from the fire on the other side due to

Answer: _____

Answer Key: Self-Test C-1.18 is on the other page.

Answer Key: Self-Test C-1.18

1. As hot coffee is stirred with a spoon, the spoon gets hot due to
    a. conduction
2. A chair is placed several feet from a fire in a fireplace. The fireplace has a glass screen. The side of the chair facing the fireplace gets warm because of
    a. radiation
3. A certain type of decorative lamp contains coloured liquids. These liquids form globs that break off and rise to the top of the liquid. The globs rise due to
    a. convection
4. Near the ceiling of a room, the air is warmer. The warm air rises because of
    a. convection
5. A college student holds the back of his hand near an iron to see if it is hot. Heat is transferred to his hand by
    a. radiation
6. A heater is placed under one corner of a waterbed mattress. Warm water moves throughout the mattress because of
    a. convection
7. A certain type of stainless steel cookware has a layer of copper applied to the bottom to help it heat evenly. The copper transfers heat to the pan by
    a. conduction
8. In a swimming pool, the water near the surface is slightly warmer. The warm water rises because of
    a. convection
9. One end of a copper tube is placed in a torch flame. Small pieces of flux placed along the tube melt at a progressively further distance from the flame. Heat is transferred through the tube by
    a. conduction
10. A house burns down. On the house across the street, all of the vinyl siding is twisted and warped by the heat. The heat was transferred across the street by
    a. radiation
11. Warm air over the beach rises while cooler dense air from the ocean rushes in due to
    a. convection
12. A huge rock at the provincial park gets so hot during the day that you can't sit on it because of
    a. radiation
13. You lie on that same rock at night so that you can keep warm by
    a. conduction
14. A fireman feels a door, which is hot from the fire on the other side due to
    a. radiation and conduction

Self-Test C-1.19: Perform Heat Load Calculations

Complete Self-Test C-1.19 and check your answers.

1. Define specific heat.

Answer: _____

_____

_____

_____

2. Define sensible heat.

Answer: _____

_____

_____

_____

3. Define latent heat.

Answer: _____

_____

_____

_____

4. Give the BTU values for the following:

   a. specific heat for ice _____ $\frac{\text{BTU}}{\text{lb.}}^{\circ}\text{F}$

   b. specific heat for water _____ $\frac{\text{BTU}}{\text{lb.}}^{\circ}\text{F}$

   c. specific heat for steam _____ $\frac{\text{BTU}}{\text{lb.}}^{\circ}\text{F}$

   d. latent heat of fusion (water) _____ $\frac{\text{BTU}}{\text{lb.}}$

   e. latent heat of vaporization (water) _____ $\frac{\text{BTU}}{\text{lb.}}$

5. How many BTUs are required to raise the temperature of 39 pounds of water at 47°F to water at 212°F?

Answer: _____ BTU

6. How many BTUs are required to raise the temperature of 17 lb. of ice at 3°F to water at 79°F?

Answer: _____ BTU

7. How many BTUs are required to raise the temperature of 23 imperial gallons of water at 150°F to steam at 225°F?

Answer: _____ BTU

8. How many BTUs are liberated when 183 pounds of steam are cooled from 250°F to –18°F ice?

Answer: _____ BTU

9. How many pounds of ice at 12°F could we change to water at 121°F if we introduced 145,000 BTU to the container?

Answer: _____ BTU

10. How many BTUs will it take to heat 4,124 lb. of ice at –17°F to steam at 233°F?

Answer: _____ BTU

11. How many pounds of steam at 245°F could we change to ice at –77°F if we removed 900,500 BTUs from the substance?

Answer: _____ BTU

12. How many BTUs would it take to heat 256 lb. of ice at –55°F to steam at 259°F?

Answer: _____ BTU

13. How many BTUs would it take to warm up a swimming pool by 20°F if the pool measured $16' \times 20'$ and had an average depth of 5′?

Answer: _____ BTU

14. How many BTUs would it take to warm up a hot tub by 25°F if the tub measured 6′ in diameter and had a depth of 4′?

Answer: _____ BTU

Answer Key: Self-Test C-1.19 is on the other page.

Answer Key: Self-Test C-1.19

1. Define specific heat.
    a. Specific heat is the amount of heat necessary to raise the temperature of 1 lb. of a substance 1 °F.
2. Define sensible heat.
    a. Sensible heat is the heat energy gain or loss that will cause the temperature of a substance to change.
3. Define latent heat.
    a. Latent heat is the heat energy gain or loss that will cause the physical state of a substance to change.
4. Give the BTU values for the following:
    a. specific heat for ice
        i. $0.5 \frac{\text{BTU}}{\text{lb.}}{}^{\circ}\text{F}$
    b. specific heat for water
        i. $1 \frac{\text{BTU}}{\text{lb.}}{}^{\circ}\text{F}$
    c. specific heat for steam
        i. $0.5 \frac{\text{BTU}}{\text{lb.}}{}^{\circ}\text{F}$
    d. latent heat of fusion (water)
        i. $144 \frac{\text{BTU}}{\text{lb.}}$
    e. latent heat of vaporization (water)
        i. $970 \frac{\text{BTU}}{\text{lb.}}$
5. How many BTUs are required to raise the temperature of 39 pounds of water at 47°F to water at 212°F?
    a. 6,435 BTU
6. How many BTUs are required to raise the temperature of 17 lb. of ice at 3°F to water at 79°F?
    a. 3,493.5 BTU
7. How many BTUs are required to raise the temperature of 23 imperial gallons of water at 150°F to steam at 225°F?
    a. 238,855 BTU
8. How many BTUs are liberated when 183 pounds of steam are cooled from 250°F to –18°F ice?
    a. 244,854 BTU
9. How many pounds of ice at 12°F could we change to water at 121°F if we introduced 145,000 BTU to the container?
    a. 597 lb.
10. How many BTUs will it take to heat 4,124 lb. of ice at –17°F to steam at 233°F?
    a. 5,480,796 BTU
11. How many pounds of steam at 245°F could we change to ice at –77°F if we removed 900,500 BTUs from the substance?

a. 659.7 lb.

12. How many BTUs would it take to heat 256 lb. of ice at −55°F to steam at 259°F?

    a. 348,416 BTU

13. How many BTUs would it take to warm up a swimming pool by 20°F if the pool measured $16' \times 20'$ and had an average depth of 5′?

    a. 1,996,800 BTU

14. How many BTUs would it take to warm up a hot tub by 25°F if the tub measured 6′ in diameter and had a depth of 4′?

    a. 176,432 BTU

Self-Test C-1.20: Describe Characteristics of Hydrocarbon Gases

Complete Self-Test C-1.20 and check your answers.

1. What is the name of the chemical grouping of petroleum gases?

Answer: _____

2. Name the three most commonly used fuel gases.

a. _____

b. _____

c. _____

3. What are the main components of natural gas?

a. _____

b. _____

4. What are the names given to the ratio of the weight of a given volume of a gas compared to the weight of the same volume of air?

a. _____

b. _____

5. What is the relative density of each of the following gases?

a. natural gas _____

b. propane gas _____

c. butane gas _____

d. air _____

6. What is the ignition temperature (°F) of each of the following gases?

a. natural gas _____

b. propane gas _____

c. butane gas _____

7. What are the six major factors that affect the flow of gas in a piping system?

a. _____

b. _____

c. _____

d. _____

e. _____

f. _____

8. What is the specific gravity of each of the following LP liquids?

a. propane gas _____

b. butane gas _____

9. What is the calorific value of each of the following fuel gases in $\frac{\text{BTU}}{\text{ft.}^3}$?

a. natural gas _____

b. propane gas _____

c. butane gas _____

10. What is the calorific value of each of the following fuel gases in $\frac{\text{kW}}{\text{m}^3}$?

a. natural gas _____

b. propane gas _____

c. butane gas _____

11. What is the calorific value of each of the following fuel gases in $\frac{\text{kW}}{\text{ft.}^3}$?

a. natural gas _____

b. propane gas _____

c. butane gas _____

12. What is the calorific value of the following fuel gases in $\frac{\text{BTU}}{\text{m}^3}$?

a. natural gas _____

b. propane gas _____

c. butane gas _____

13. What is added to fuel gases to make leaks more noticeable?

Answer: _____

Answer Key: Self-Test C-1.20 is on the other page.

Answer Key: Self-Test C-1.20

1. What is the name of the chemical grouping of petroleum gases?
    a. hydrocarbons
2. Name the three most commonly used fuel gases.
    a. natural gas
    b. propane
    c. butane
3. What are the main components of natural gas?
    a. methane
    b. ethane
4. What are the names given to the ratio of the weight of a given volume of a gas compared to the weight of the same volume of air?
    a. specific gravity
    b. relative density
5. What is the relative density of each of the following gases?
    a. natural gas
        i. 0.6
    b. propane gas
        i. 1.5
    c. butane gas
        i. 2.0
    d. air
        i. 1.0
6. What is the ignition temperature (°F) of each of the following gases?
    a. natural gas
        i. 1,100-1,200 °F
    b. propane gas
        i. 920-1,020 °F
    c. butane gas
        i. 900-1,000 °F
7. What are the six major factors that affect the flow of gas in a piping system?
    a. type of gas
    b. type of pipe
    c. length of pipe
    d. diameter of pipe
    e. number of fittings
    f. pressure drop
8. What is the specific gravity of each of the following LP liquids?
    a. propane
        i. 0.51

b. butane

i. 0.58

9. What is the calorific value of each of the following fuel gases in $\frac{\text{BTU}}{\text{ft.}^3}$?

a. natural gas

i. $1,000 \frac{\text{BTU}}{\text{ft.}^3}$

b. propane gas

i. $2,500 \frac{\text{BTU}}{\text{ft.}^3}$

c. butane gas

i. $3,200 \frac{\text{BTU}}{\text{ft.}^3}$

10. What is the calorific value of each of the following fuel gases in $\frac{\text{kW}}{\text{m}^3}$?

a. natural gas

i. $10.35 \frac{\text{kW}}{\text{m}^3}$

b. propane gas

i. $25.86 \frac{\text{kW}}{\text{m}^3}$

c. butane gas

i. $33.1 \frac{\text{kW}}{\text{m}^3}$

11. What is the calorific value of each of the following fuel gases in $\frac{\text{kW}}{\text{ft.}^3}$?

a. natural gas

i. $0.293 \frac{\text{kW}}{\text{ft.}^3}$

b. propane gas

i. $0.732 \frac{\text{kW}}{\text{ft.}^3}$

c. butane gas

i. $0.937 \frac{\text{kW}}{\text{ft.}^3}$

12. What is the calorific value of the following fuel gases in $\frac{\text{BTU}}{\text{m}^3}$?

    a. natural gas

        i. $35,310 \frac{\text{BTU}}{\text{m}^3}$

    b. propane gas

        i. $88,275 \frac{\text{BTU}}{\text{m}^3}$

    c. butane gas

        i. $112,992 \frac{\text{BTU}}{\text{m}^3}$

13. What is added to fuel gases to make leaks more noticeable?

    a. mercaptan

C-2 ELECTRICAL CONCEPTS AND PRINCIPLES OF ELECTRICITY

Plumber Apprenticeship Program – Level 1

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C-2 Electrical Concepts and Principles of Electricity Introduction

Understanding the basic principles of electricity is important for working safely and effectively in the trades. In this section, you will learn how electricity behaves, how circuits work, and how to read and use electrical information in practical situations.

Learning Objectives

After completing this section, you should be able to:

- Describe electron theory and the causes of electricity.
- Explain how electrical circuits work.
- Interpret basic wiring diagrams and electrical symbols.
- Measure electrical quantities using appropriate tools.
- Apply the principles of electricity to trade-related tasks.
- Use mathematics and science to help you solve trade-related problems.

Topic areas covered in this publication are in alignment with SkilledTradesBC Harmonized 2018 Program Outlines.

You will be required to reference publications and videos available online at WorkSafeBC.

Supplementary Resources

- Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus by Camosun College.

Terminology

The following terms may be used throughout this section. Note that some glossary terms may be in italics throughout the section content but are not included in this list. A complete list of terms for Section C-2 can be found in the **Glossary.**

- **AC generator:** A machine that makes electricity by spinning a coil or magnet, producing alternating current (AC). (Section C-2.1)
- **alternating current (AC):** Electricity that flows back and forth in a circuit many times per second. (Section C-2.1)
- **American wire gauge (AWG) system:** A standard way to measure how thick electrical wires are. Smaller numbers mean thicker wires. (Section C-2.1)
- **ammeter:** A tool used to measure how much electrical current is flowing in a circuit. (Section C-2.1)
- **Ampere's Force Law:** A law that explains how electricity flowing through a wire creates a magnetic force that can act on other wires carrying current. (Section C-2.1)
- **anode:** The electrode where electric current leaves a device or where oxidation happens in a chemical reaction. (Section C-2.1 and Section C-2.2)
- **block diagram (functional block diagram; block and line diagram)**: A diagram that shows how parts of a system work together in steps. (Section C-2.3)
- **cathode:** The electrode where electric current enters a device or where reduction happens in a chemical reaction. (Section C-2.1)
- **cation:** A positively charged ion (an atom that has lost electrons). (Section C-2.1)
- **circuit breaker:** A safety device that automatically shuts off electricity when too much current flows. (Section C-2.1)
- **clamp-on ammeter**: A tool that measures current by clamping around a wire without touching it directly. (Section C-2.4)
- **closed circuit:** A complete path that allows electricity to flow. (Section C-2.1)
- **conductor:** A material, usually metal, that allows electricity to flow easily. (Section C-2.1)
- **continuity**: When electricity can flow through a circuit without a break. (Section C-2.4)
- **coulomb:** A unit used to measure electric charge. (Section C-2.1)
- **current (amperage):** The flow of electrical charge through a circuit. (Section C-2.1)
- **direct current (DC):** Electricity that flows in one direction only. (Section C-2.1)
- **electrical symbols:** Simple drawings used to represent electrical parts in a diagram. (Section C-2.3)
- **electrical circuit:** A complete path that allows electricity to travel from a source, through components, and back again. (Section C-2.1)
- **electricity:** The flow of tiny particles called electrons through a material, usually a wire. (Section C-2.1)
- **electromagnetism:** The force created by electricity and magnetism working together, such as when electric current makes a magnet. (Section C-2.1)
- **electromotive force (EMF):** Another name for voltage; the force that pushes electricity through a circuit. (Section C-2.2)
- **fuse:** A safety device that melts and breaks a circuit if too much current flows. (Section C-2.1)
- **induction:** The process of creating electrical current using a changing magnetic field. (Section C-2.1)
- **in series**: A way of connecting a meter so that electricity must flow through the meter as part of the circuit, allowing all the electrical current to flow through it before moving on. (Section C-2.4)
- **load:** A device that uses electrical energy to do work, such as producing heat, light, or motion. (Section C-2.1)
- **magnetic field:** An invisible area around a magnet or electrical current where magnetic forces can be felt.

(Section C-2.1)

- **milliamps (mA):** A unit used to measure small electrical currents; 1 milliamp equals 0.001 amps; small amounts of electrical current measured by a meter, where one milliamp equals one-thousandth of an amp. (Section C-2.4)
- **multimeter:** A tool that can measure voltage, current, and resistance in a circuit. (Section C-2.3; Section C-2.4)
- **Ohm's law:** A rule that shows the relationship between voltage, current, and resistance in a circuit. (Section C-2.1)
- **open circuit:** A broken path that prevents electricity from flowing. (Section C-2.1)
- **parallel circuit:** A circuit with more than one path for electricity to flow. (Section C-2.1)
- **pictorial diagram (or schematic):** A diagram that shows electrical parts as they actually look in real life. (Section C-2.3)
- **polarity:** The arrangement of positive and negative connections in a circuit, which determines the direction electricity flows; the correct way to connect meter leads to positive (+) and negative (–) points so the meter reads properly. (Section C-2.4)
- **power:** The rate at which electrical energy is used or converted into other forms of energy. (Section C-2.1)
- **relay:** An electrically controlled switch that uses a small current to control a larger one. (Section C-2.1)
- **resistance:** The opposition to the flow of electrical current in a circuit. (Section C-2.1)
- **schematic diagram (ladder diagram):** A diagram that uses symbols to show how an electrical circuit works. (Section C-2.3)
- **series circuit:** A circuit with only one path for electricity to follow. (Section C-2.1)
- **single-phase power:** A type of electrical power that uses one alternating voltage supply, commonly found in homes. (Section C-2.1)
- **solenoid valve:** A valve that opens or closes using an electric current and a magnetic coil. (Section C-2.1)
- **switch:** A device used to open or close a circuit to control the flow of electricity. (Section C-2.1)
- **thermocouple:** A device made of two different metals that produces a small voltage when heated, used to measure temperature. (Section C-2.1)
- **thermoelectricity (thermoelectric effect):** The creation of electricity from heat differences between two materials. (Section C-2.1)
- **three-phase power:** A type of electrical power that uses three alternating voltages, commonly used in commercial and industrial settings. (Section C-2.1)
- **transformer:** A device that increases or decreases voltage in an alternating current (AC) circuit. (Section C-2.1)
- **voltage:** The electrical pressure that pushes current through a circuit. (Section C-2.1)
- **voltage drop:** The loss of voltage as electricity moves through a circuit or component. (Section C-2.1)
- **voltmeter:** A tool used to measure the voltage between two points in a circuit. (Section C-2.3)
- **wiring diagram:** A drawing that shows how wires and components are connected in a circuit. (Section C-2.3)
- **watt (W):** The unit used to measure electrical power. (Section C-2.1)

C-2.1 Electron Theory and Causes of Electricity

Electricity

Electricity is a form of energy that has the ability to do work. Energy cannot be created or destroyed; it merely changes from one form to another. Electricity is the movement of ***electrons***, and it can be converted to ***light energy***, ***mechanical energy***, and ***heat energy***. These electrons can be harnessed, stored and put to work. To understand how this is done, the theory of the electron must be examined.

Pipe trades workers are required to use electricity daily and require a basic understanding of the predictable and measurable nature of electricity and ***electrical circuits***. Understanding electricity is crucial for the following:

- Using, troubleshooting, and maintaining electrical power tools
- Installing, troubleshooting, and servicing electrical appliances like hot water storage tanks, boilers and pumps
- Installing and troubleshooting electrical control systems like those found in heating and cooling
- Using multimeters safely

Matter

All *matter*, whether it is solid, liquid, or gas (Figure 1), is composed of tiny particles called ***atoms***. Millions of these atoms could be placed on the head of a pin and still not be seen. Atoms are composed of three even smaller particles: *electron*s, ***proton***s, and ***neutron***s (Figure 2).

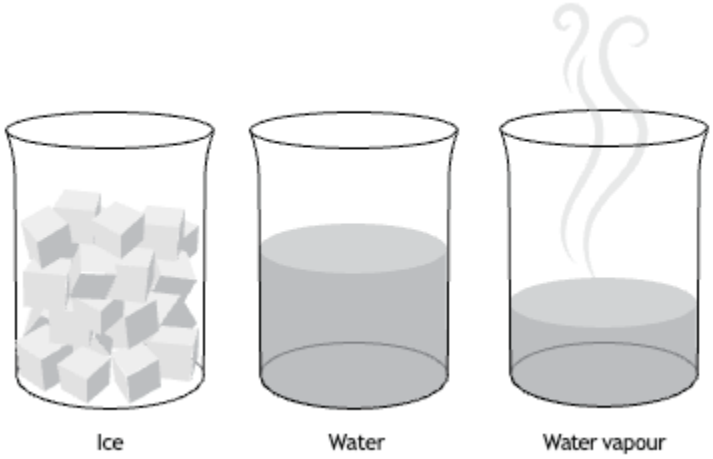

Figure 1 *States of matter* (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

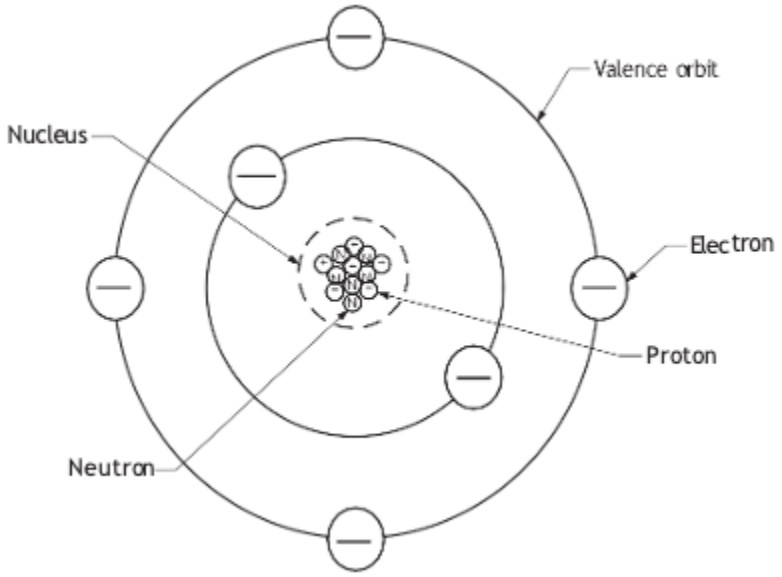

Figure 2 *The atom (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Atoms look very much like miniature solar systems. The sun is the core of the solar system; within the atom, the core is the *nucleus*, consisting of protons and neutrons tightly bound together. The sun has planets revolving around it; the atom's "planets" are its electrons, which revolve around it at extremely high speeds (approximately 299,792 km/s or 186,000 miles/s).

In the solar system, the gravitational pull of the sun (its nucleus) holds its planets in orbit around it. The atom differs in that the protons and electrons are ***charged particles*** that attract one another, holding the atom together. Electrons have a negative (−) charge, and protons have a positive (+) charge. Neutrons are neutral and have no charge. Since opposite charges attract and like charges repel, the oppositely charged protons and electrons attract one another, holding electrons in orbit around the nucleus.

Electron orbits, called *shells* (Figure 3), vary in their distance from the nucleus. The electrons farthest from the nucleus are not bound as strongly to the atom. Atoms with one to three electrons in their outermost, or ***valence shell***, are considered to be ***conductor***s. Under certain conditions, electrons in the valence shell can be knocked out of their orbits and become "free" electrons.

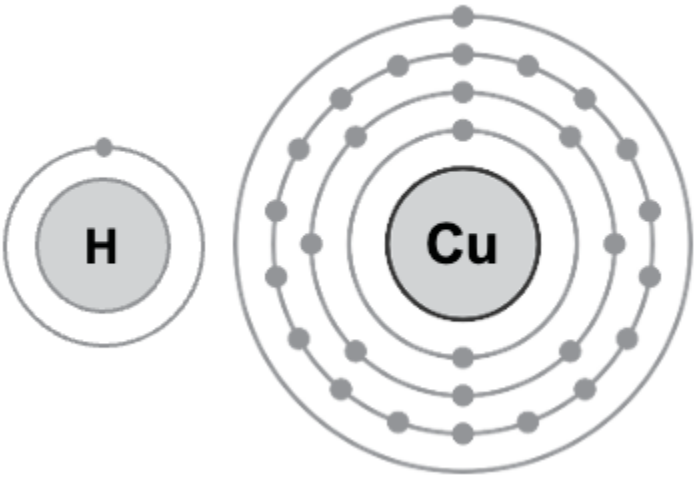

Figure 3 *Orbital shells of hydrogen and copper (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

When this happens, an atom has more protons than electrons and is said to be *ionized*. In this condition, the atom has a positive charge and is called a ***cation***. Since atoms normally have an equal number of protons and electrons, the positively charged atom would then try to pick up a stray electron to balance itself. This new electron might come from an atom nearby that may be experiencing the same condition that excited its atoms, and the process would repeat. Thus, there is a flow of electrons from atom to atom, and this is called ***electricity***.

Fundamentals of Magnetism

A basic understanding of ***magnetism*** will help in your understanding of electricity. There are three classes of magnets: natural, artificial, and electric. Natural magnets, such as ***magnetite***, are very weak and are not commonly used in the trades.

Artificial magnets are made from magnetic material such as iron, nickel, or cobalt and are permanently induced with magnetic force (magnetized) during their construction. They are used in devices such as electric motors, credit cards, and speakers.

The ***electromagnet*** is created by pushing a current through a coiled conductor and can be turned on and off.

All magnets have specific rules that govern their operation:

1. Magnets have two poles, north and south. Like poles will repel, and unlike poles will attract. This rule highlights the magnetic force associated with magnets and explains the science behind a compass.
2. Magnetic lines of force (flux lines) are continuous and form loops from the north pole to the south pole.

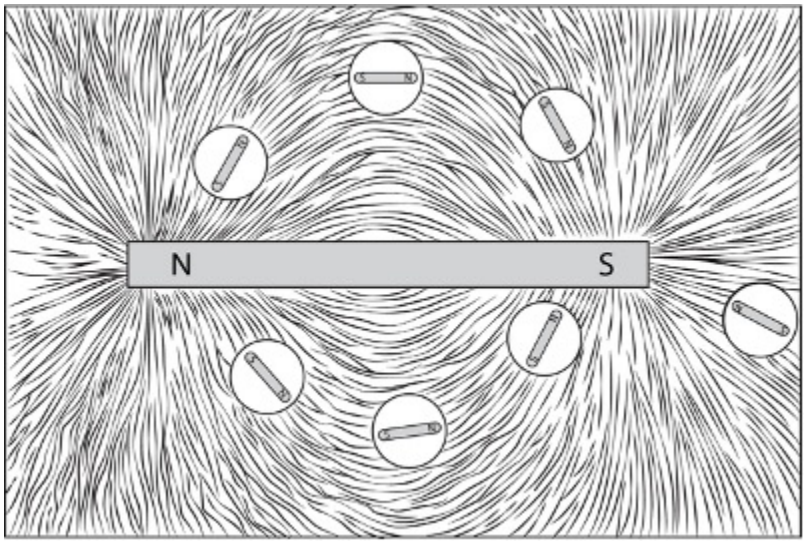

Figure 4 *Magnetic lines form loops (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

3. Magnetic lines of force never cross. This is illustrated in Rule 1: like poles repel. As these lines cannot cross, they must act against each other.

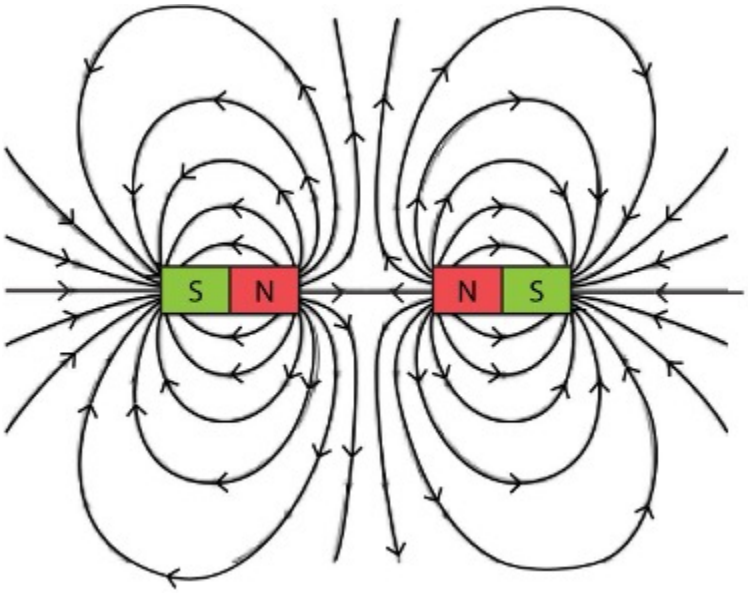

Figure 5 *Magnetic lines never cross (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

4. Lines of flux form tight loops when unlike poles attract. This is illustrated in Rule 1: unlike poles attract. These tight loops act like rubber bands constricting, forcing two magnets to become one.

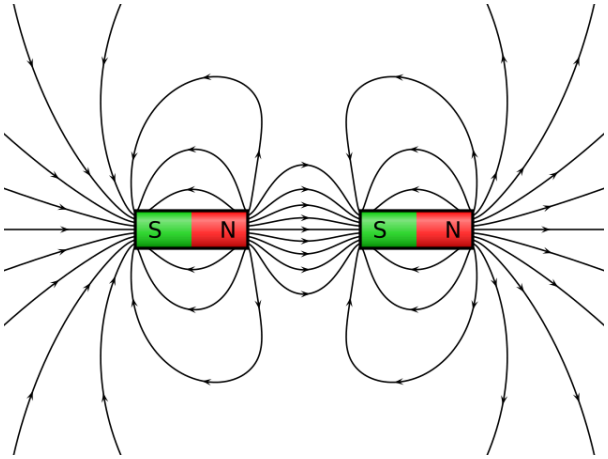

Figure 6 *Lines of flux form tight loops (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

5. Magnetic lines of force can pass more easily though materials that can be magnetized. This property is called *permeability*, the measure of response to a magnetic field of force.
6. There is NO insulation against magnetic lines of force.

Electricity and Magnetism

Electricity and magnetism are directly related. If a current is pushed through a ***conductor***, magnetic lines of force, or magnetic force, are created around it. If a conductor moves through a magnetic field, or a magnet moves through a coiled conductor, the moving magnetic field will induce a ***voltage*** potential. The faster the magnet moves, the stronger the voltage.

We see this phenomenon of ***electromagnetism*** in the generation of AC current, where kinetic energy, like falling water through a hydro dam, turns a conductor through a magnetic field called an **AC *generator***, producing *voltage* potential. We see it in equipment such as a ***solenoid valve***, where a current flow actuates a *valve stem* to control flow of fluid through the valve or a current pushed through a coil around a magnet moves an electrical motor. In each, the higher the voltage potential, the stronger the magnetic force, and vice versa.

We see the relationship between electricity and magnetism in ***Ampere's Force Law*** that explains the magnetic force of attraction and repulsion by two wires carrying current. Taken further, this law explains what happens when a conductor is formed into a loop (see Transformers in C-2.2 Electrical Circuits).

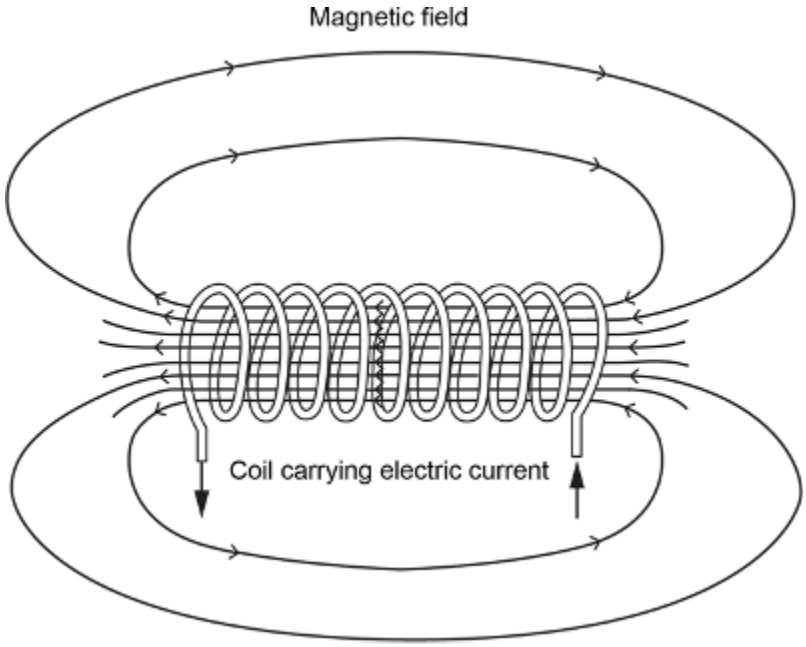

Figure 7 *Conductor formed into a loop (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Conductors

To use electrons (electricity) to do work, they must be transported from one place to another. Electrons can be made to flow in all matter; however, this flow is much easier in some kinds of matter than others. The atoms of some matter tend to hold on to their valence electrons very tightly, while other forms of matter easily lose their valence electrons. To transport electrons, select material that permits easy flow. These materials are called ***conductor***s. Examples of good conductors are silver, copper, aluminum and mercury. Conductive material is usually formed into wire. Wire permits easy transportation of electrons over great distances.

Conductors in the form of wires are one of the four basic components of an electric circuit. Conductors are not all equal in composition, and there are possible dangerous consequences of choosing the wrong size or type of conductor.

The quantity of electrons that can be safely transferred by a conductor depends upon the diameter of the conductor (Figure 8). If too many electrons flow through a small conductor, large amounts of heat are generated and, as the undersized conductor heats up, the wire's ***resistance*** tends to rise, creating a feedback loop that has the potential for fire. Therefore, the cross-sectional area of a conductor is the basis for sizing conductors or wire. Conductors are sized according to gauge numbers. In the ***American wire gauge*** **(AWG)** system of wire sizing, the lower the gauge number, the larger the cross-sectional area and the greater the flow of electrons (simplified: "lower number = thicker wire"). AWG, along with wire material selection, factors in the choosing of an appropriate conductor in a given system. Actual conductor selection goes beyond the scope of this material.

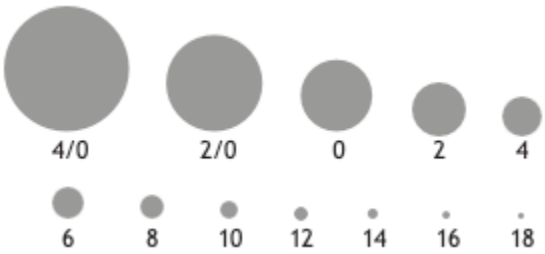

Figure 8 *Conductor wire sizes (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Insulators are materials with extremely low conductivity (Figure 9). They have five to seven electrons in their ***valence shell*** and cling tightly to their valence electrons. Some examples of good insulators are rubber, wood, glass, and cork. The properties of conductors and insulators are essential in utilizing electricity. Conductors put electricity where it is needed, while insulators isolate the flow of electricity.

Figure 9 *Insulators (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Sources of Electromotive Force

It is necessary to have a force or pressure to make electricity flow through a path called a ***circuit***. Electrical pressure, like most other pressures, is a force. It is this force that creates the action and keeps the electrons moving in a circuit. This electrical pressure is called ***electromotive force (EMF)*** and is measured in units called ***volts***. Voltage is the potential pressure difference measured between two points in an electrical circuit, and 6.24 quintillion (6.24 × 1018) electrons gathered at one point are known as a ***coulomb*** of potential. Voltage potential describes the source in a circuit, such as a storage battery or an AC source, and is one of the four basic components of an electric circuit.

There are six principal causes of electromotive force or potential:

- Heat
- Magnetism
- Chemicals

- Pressure
- Friction
- Light

Heat

When heat is applied to two dissimilar metals at the point where they are joined, electrons move from one metal to the other, and electricity is produced. This method is known as ***thermoelectricity*** and is called the ***thermoelectric effect***.

The more heat applied, the greater the amount of electric charge produced. The electric charge created is a result of differences in temperatures within the hot and cold junctions of the metals and the different ability that each metal has in holding on to its electrons. Each of the metals responds to the difference in temperature in different ways. Electrons will flow from the material that gives up its electrons easily (the ***anode***) to the other material, which has a greater tendency to hold on to its electrons (the ***cathode***).

A good example of this method of generating electricity used in the heating trade is a ***thermocouple*** (Figure 10). A thermocouple is made of two dissimilar metals welded together at the tip. When a pilot flame is directed at the tip of a thermocouple, a charge of electricity is created at the thermocouple's ***cold junctions***. The connection of the cold junctions to a safety shutoff valve causes current to flow through a coil of wire within the valve, energizes an electromagnet that holds the valve in the open position, and allows gas to flow to the appliance.

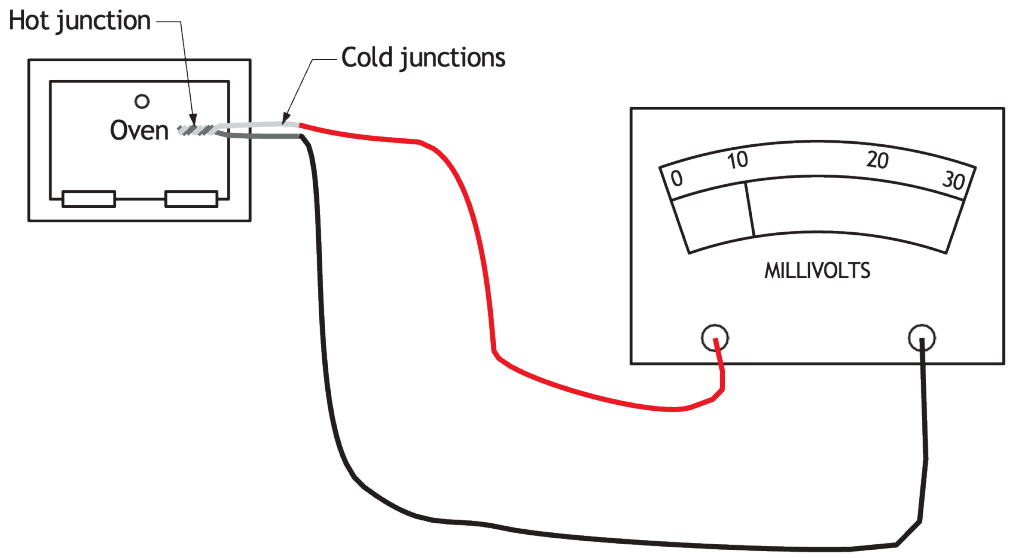

Figure 10 *Heat used to generate electricity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Magnetism

Moving a ***conductor*** through a *magnetic field*, or moving a magnetic field across a conductor, induces a ***voltage*** and causes an electric current to flow. This process, known as ***electromagnetic induction***, is a key principle of *electromagnetism*, and is used to generate alternating current (AC) electricity using permanent magnets.

The pressure of water or steam, as found in a nuclear or natural gas power plant, is used to rotate a coil of wire between the north and south poles of a magnetic field (Figure 11). The movement of the coil within the magnetic field induces current and voltage within the coil.

Watch the following video by Science ABC (2024) on YouTube titled "Electromagnetism Explained in Simple words" [4:13].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2411#oembed-1

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Electromagnetism Explained in Simple Words

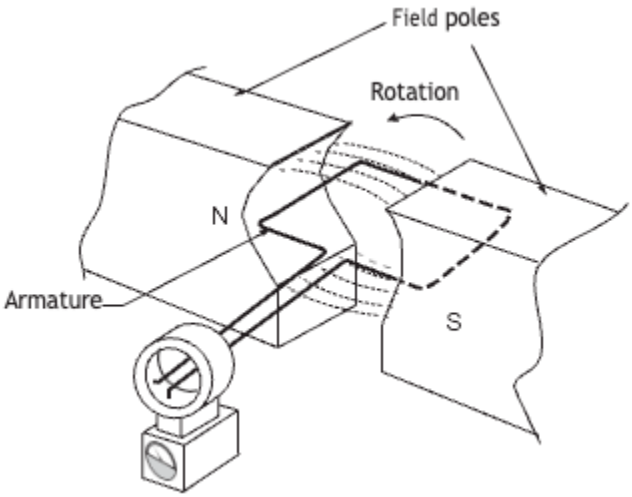

Figure 11 *Electricity created through magnetism (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Split-ring commutators, brushes and other devices are used to harness this energy, which is called ***alternating current (AC)***. In North American–generated voltage, current and voltage build up and drop off in a positive cycle, then build up and drop off in the opposite direction 60 times every second, a frequency of 60 ***hertz (Hz)***. In Europe, the generators are turned at slightly slower speeds, causing AC electricity to be generated at a frequency of 50 cycles per second, or 50 Hertz.

Chemicals

Batteries produce electricity through ***electrochemical reactions***. Each battery (or cell) contains electrodes and an electrolyte that allow charged particles to move. This process, called ***electrochemistry***, produces ***direct current (DC)*** electricity.

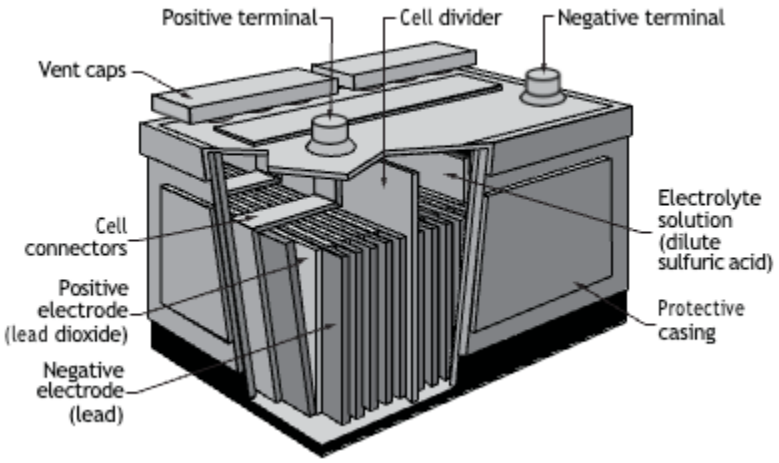

Figure 12 *Automobile battery (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

All batteries contain one or more cells, but people often use the terms battery and cell interchangeably. A cell is just the working chemical unit inside a battery; one battery can contain any number of cells. A cell has three main parts: a positive electrode (cathode), a negative electrode (anode), and a liquid or paste in contact with them called the ***electrolyte*** (Figure 12). When a battery is externally connected to an electric circuit, a chemical reaction takes place in the electrolyte. This causes ions (in this case, atoms with a positive electrical charge) to flow through the electrolyte in one direction, with electrons (particles with a negative charge) flowing through the outer circuit in the other direction. This movement of electric charge makes an electric current flow through the cell and through the circuit it is connected to.

It's important to note that **the electrodes in a battery are always made from two dissimilar materials.** This is the key to how and why a battery works: one of the materials, the anode, readily gives up electrons; the second material, the cathode, readily receives electrons. If both electrodes were made from the same material, there would be no exchange of electrons and no current would flow. This phenomenon is seen in a serious nuisance condition called ***electrolysis***, occurs naturally in metal systems such as underground pipelines, and causes material corrosion.

Pressure

Applying pressure to certain materials produces electricity. This is called ***piezoelectricity***. The force of the pressure passes through the material to its atoms and drives the electrons out of orbit toward the force. Positive and negative charges are built up on opposite sides of the material.

The effect is most noticeable in crystal materials. Piezoelectricity can be seen clearly in an ordinary spark igniter used to light a gas barbecue (Figure 13).

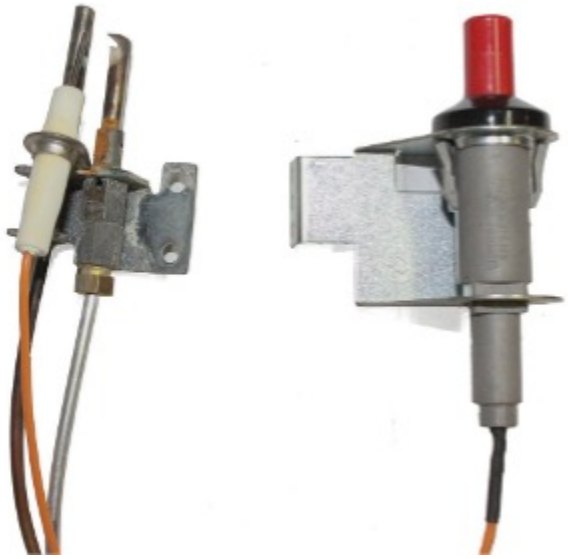

Figure 13 *Piezo igniter assembly (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Friction

If you walk across a carpet and get a shock when you touch a metal doorknob, or get a jolt from the door handle of a car, you have experienced the creation of electricity through ***friction***, which is known as ***triboelectricity or static electricity***. This occurs when two dissimilar materials are rubbed together, causing electrons to migrate to one of the materials. A path for the electrons to get to ground is completed when you touch the energized material and are in contact with the earth or ground through your feet. Large trucks carrying gasoline drag chains to constantly discharge any buildup of static electricity so that there cannot be any spark created once the truck stops moving. Lightning is an extreme effect of static discharge.

Light

Light is another form of energy and is thought to consist of small particles of energy called ***photons***. When a light beam strikes certain materials (including potassium and sodium), the energy from the photons causes the atoms to release electrons. This is called ***photoelectricity*** or the *photoelectric effect* (Figure 14). The best example of this is using the sun to generate electricity. Also known as ***photovoltaics***, using solar panels to generate electricity has become common these days.

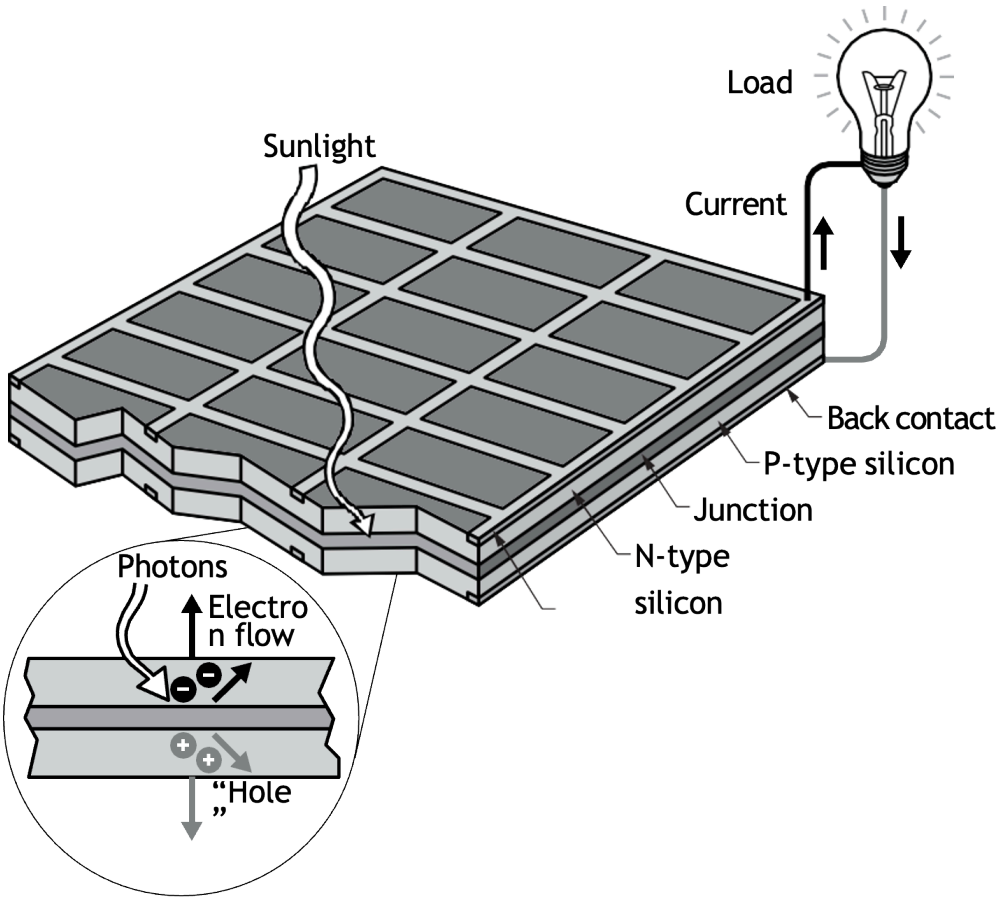

Figure 14 *Photoelectricity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Of these six causes of electricity, all but magnetism cause direct current (DC) voltage; magnetism or *electromagnetic induction* causes alternating current or (AC) voltage.

Self-Test C-2.1: Electron Theory and Causes of Electricity

Complete Self-Test C-2.1 and check your answers.

If you are using a printed copy, please find Self-Test C-2.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2411#h5p-29

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C-2.2 Electrical Circuits

Electrical circuits operate using three fundamental concepts: ***voltage***, ***current***, and ***resistance***. These concepts describe how electrical energy is supplied, how it flows, and how it is controlled within a ***circuit***. Understanding these three ideas is essential before working with any powered equipment or electrical components in the piping trades.

Voltage, Amperage and Resistance

To illustrate the three concepts involving an electrical circuit, consider a tank filled with water to a certain level as an analogy. At the bottom of this tank, there is a hose. If the hose is capped off, there will be head pressure available due to gravity but no flow will occur unless the cap is removed. This available pressure can be compared to ***voltage*** in an electrical circuit (Figure 1).

Voltage

Voltage is the electrical pressure or potential created by one of the six methods mentioned earlier: friction, pressure (piezoelectricity), heat (thermoelectric effect), light (photoelectric effect), chemical action, and magnetism (electromagnetic induction). This pressure is needed to push electrons through a circuit. One ***coulomb*** of electrical charge is defined as 6.28 quintillion (6.28×10^{18}) electrons, and 1 ***volt*** is defined as the electrical pressure needed to force 1 coulomb of charge through 1 ohm of resistance in 1 second. Voltage is the difference in potential between two points in a circuit, and without a source of voltage there can be no current flow.

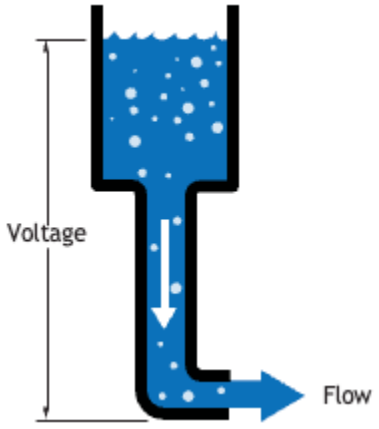

Figure 1 *Voltage (electrical pressure) (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Amperage

As electrons flow through a ***conductor***, their quantity can be measured. One method of measuring electron flow would be to select a single point on a conductor and count the electrons that pass that point. Since electrons are extremely small, it would be impractical. Instead, electron flow (or ***current***) is measured in large units called ***amperes (or amps)***. One ampere is 1 coulomb of charge passing a given point in a circuit in 1 second. It is the flow of current (amperage) that produces work in a circuit. Current must flow in order for lights to light or motors to turn.

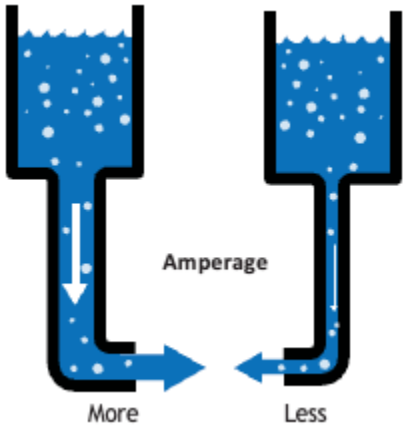

Figure 2 *Amperage (current flow)* (*BC Industry Training Authority*, 2019). CC BY-NC-SA 4.0

In our illustration, the amount of water flowing through the hose from the tank can be compared to ***current*** (Figure 2). The higher the water level, the higher the pressure and the higher the flow rate of water through the hose. A larger hose also allows a higher flow rate. With water, we measure flow as volume of water flowing through the hose over a certain period of time, usually expressed in gallons per minute or litres per second. Conductors (wires) in an electrical circuit are sized on their ability to carry amperage without causing excessive heat build-up.

Resistance

Resistance is generally associated with a ***load***, a basic component of an electric circuit that converts electricity into work. As electrons flow through a conductor, they have a tendency to crowd and push other atoms and electrons. This crowding is minimal and causes little resistance in the conductor. However, a load acts much like a funnel, in that it causes a greater crowding of the electrons and restricts flow. This resistance to flow creates heat as a byproduct, and in the case of a toaster or electric kettle this heat is desirable (Figure 3). However, when electricity is converted to light or mechanical energy (such as in a light bulb or motor), heat is an undesirable byproduct. Conductors must be sized to minimize this heat buildup. Resistance to current flow is measured in units called ***ohms***. In an AC circuit, an additional factor called ***impedance*** opposes electron flow. Impedance is also measured in ohms. For the sake of ease, we will use the term *resistance* to describe impedance in an AC circuit.

Figure 3 *Glowing filaments of a modern toaster (Nick Carson/en.wikipedia)* *CC BY 3.0*

Consider two water tanks: one with a narrow pipe and one with a wide pipe. A wider pipe can transport more volume than a narrow pipe under the same pressure. The narrow pipe "resists" the flow of water through it even though the water is at the same pressure as in the tank with the wider pipe (Figure 4).

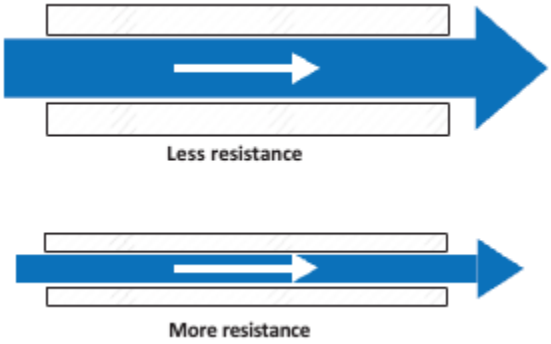

Figure 4 *Resistance in narrower pipe (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Ohm's Law

In 1827, German physicist Georg Simon Ohm discovered that there is a calculable relationship between electrical pressure, resistance, and current flow in any circuit, and his published theory is called ***Ohm's law***. Stated as an equation, depending on which value is unknown, Ohm's law can be expressed in three variations:

$$E = I \times R \quad R = \frac{E}{I} \quad I = \frac{E}{R}$$

where

$$E = \text{electromotive force (EMF) measured in volts}$$

I = intensity of current measured in amperes or amps

R = resistance measured in ohms

The abbreviations for each are V for volts, A for amps and the Greek symbol Ω (omega) for ohms. The omega symbol is used instead of the letter O, which could cause confusion if numbers precede the symbol.

Ohm's law is commonly presented as a learning triangle (Figure 5) in order to make the relationship between the three electrical entities easier to understand.

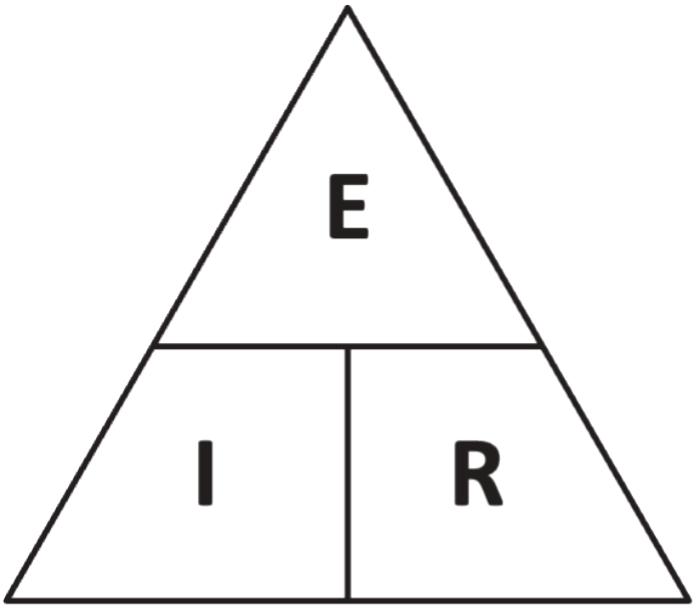

Figure 5 *Ohm's law triangle* (BC Industry Training Authority, 2019). *CC BY-NC-SA 4.0*

Ohm's law states that it takes 1 volt to push 1 ampere through 1 ohm of resistance and is a useful tool to assess a circuit and find unknown values.

Watch the following video by Tradestutor (2020) on YouTube titled *Ohms law quick and easy* [4:17].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#oembed-1

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video:

Ohms law quick and easy

Ohm's Law Put to Use

Example 1.

A 12 V battery pushes 3 A of current through a circuit. What is the resistance found in this circuit?

Solution.

The unknown value is R, resistance.

$$\text{Therefore } \mathrm{R} = \frac{\mathrm{E}}{\mathrm{I}}$$

$$\mathrm{R} = \frac{12\mathrm{V}}{3\mathrm{A}}$$

$$\text{Resistance} = 4\ \Omega$$

Example 2.

Given a circuit with a resistance of 10 Ω, an EMF of 24 V, what is the current flow?

Solution.

The unknown value is I, amperage.

$$\mathrm{I} = \frac{\mathrm{E}}{\mathrm{R}} \quad \mathrm{I} = \frac{24\ \mathrm{V}}{10\ \Omega} \quad \mathrm{I} = 2.4\ \mathrm{A}$$

Example 3.

If a circuit has a current flow of 2 amps and the resistance is 20 Ω, what is the pressure in volts?

Solution.

The unknown value is E, voltage.

$$\mathrm{E} = \mathrm{I} \times \mathrm{R} \quad \mathrm{E} = 2\ \mathrm{A} \times 20\ \Omega \quad \mathrm{E} = 40\ \mathrm{V}$$

Power

Voltage potential pushes electron flow though a load that changes electrical energy into other forms of energy, such as ***kinetic energy*** (in a motor) or heat and light (in a lamp). This work performed by the load is described as ***power (P)*** and measured in ***watts (W)***.

Power can be expressed as:

$$\mathrm{P} = \mathrm{E} \times \mathrm{I} \quad \mathrm{E} = \frac{\mathrm{P}}{\mathrm{I}} \quad \mathrm{I} = \frac{\mathrm{P}}{\mathrm{E}}$$

Where:

$$\mathrm{E} = \text{electromotive force, volts} \quad \mathrm{I} = \text{intensity of current, amps} \quad \mathrm{P} = \text{power, watts}$$

These relationships are often shown using a *Watt's law triangle* (Figure 6), which helps visualize the relationship between voltage, current, and power, and makes it easier to determine unknown values.

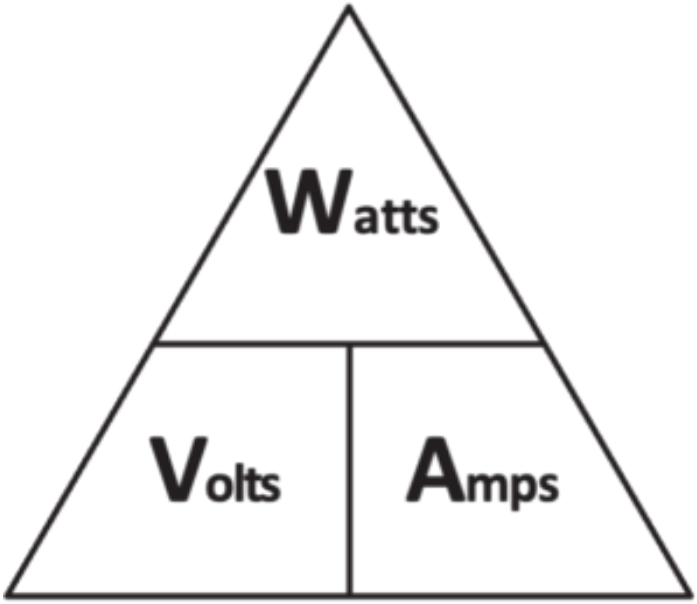

Figure 6 *Watt's law triangle (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Power Calculation Put to Use

Example 1.

\quad\text{What size [pb_glossary id="5466"]fuse[/pb_glossary] is appropriate for a 96 W bulb in a 12 V DC system?}

$$\mathrm{I} = \frac{\mathrm{P}}{\mathrm{E}} \quad \mathrm{I} = \frac{96\ \mathrm{W}}{12\ \mathrm{V}} \quad \mathrm{I} = 8\ \mathrm{A}$$

The fuse would need to be rated for more than 8 amps.

Example 2.

How much power would a soldering gun produce if it uses 6 A in a 120 VAC circuit?

$$\mathrm{P} = \mathrm{E} \times \mathrm{I} \quad \mathrm{P} = 120\ \mathrm{V} \times 6\ \mathrm{A} \quad \mathrm{P} = 720\ \mathrm{W}$$

Example 3.

Here we see how Ohm's law and the power calculation can be used together.

What is the correct theoretical resistance of a hot water tank element with a power rating of 4,500 W in a 240 VAC system? Note: this info, Watts and VAC, is given on the name plate of an element.

$$\mathrm{I} = \frac{\mathrm{P}}{\mathrm{E}} \quad \mathrm{I} = \frac{4,500\ \mathrm{W}}{240\ \mathrm{V}} \quad \mathrm{I} = 18.75\ \mathrm{A} \quad \mathrm{R} = \frac{\mathrm{E}}{\mathrm{I}} \quad \mathrm{R} = \frac{240\ \mathrm{V}}{18.75\ \mathrm{A}} \quad \mathrm{R} = 12.8\ \Omega$$

Summary

Electricity flowing through a conductor can be compared to water flowing through a hose. The voltage that forces electrons to flow through the conductor is comparable to the water pressure or ***psi*** that forces water through the hose. The amperage is the number of electrons that pass through the conductor and compares to the number of gallons of water that pass any given point over time. Resistance is similar to the friction between the water and the walls of the hose. In any electrical circuit, it is the electrical pressure or voltage from the source that causes electrons to flow, and in most circuits, this voltage is kept fairly constant. The amount of electron flow or amperage depends upon the resistance in the circuit. If the total resistance in the circuit is high, then the amperage will be low, and vice versa. If at any time the resistance of a given circuit is changed, then the amperage will also change.

Using Electric Current

For electric current to be usable, it must be able to travel from the source through the conductor to the load and then back to the source. As mentioned earlier, the source produces one of two basic types of electric current: *alternating current* (AC) or *direct current* (DC). Each has unique properties that make it more desirable than the other under certain circumstances.

Direct current (DC)

As mentioned earlier, chemicals, heat, pressure, light, and friction are all causes of direct current or DC voltage.

A battery is a common source of ***direct current (DC)*** (Figure 7). A battery will always have two poles or terminals: one negative and one positive. A chemical reaction inside the battery between the anode and the cathode causes electrons to move through an *electrolyte* (acid or alkali) to the negative terminal, giving it a negative (−) electrical charge (creating electrical flow). The other terminal has a corresponding lack of electrons, making its charge positive (+). If a wire is connected from a negative terminal to a light bulb and then to a positive terminal, electrons will flow through the conductors from the negative terminal to the positive terminal through the bulb, and the bulb will light.

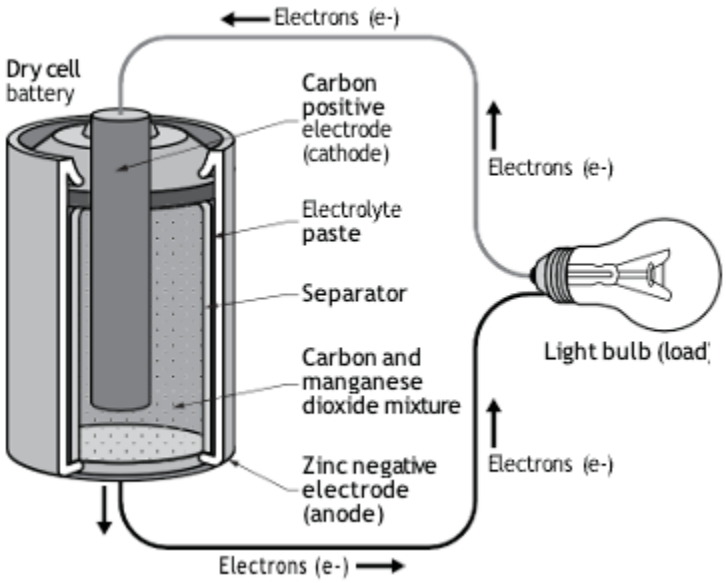

Figure 7 *A cell creating electricity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Although there are conflicting theories in the field, the most popular theory is that electron flow in a DC circuit is always negative-to-positive, and this direct current flows constantly in one direction until the circuit is broken or the source stops supplying electrons.

Another characteristic of any electron flow can be demonstrated using a DC power source, a square piece of cardboard, and some iron filings (Figure 8). A hole is cut through the centre of the cardboard. A wire is run from one terminal of a battery, through the hole in the cardboard, and back to the other battery terminal. Iron filings are lightly scattered on the cardboard, and the cardboard is gently tapped. The filings will arrange themselves in concentric circles on the cardboard around the conductor. This illustrates the presence of a magnetic field around the conductor whenever current flows through it. The iron filings align themselves with the magnetic field that exists while current flows. If the wires are disconnected, the magnetic field collapses and disappears, and the filings will no longer be arranged in any pattern. This illustrates the concept that a magnetic field is associated with any movement of electrons.

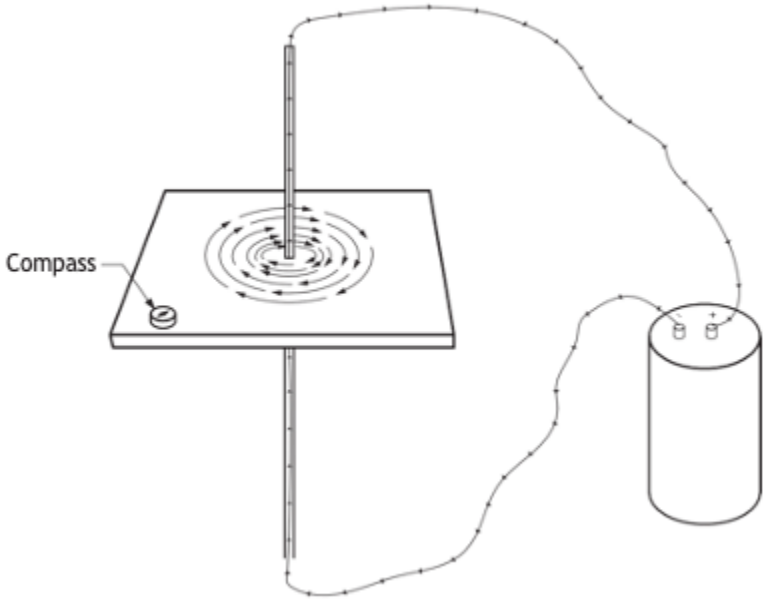

Figure 8 *Current flow in a conductor (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Alternating Current (AC) and Electromagnetic Induction

Alternating current* (AC)** is a current that flows through a conductor in one direction for a split second and then in the opposite direction for a split second. Current alternates because of the generation techniques used at the power plant. The power of steam or water spins a loop of wire within an external magnetic field. Current is produced in a conductor when it is moved through a magnetic field because the magnetic lines of force are applying a force on the free electrons in the conductor and causing them to move (Figure 9). This process of generating current in a conductor by placing the conductor in a changing magnetic field is called ***induction. It is called induction because there is no physical connection between the conductor and the magnet. The current is said to be ***induced*** in the conductor by the magnetic field.

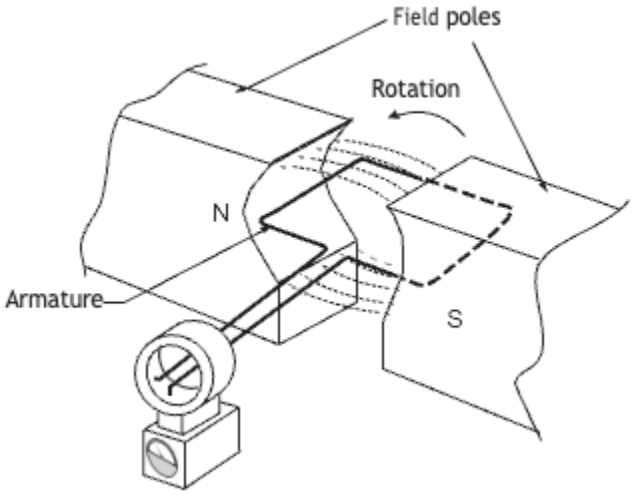

Figure 9 *Spinning a loop of wire within a magnetic field produces current and voltage (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

One requirement for this ***electromagnetic induction*** to take place is that the conductor, which is often a piece of wire, be perpendicular to the magnetic lines of force to produce the maximum force on the free electrons. The direction in which the induced current flows is determined by the direction of the lines of force and by the direction in which the wire is moving in the field. If an AC current is fed through a piece of wire, the electromagnetic field that is produced is constantly growing and shrinking due to the constantly changing current in the wire.

This growing and shrinking magnetic field can induce electrical current in another wire that is held close to the first wire. The current in the second wire will also be AC and, in fact, will look very similar to the current flowing in the first wire. It is common to wrap the wire into a coil to concentrate the strength of the magnetic field at the ends of the coil. Wrapping the coil around an iron bar will further concentrate the magnetic field in the iron bar. The magnetic field will be strongest inside the bar and at its ends (poles).

Here in North America, the generators that create alternating current might spin at a rate of 3,600 rpm (revolutions per minute), whereas in Europe it's slightly slower, perhaps 3,000 rpm.

As the coil moves through its rotation, it will experience a buildup and dropoff of current in a positive polarity through 180 degrees and then a buildup and dropoff in the other half-rotation but in a negative polarity. In North America, AC typically operates at 60 hertz (Hz), meaning the current changes direction 60 times per second, whereas in Europe, the frequency is 50 Hertz. An estimated 95% of all electricity generated and distributed in North America is alternating current.

Single-Phase Power Supply

Single-phase electric power refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly lighting and heating, and with a few large electric motors. Single-phase power comprises two independent voltages that are carried on two separate conductors or hot lines.

The two hot lines are called *Line 1* and *Line 2*. Single phase is typically found in residential and small commercial

applications. Single-phase AC supply voltage is commonly stepped from three-phase distribution to 120 or 240 VAC at point of use.

Three-Phase AC Power Supply

Three-phase AC electrical power refers to a type of electrical power distribution in which three or more energized electrical conductors are carrying alternating currents. Examples of three- phase power systems are industrial applications and power transmission. Three-phase power supply is used to power large motors and other heavy loads. A three-phase system is generally more economical than equivalent single-phase systems at the same voltage.

Three-phase power comprises three independent voltages that are carried on three separate conductors. The three hot lines are called Line 1, Line 2, and Line 3. Like single phase AC, three phase AC uses ***transformers***, described as delta and/or wye windings that provide multiple step-up or -down options. Three-phase power is typically found in commercial and industrial applications. Three phase AC supply is commonly stepped to 208 VAC at point of use.

Advantages of Using Alternating Current

For generating and distributing large quantities of electrical energy, alternating current is used rather than direct current. There are several reasons for this:

- Alternators can be manufactured with much higher voltage and power ratings than DC generators. In North America, large alternators commonly generate electrical voltages as high as 13,800 volts. The output windings called the armature can be mounted on the stationary part of the machine, and the magnetic field can be made to rotate by mounting it on the rotor. The current produced by an AC generator (alternator) need not pass through a set of commutators and brushes. It is the commutator and brushes in a DC generator that limit the maximum voltage and power rating of the machine.
- Alternating voltages can be easily stepped up and down. Transformers allow the alternating voltages to be stepped up at the source so that they can be transmitted long distances at higher voltages with lower currents. This reduces both line drop and line loss. At the load end, the transformers can step down the voltage to a lower, safer voltage for utilization. These transformers have efficiencies in the range of 95% to 99%. With DC voltages, this process is much more difficult and much less efficient.
- AC motors and controls are generally smaller, simpler, cheaper and more reliable than DC motors with similar ratings. Because AC induction motors do not require brushes, they are much more reliable. The brushes required in a DC motor need a lot of maintenance. Also, the initial cost of an AC induction motor is lower than that of a comparable DC motor.

Advantages of Using Direct Current

It is easy to understand how these advantages make alternating current a less expensive, more efficient and more reliable way of transmitting energy over long distances. However, there are some situations in which the use of direct current is a better choice. Sometimes it is the only choice.

- Direct current is required to produce the magnetic fields for alternators and synchronous motors. An alternating

current would produce a field with poles that constantly reverse.
- Electrochemical processes such as electroplating and battery charging require DC voltages.
- High-intensity light sources that use carbon arcs require direct current.
- Many manufacturing processes require very precise speed control of motors. In the past, it was not possible to get the same speed accuracy with AC motors as with DC motors. However, with the advent of variable-frequency drives, this is changing. Many applications that once required DC motors and controls are now using AC motors and variable-frequency drives.
- The use of DC traction motors on such equipment as electric trains and mining rock-trucks eliminates the need for transmissions, clutches and drive shafts.

A Simple Circuit

A ***simple circuit*** (Figure 10) contains four basic components:

1. **A power source**: Provides the voltage needed to push current through the circuit.
2. **Conductors:** Wires or pathways that allow current to flow.
3. **A control device:** Usually a switch that opens or closes the circuit.
4. **A load**: A device with resistance that performs work, such as producing heat, light, or motion.

In this type of circuit, the electrical energy supplied by the power source is used by the load and converted into useful work—for example, heating a toaster, lighting a bulb, or turning a motor.

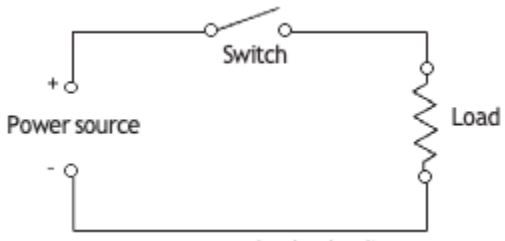

Figure 10 *A basic circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Switches

Switches are used to control a load in a circuit. A ***switch*** is a device that simply opens or closes an electrical circuit. A switch has at least two positions: open or closed. When a switch is open, no electricity can flow through it. An open switch will de-energize the load. When a switch is closed, electricity can flow through the circuit and energize the load. Circuits are called ***open*** or ***closed*** in conjunction with switches being opened or closed. Open means OFF, and closed means ON.

Most switches have two parts: a ***throw*** and a ***pole*** (Figure 11). The throw is the part of a switch that remains stationary. The pole is the part of the switch that moves to open or close the switch. When the pole is touching the throw, the switch is closed. Switches are described by the number of poles and throws they have. To throw a switch, the pole is

moved to another position. Thus, a throw is a position of the pole. The simplest switch is a single pole, single throw (SPST) switch. This means it has one pole (moving mechanism) and one throw (position) that the pole can make contact with. An example of an SPST switch would be the switch that turns your bedroom light on or off.

Figure 11 *Single pole switch configurations (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

If another contact is added to an SPST switch, it becomes a single pole, double throw (SPDT) switch. The pole can be thrown to one of two positions to energize one of two different circuits or loads. An example of an SPDT switch would be a three-way switch that operates a hallway light fixture. One of these switches at either end of the hallway can turn the light on or off.

Some household appliances such as electric ranges and water heaters require 240 volts AC. In this case, two circuits are connected to the two "***busbars***" within an electrical panel, each with 120 volts of potential but each being 180 degrees "***out of phase***" from each other. Electrical panels are designed so that two breakers installed side-by-side will each make contact with the different busbars (Figure 12). In this method, the voltages are added together and fed to the same piece of equipment through a cable that will have each of these voltages carried by a different-coloured insulated conductor, think a range fed with Lines 1 and 2 for 240 VAC. Typically, the colours of these two "*hot*" wires are red and black. The two breakers supplying the circuit will have their poles tied together for safety. This is to prevent one circuit from being de-energized without interrupting voltage to the other. Because the two switches are operated simultaneously and are either open or closed, the breaker would be categorized as double pole, single throw (DPST) (Figure 13).

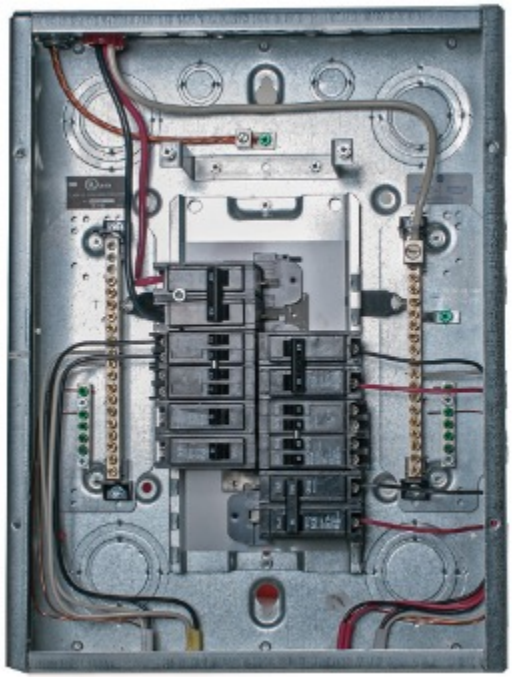

Figure 12 *Residential panel (BC Industry Training Authority, 2019/BCcampus [modified]). CC BY-NC-SA 4.0*

Figure 13 *Double pole switch configurations*

If another throw is added to the DPST switch, it becomes a double pole, double throw (DPDT) switch. Now the poles can make contact in two positions, such as might be found in a circuit that has a forward/reverse operation of a 240 volt piece of equipment.

If a single pole can be thrown so that it will make contact with any one of a number of contacts, it is called a ***rotary switch*** (Figure 14). An example of a rotary switch might be one that is used in an audio store to enable one set of speakers at a time to be listened to.

Figure 14 *Rotary switch (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Disconnect switches (Figure 15) should always be placed in the "hot" leg of a circuit and should be the first electrical device in the path from the source. All loads in the circuit can be de-energized by opening the disconnect switch. Only the contacts of the switch will have electrical potential when the switch is open, and the rest of the circuit can then be worked on safely.

Figure 15 *A utility disconnect switch to control power to a building. It controls 3-phase 120/208 V, 200A service to a commercial building. (Rsparks3/Wikimedia Commons) CC0 1.0*

Figure 15 *Disconnect switch (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Excessive current flowing through a circuit can be dangerous for both people and property. To protect against overheating of circuit components, especially wiring buried in walls and ceilings, something must be placed in the circuit to sense excessive current and open before danger arises. This protection is provided by circuit protectors. There are two main types of circuit protectors: fuses and circuit breakers.

Fuses

A ***fuse*** is used in a circuit to protect against wiring overloads (Figure 16). An overload occurs whenever there is too much current for the size of the wire. This could happen if too many loads are plugged into the same circuit. Because they would be wired in parallel to each other (covered later in this section), the amperage would increase and cause overheating of the conductors.

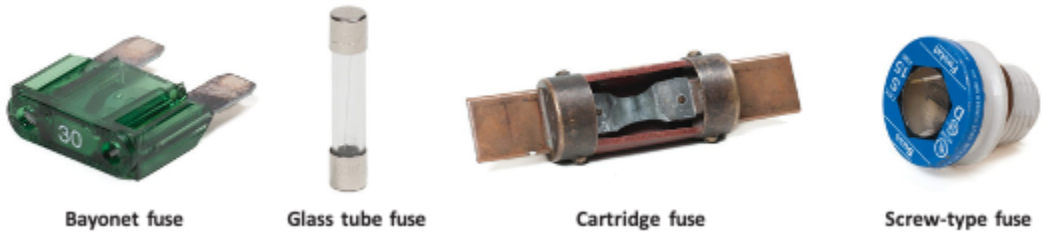

Figure 16 *Fuses (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Another example of an overload would be if a piece of metal fell across the bare wires of a circuit, in effect bypassing the load. This is known as a ***short circuit*** or *simply short* (Figure 17). This means that current has an unrestricted path from the source out and back, without encountering a load. If there is no load in the circuit, there is nothing to limit the

amount of current that is being pushed by the source voltage and, consequently the amperage will shoot up to an unsafe point, where it will cause overheating of conductors and possibly a fire.

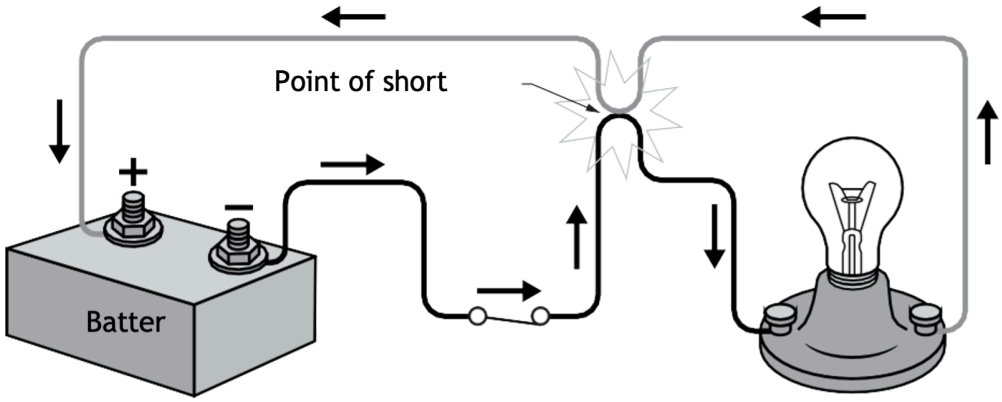

Figure 17 *Short circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A short could also occur if there is a malfunction in the load, such as the windings in a motor coming in contact with its ground connection. In these cases, the current will always take the path of least resistance, and electrons will surge through the short circuit back to the source. Since the wires in the circuit are sized for the normal operating amperage of the circuit, they are much too small to handle the high amperage cause by the short, so something must be installed in the circuit that will open it whenever current flow gets to an unsafe level.

Time-Delay Fuses

Time-delay fuses are designed and built to withstand the initial current load caused by the starting of electric motors. A motor will take several seconds to come up to speed after starting. This start takes more current than when the motor is up to its operating speed. If a fuse were sized for start-up, it would be too large to protect the wire in the circuit under normal operation, and if it were sized for normal operating amperage, it would blow each time the motor started.

A time-delay fuse has a metal fuse strip that has one end attached to the case of the fuse and the other end attached to a pin held under spring tension (Figure 18). The end of the pin is embedded in solder. If the solder gets hot enough to melt, the pin pulls out of the solder, breaking the circuit.

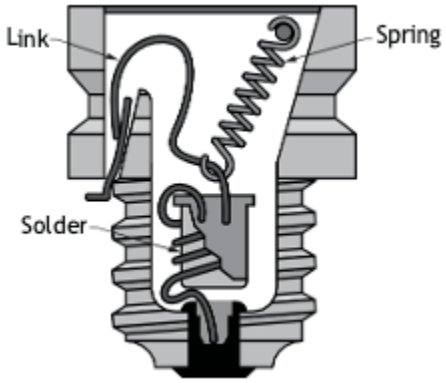

Figure 18 *Time-delay fuse (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

This solder will withstand a momentary overload (such as at motor start-up) without melting. If the heat from the overload is continuous, the solder melts and the circuit breaks. This might take several seconds. If a direct short should occur, the metal fuse strip melts instantly and opens the circuit.

Circuit Breakers

The other type of circuit protector is the ***circuit breaker*** (Figure 19). The advantage of circuit breakers over fuses is that the breakers can be reset whereas a fuse must be replaced.

Figure 19 *Circuit breakers (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Some circuit breakers look very much like a switch. They usually have a lever with "on" and "off" positions. When the switch is in the "on" position, current flows through a thermal device within the breaker. If excessive current flows through this device, which is simply a bimetal element that will warp when it gets hot, it "***trips***" the breaker and opens the circuit. When the breaker is tripped, the lever moves into a position that is indicated as neither "on" nor "off" to the observer, but the circuit is open. After the thermal element has cooled sufficiently, the breaker can be manually reset by cycling the lever to the "off" position and then "on." If the condition that caused the breaker to trip is still there, the breaker won't allow itself to stay in the "on" position.

Another type of circuit breaker looks like a regular strip fuse with a button protruding from the top. When this breaker trips, it can be manually reset by pushing the button.

Whenever a fuse blows or a breaker trips, the cause should be determined and corrected before replacing or resetting. In a 120 V household circuit, the fuses or circuit breakers are always placed in the energized portion of the circuit. In a 240 V circuit, both energized portions are fused.

Circuits

Before looking at the different ways electrical components can be connected, it is important to understand that a circuit is simply a complete path that allows current to flow. Circuits can be arranged in different ways depending on how we want the loads to behave. The two most common types are:

- *Series circuits* (one path)
- ***Parallel circuits*** (multiple paths)

Each type has different characteristics and uses.

Series Circuits

A ***series circuit*** is one in which electrons have only one path they may follow. Loads and switches are wired together end-to-end so that the electricity must pass through the first load to get to the second one, in much the same way as in a series loop hot water heating system (Figure 20). If three light bulbs with equal resistance are wired in series, electricity passing through one of the light bulbs must also pass through the other two in order for the bulb to light up. If one of the bulbs is removed, the path or circuit is broken and none of the bulbs will light. Old-fashioned Christmas lights were wired in series, and if one bulb went out, they all went out. Each bulb had to be tested one at a time until the bad bulb was found. A break in any part of a series circuit ends the flow of electricity throughout the circuit.

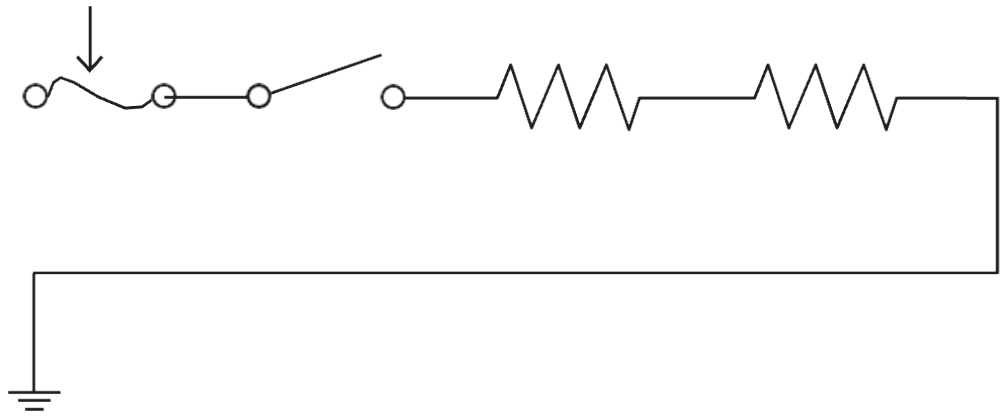

Figure 20 *Series circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

For Ohm's law calculations, the one constant is that the total resistance in a series circuit will be the sum of all individual

resistances in the circuit. For example, if two 20 ohm loads are wired in series, the total resistance of the circuit is 40 ohms (Figure 21).

Watch the following video by Tradestutor (2020) on YouTube titled "Series circuit Explanation (quick and easy)" [4:25].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#oembed-2

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Series circuit Explanation (quick and easy)

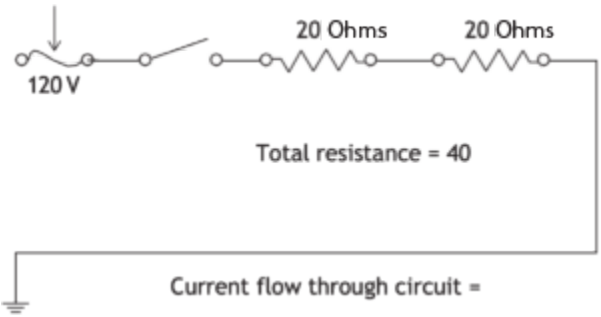

Figure 21 *Resistance in a series circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The amperage or current flow everywhere in a series circuit is equal. If an ammeter (an instrument that measures amperage) is placed at any point in the circuit, the amperage will be the same.

Amperage is determined by the total resistance in the circuit. If at any time the resistance in the circuit is changed, the rate of electron flow will be altered. If the total resistance goes up, then the amperage will decrease. If the total resistance drops, the amperage will increase.

The total resistance in a series circuit can be determined by using a ***voltmeter*** (an instrument that measures voltage difference between two points) to measure the voltage drop across each load. ***Voltage drop*** is the amount of voltage used at each load. The total circuit voltage will be the sum of the individual voltage drops. For example, the voltage drop across the two loads in the circuit shown in Figure 22 will be 60 volts each. This phenomenon is known as ***Kirchhoff's law*** and is seen in all series circuits. Not all circuits have loads of equal resistance, but Kirchhoff's law still applies: the sum of the voltage drop across each individual load will equal the supply voltage.

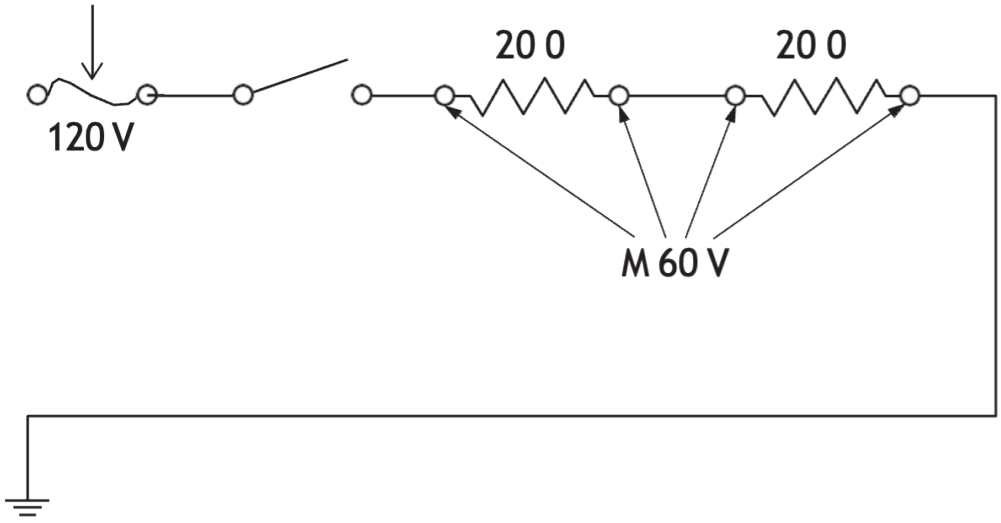

Figure 22 *Voltage drop across loads (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A series circuit will exhibit the following characteristics:

1. The total resistance of the circuit is equal to the sum of the resistances of the individual loads of the circuit.
2. The amperage or current is the same through all parts of the circuit.
3. Kirchhoff's law states the total voltage applied to the circuit is equal to the sum of the voltage across the individual loads. The voltage drops that occur in a series circuit are proportional to the resistances of the various loads. The load with the greatest resistance will have the largest voltage drop. The load with the least resistance will have the smallest voltage drop. If all loads have the same resistance, then the source voltage divides evenly among the loads.

Parallel Circuits

A ***parallel circuit*** is one in which electricity has two or more paths to follow. If three light bulbs are wired in parallel, electricity can pass through any one of the bulbs without passing through the other two (Figure 23). If one of the bulbs is removed, electricity still reaches the other two and they remain lighted.

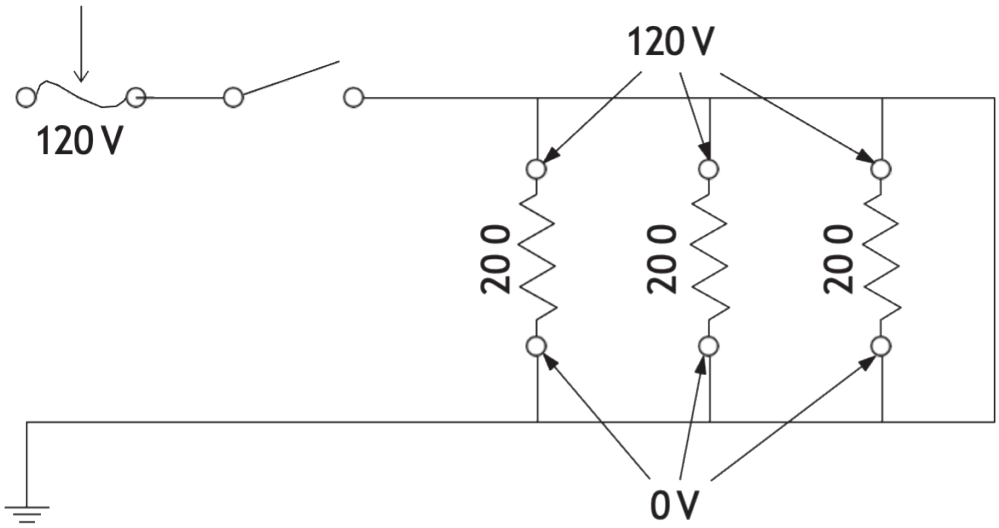

Figure 23 *Parallel circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

In Figure 23, the voltage potential between the 120 V, also known as the hot (H) terminal, and the 0 V grounded or neutral terminal (N) is 120 V. Since loads A, B and C are wired across H and N, the voltage across each load is also 120 V. In a parallel circuit, the voltage is equal in each path. If loads A, B and C are equal in resistance and also have the same voltage across each, the current (amperage) passing through each of the loads is equal. The total amperage of a parallel circuit can be determined by adding the amperage of all the loads in that circuit.

Watch the following video by Tradestutor (2020) on YouTube titled "Parallel circuit calculations (quick and easy)" [4:46].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#oembed-3

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Parallel circuit calculations (quick and easy)

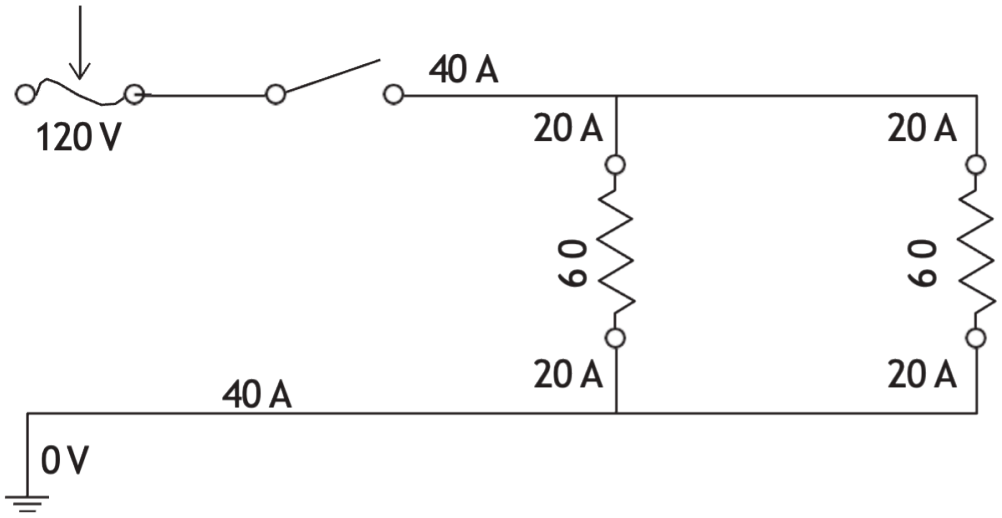

Figure 24 *Amperage in a parallel circuit with equal loads (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

In Figure 24, the total amperage of the circuit is found by adding the amperage draw of load A (20 amps) and the amperage draw of load B (20 amps) to equal a total circuit amperage of 40 amps $(20\ \text{A} + 20\ \text{A} = 40\ \text{A})$. This can be proven by measuring the amperage at H or N with an ammeter and comparing to the sum of the two individual amperage draws.

In Figure 25, if the resistance of load A is 60 ohms and the resistance of load B is 10 ohms, then load A has six times the resistance to current flow as load B does. Since load A has more resistance to current flow than load B, more amperes will flow through load B (remember, the voltage is the same across both loads). In fact, six times as many amps will flow across load B than load A.

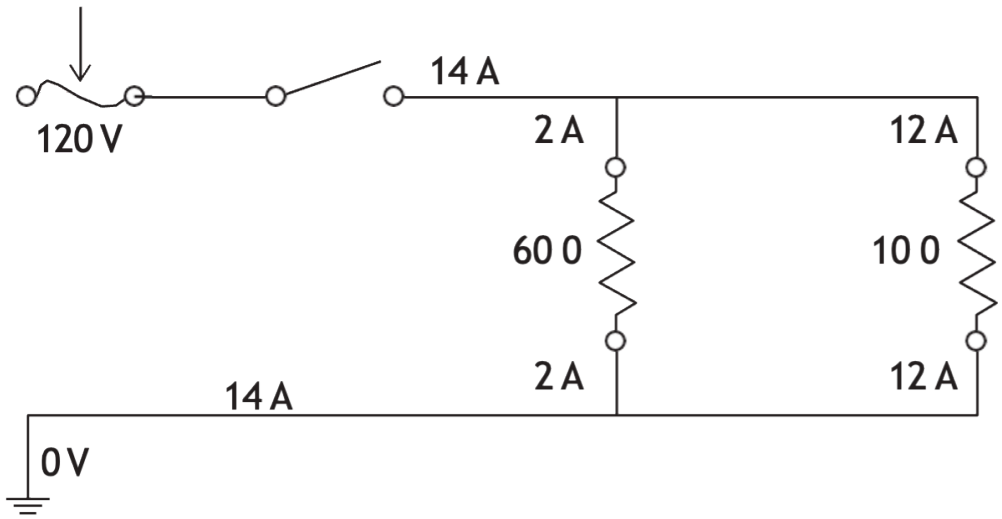

Figure 25 *Amperage in a parallel circuit with unequal loads (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

For example, the 60 Ω resistor (load A) draws 2 amperes $(\frac{120\ \text{V}}{60\ \Omega} = 2\ \text{A})$ and the 10 Ω resistor (load B) draws

12 amperes $(\frac{120\text{ V}}{10\ \Omega} = 12\text{ A})$. To arrive at total amperage for the entire circuit, add A's amperage (2 A) and B's amperage (12 A) for a total amperage of 14 amps.

The total resistance in a parallel circuit is not as it is in a series circuit. The total resistance of a parallel circuit is always less than the resistance of the smallest of the individual resistances. For example, if two 20-ohm loads are wired in parallel in a 120 V circuit, as shown in Figure 26, the total amperage of the circuit is 12 A. The total resistance, therefore, can be calculated as $\frac{120\text{ V}}{12\text{ A}} = 10\ \Omega$, which is smaller than the smallest individual resistance of 20 Ω.

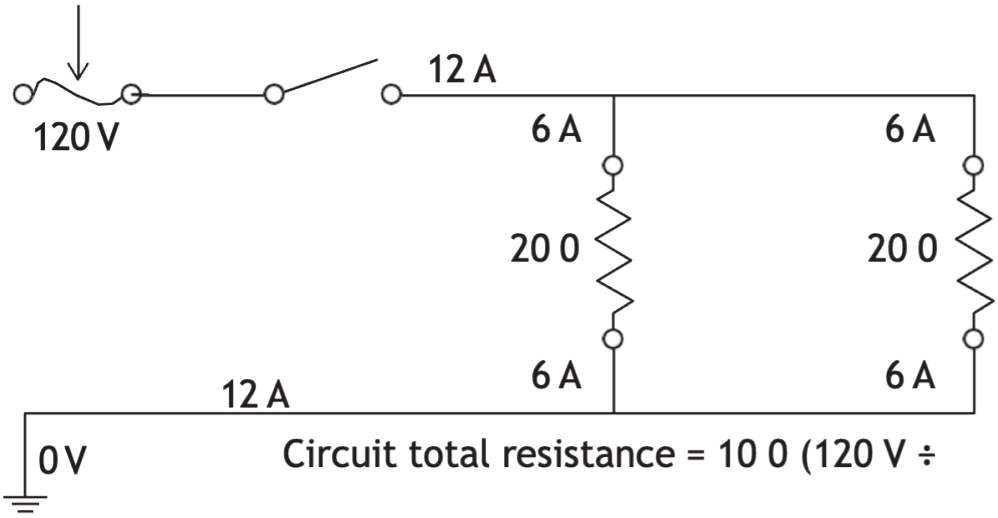

Figure 26 *Resistance in a parallel circuit with equal loads (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The important thing to remember is that **total resistance decreases as more loads are added to a parallel circuit.** If too many loads are plugged into an electrical circuit, resistance will decrease and amperage will increase, eventually causing the fuse or circuit breaker to open the circuit.

A parallel circuit will always exhibit these three characteristics:

1. The voltage across each path in the circuit is the same as that of the source.
2. The total amperage flowing into the circuit is equal to the sum of the amperes flowing through the separate paths. The amperage in the separate paths is inversely proportional to the amount of resistance of the loads in these paths. The path with the greatest resistance will have the least amperage. The path with the smallest resistance will have the most amperage.
3. The total resistance of the circuit is always less than the resistance of the smallest of the individual resistances. Total resistance decreases as more loads are added to the parallel circuit.

Series-Parallel Circuits

Series-parallel circuits are merely combinations of series and parallel circuits. Figure 27 is an example of a series-parallel

circuit. Loads A, B, C and D are all in the circuit. When working with series-parallel circuits, divide the overall circuit into sub-circuits. This will result in several series and/or parallel sub-circuits that can then be analyzed by using the fundamentals of series and parallel circuits discussed earlier.

For instance, loads B (5 Ω) and C (10 Ω) in Figure 27 comprise a parallel sub-circuit. That parallel sub-circuit is in series with loads A and D. The characteristics of parallel circuits can be used to analyze sub-circuits B and C. Then, by considering sub-circuit B/C as a single load in series with A and D, the characteristics of series circuits can be used to analyze the larger parent circuit.

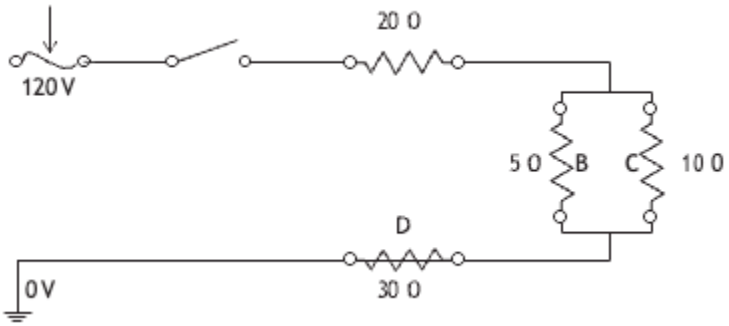

Figure 27 *Series-parallel circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The resistance of two loads in parallel can be calculated using the following formula:

$$\mathrm{R} = \frac{\mathrm{R_1} \times \mathrm{R_2}}{\mathrm{R_1} + \mathrm{R_2}}$$

For sub-circuit B/C, the resistance would be:

$$\mathrm{R} = \frac{5 \times 10}{5 + 10} \quad = \frac{50}{15} \quad = 3.33$$

When the resistance of B/C (3.33 Ω) is added to the two other resistances of 20 Ω and 30 Ω, the total resistance of the circuit can be calculated to be 53.33 Ω. The amperage flowing through the circuit can then be calculated by dividing the total resistance into the source voltage, to get 2.25 amps $(\frac{120\ \mathrm{V}}{53.33\ \Omega} = 2.25\ \mathrm{A})$.

Any electrical circuit can be reduced to (1) a source, (2) a path, conductors, and (3) a single resistance, a load.

Transformers

A *transformer* is an electrical device used to change alternating current (AC) voltage to either a higher or lower level. Transformers only work with AC because they rely on a changing magnetic field. If a transformer changes 120 VAC to 24 VAC, it is called a ***step-down transformer*** (Figure 28). If it increases voltage (for example, from 120 VAC to 12,000 VAC), it is called a ***step-up transformer***. An ***isolation transformer*** does not change voltage but provides protection from electrical

shock by separating circuits. An isolation transformer neither steps up or down but, rather, provides galvanic protection from electric shock to sensitive equipment. Transformers are available in a variety of capacities for isolation, stepping up or stepping down AC voltages. A transformer is considered to be a load on the primary side and a source on the secondary side.

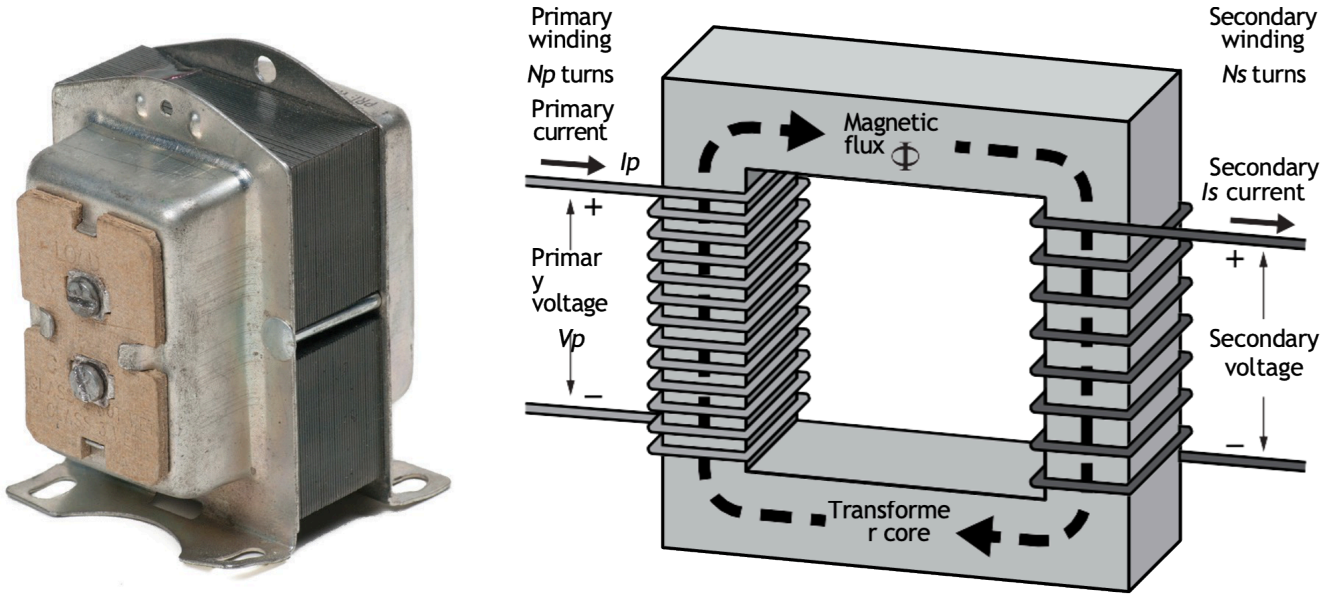

Figure 28 *Step-down transformer (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Construction and Operation

The construction of a transformer is relatively simple. It consists of two coils of wire, called ***windings***. Windings or wire are placed around one side of an iron ring:

- The ***primary winding*** is connected to the power source.
- The ***secondary winding*** delivers the output voltage.

There is no direct electrical connection between the primary and secondary windings. Instead, energy is transferred through ***magnetic induction***.

Two important principles explain how transformers work:

- When electric current flows through a conductor, it creates a magnetic field (Figure 29).
- When a conductor moves through a magnetic field, a voltage is induced in that conductor (Figure 30).

In an AC circuit, current is constantly changing direction. This causes the magnetic field around the primary winding to continually grow and collapse. This changing magnetic field induces a voltage in the secondary winding.

Because direct current (DC) flows in only one direction and does not continuously change, DC cannot be used to operate a transformer.

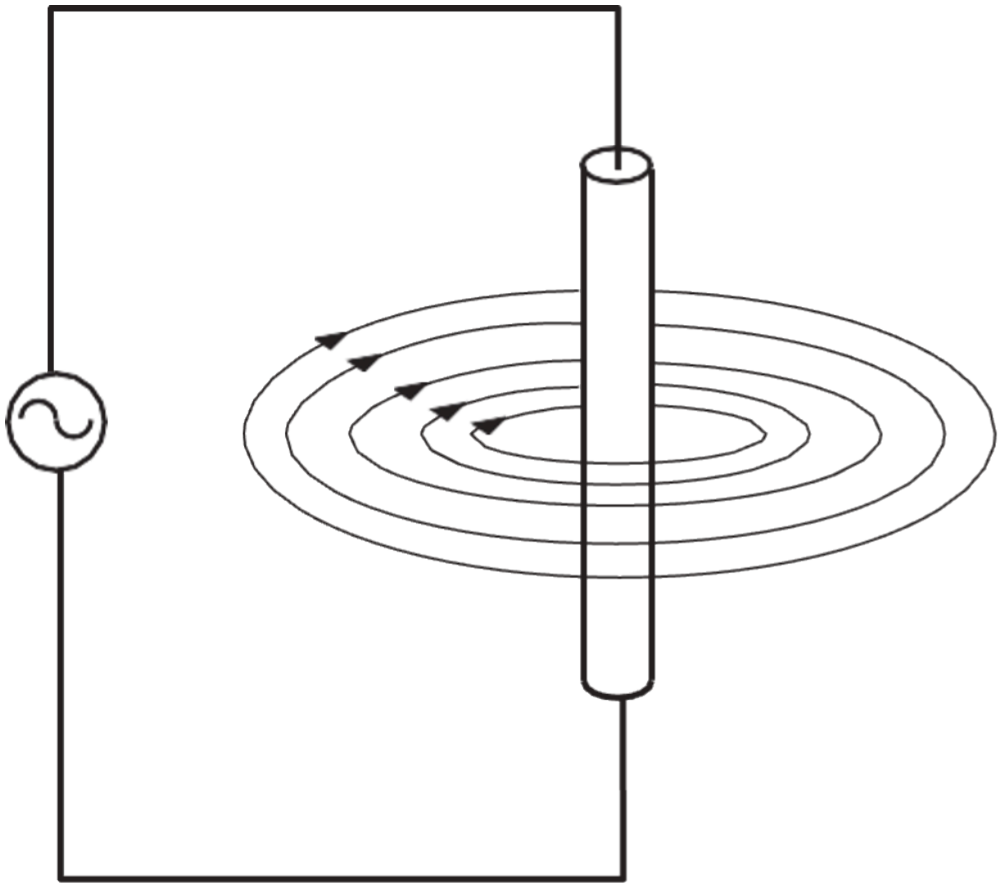

Figure 29 *Magnetic field produced by current flow through a conductor (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

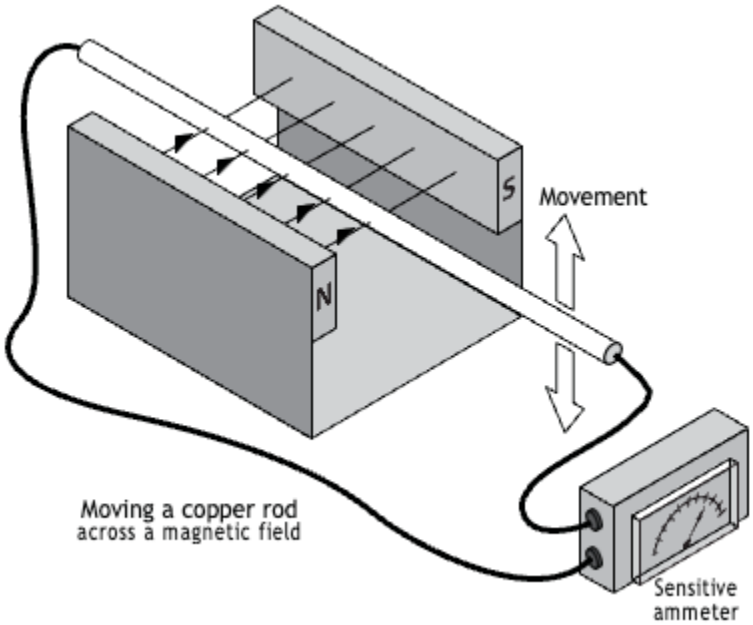

Figure 30 *Current flow generated in a conductor (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Voltage Transformation

The output voltage of a transformer depends on the ratio of turns (loops of wire) in the windings:

- If the secondary winding has **more turns** than the primary, the voltage increases.
- If the secondary winding has **fewer turns**, the voltage decreases.

Power Rating (VA)

Transformers are rated based on the amount of power they can handle. This is expressed in *volt-amperes* (VA).

For example:

$$24\ \text{V} \times 2\ \text{A} = 48\ \text{VA}$$

The unit VA is equivalent to *watts*, since power is calculated as voltage multiplied by current.

When replacing a transformer, if one with an identical wattage cannot be obtained, use one with a higher VA rating. If one of a lower rating is used and the original had been sized close to its capacity, the new transformer will burn out in time due to excessive heat created by an undersized secondary winding.

Sensitive Ammeter

A magnetic field must remain in motion if a continuous voltage is to be induced in the secondary windings. The magnetic lines of force must continually cut the conductor. In AC current, electrons flow in one direction, then stop and flow in the opposite direction. This occurs 60 times a second. This means that as electrons flow in the primary winding, the magnetic field builds up in intensity. When electron flow stops, the magnetic field collapses. As the electron flow changes direction, the magnetic field again builds up, this time in the opposite direction. It is this pulsating magnetic field moving in and out of the secondary windings that induces voltage. Because a DC source produces current flowing in one direction at a constant level, it cannot be used with a transformer.

The AC voltage output of the secondary winding of the transformer is determined by the ratio of the number of windings in the secondary to the number of windings in the primary. If the number of windings in the secondary is greater than in the primary, more electrons are excited and the voltage produced will be higher than in the primary. If there are fewer windings in the secondary than in the primary, fewer electrons are excited and a lower voltage is produced.

Solenoids

A ***solenoid*** consists of a coil of insulated conductor wire and a movable iron rod (Figure 31).

A solenoid may also be called an ***electromagnet***. The tip of the iron rod is positioned just inside the entrance of the coil opening. When the coil is electrically energized and current flows through it, the resulting intensified magnetic field of the coil pulls the iron rod into the centre of the coil. The iron rod will remain in this position until the coil is de-energized. Normally, gravity allows the iron core to return to its original position, although some solenoids, particularly those used in pressurized water systems, use a spring on the return. Solenoids are used for such things as valves, doorbells, locking devices and many other types of electromechanical equipment.

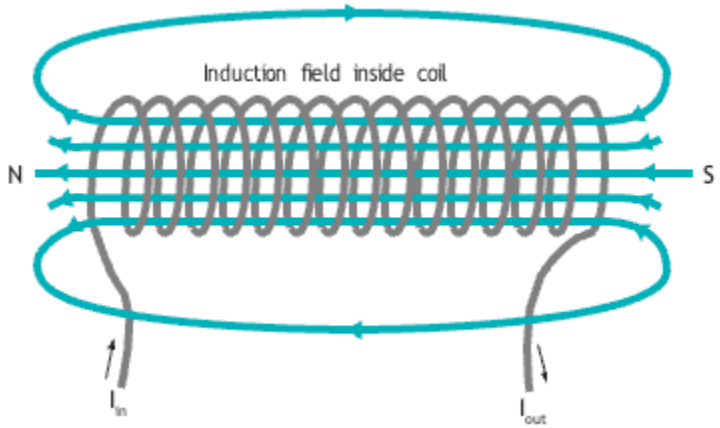

Figure 31 *Solenoid (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Relays

Electrical ***relays*** use the principle of the electromagnet. A relay consists of a coil of insulated wire with an iron core fixed within it (Figure 32). A movable metal armature is located nearby the end of the iron core. The armature has an electrical contact on one end. Another contact is stationary. When the relay becomes electrically energized, the iron core becomes magnetized and attracts the metal armature toward it. When the armature moves to the magnet, the armature contact closes against the stationary contact. When the relay is de-energized, the core is de-magnetized. A spring returns the armature to its original position and the contacts separate.

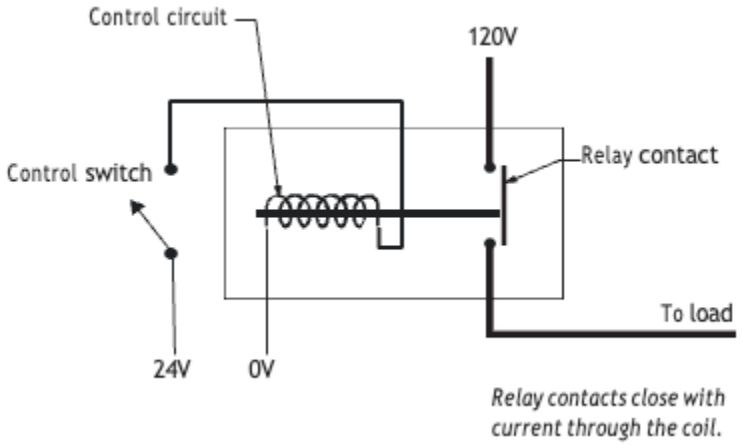

Figure 32 *Relay (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A relay is used when it is necessary to control an electrical device that operates on, for instance, 120 VAC by using a control voltage of another value, for instance, 24 VAC. If the 24 V were to be directly interconnected with the 120 V, the 24 V components would likely burn out. This strategy is used quite successfully in hydronic heating and air conditioning, where 120 V or 240 V motors are switched on and off by a 24 V control circuit. The relay would be identified as a load on the 24 V side and a switch on the 120 or 240 V side.

Another reason to use a relay might be to operate a piece of large equipment from a remote location. For instance, a large electric motor operating on 600 VAC and drawing many amps needs to be controlled from a location that is 10 storeys above it (Figure 33). To do this, heavy wires would have to be routed from the source in the basement up to the 10th floor, through a heavy switch, then back down to the motor and subsequently back to the power panel. If a relay were used, a 24 VAC source (step-down transformer) located in the basement close to the motor could supply a light wire with voltage right up to the 10th floor, through a light-duty switch, back down to the coil in the relay. The normally open relay contacts would have the 600 V wired through it to the motor. When the switch on the 10th floor is closed, 24 V is sent to the relay coil, which pulls in the armature and closes the normally open contacts, sending the 600 V to the motor. The addition of an inexpensive relay is more than offset by the cost savings realized by not having to run very much heavy, expensive wire.

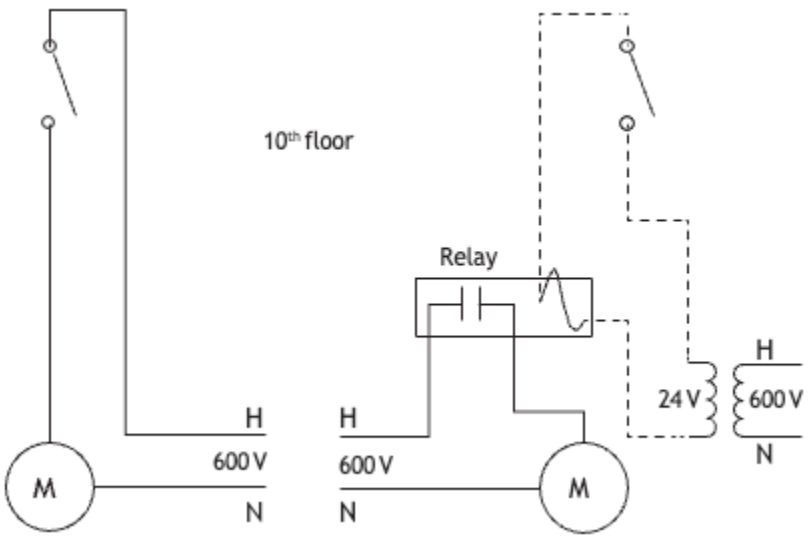

Figure 33 *Sample application of a relay (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

There are several types of relays. The relay described in the previous examples is used to close or complete a circuit. This type of relay contains a set of normally open (NO) contacts. This means that the contacts are open when the relay is not energized and closed when the relay is energized. Another type of relay is used to open a circuit. This relay contains a set of normally closed (NC) contacts. This means that the contacts are closed when the relay is not energized and opened when the relay is energized.

Some relays are also capable of opening or closing several circuits at the same time.

The description of this switching action is the same for relays as it is for manual switches. Figure 34 shows a typical relay capable of opening and closing several circuits.

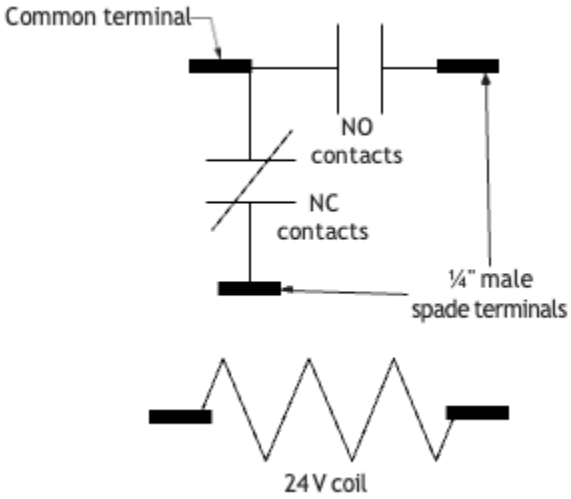

Figure 34 *SPDT (single pole, double throw) relay for multiple circuits (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Capacitors

A ***capacitor*** is an electrical component composed of two metal plates separated by an insulator that stores a charge to help equipment such as motors and compressors run more efficiently.

When a capacitive motor starts up, there is a large current draw on the system that is bolstered by the stored charge captured in the capacitor, supporting smooth motor start and run.

Capacitance, measured in the SI system in ***farads (F)***, describes how efficiently a capacitor stores a charge.

Ampacity

Ampacity is an electrical rating used to properly size conductors used for electrical wiring circuits. This rating is based on a few variables such as type of conductor, size of conductor and insulation that covers the conductor. Manufacturers put ampacity ratings on the nameplates of their electrical equipment. When selecting wire size for equipment, take the ampacity rating shown on the equipment and apply this to the ampacity tables found in the Canadian Electrical Code. Normally, conductors that supply electricity to any equipment that has a motor have to be rated at 125% of the equipment's rated ampacity. For example, if a motor's rated current draw is 5 amps, the conductors will have to be capable of 125% of 5 amps, or 6.25 amps. The extra 25% is to make sure that the wiring will not catch fire in the event of an electrical overload. If the circuit is properly fused, an overload will blow the fuse or trip the breaker before the wire gets hot enough to ignite its coating of insulation.

Supplementary Videos

To better understand motors and electrical principles, check out the excellent information in some of "The Engineering Mindset" videos:

- Alternating Current Basics: *How does an Electric Motor work? (DC Motor) [4:49]*
- AC and DC Electricity: *AC and DC Electricity basics [2:56]*
- How DC Motors Work: *How does an Electric Motor work? (DC Motor) [4:49]*
- Induction Motors: *Induction Motor Basics [8:38]*
- How 3-phase Electricity Works: *How Three Phase Electricity works – The basics explained [7:52]* (originally linked: *AC and DC Electricity basics [2:56]*)
- Main electrical panel explained: *Main electrical panel explained – Load center – service panel [10:18]*

Self-Test C-2.2: Electrical Circuits

Complete Self-Test C-2.2 and check your answers.

If you are using a printed copy, please find Self-Test C-2.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#h5p-30

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- Steamfitter: Level 2 Competency K-1 Use the Principles of Electricity
- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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- **Figure 14** Utility Disconnect Switch by Rsparks3 on Wikimedia Commons is used under the CC0 1.0 public domain license.

C-2.3 Wiring Diagrams and Symbols

Wiring Diagrams

A ***wiring diagram*** is a roadmap of an electrical circuit. Using it, a service technician can analyze the circuit. Diagrams are also used to systematically troubleshoot problems in a circuit. There are four main types of wiring diagrams:

- Pictorial
- Block and line
- Wiring
- Schematic

Pictorial Diagrams

A ***pictorial diagram*** shows the circuit components in detail as they really look and indicates how the wiring is attached (Figure 1). These diagrams can be used to locate components in a complex system. A pictorial diagram is best suited for individuals with little knowledge of wiring, as the diagram can be followed easily because the components can be recognized.

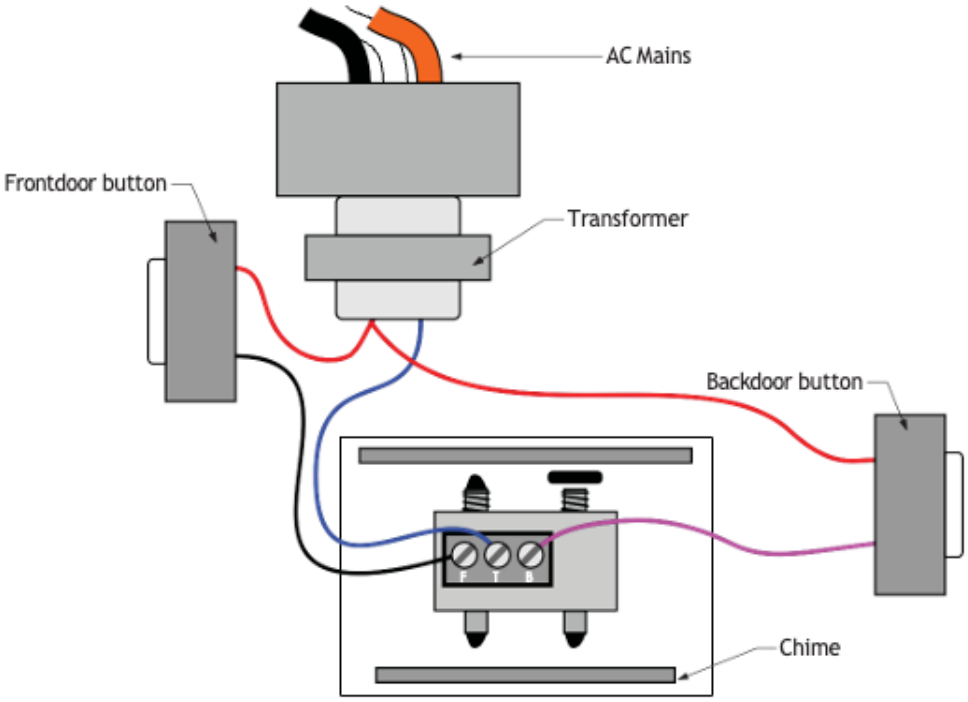


Figure 1 *Pictorial diagram of a doorbell circuit* (*BC Industry Training Authority*, 2019). CC BY-NC-SA 4.0

Block and Line Diagrams

The ***block diagram***, also called a *functional block diagram* or *block and line diagram* (Figure 2), is used to describe the sequence of circuit operation. This diagram indicates, by functional descriptions, which components must operate first in order to get a final outcome. It does not make reference to specifics, like device symbols or related wire connections. These types of diagrams are used widely for troubleshooting as they relate directly to a sequence of operation.

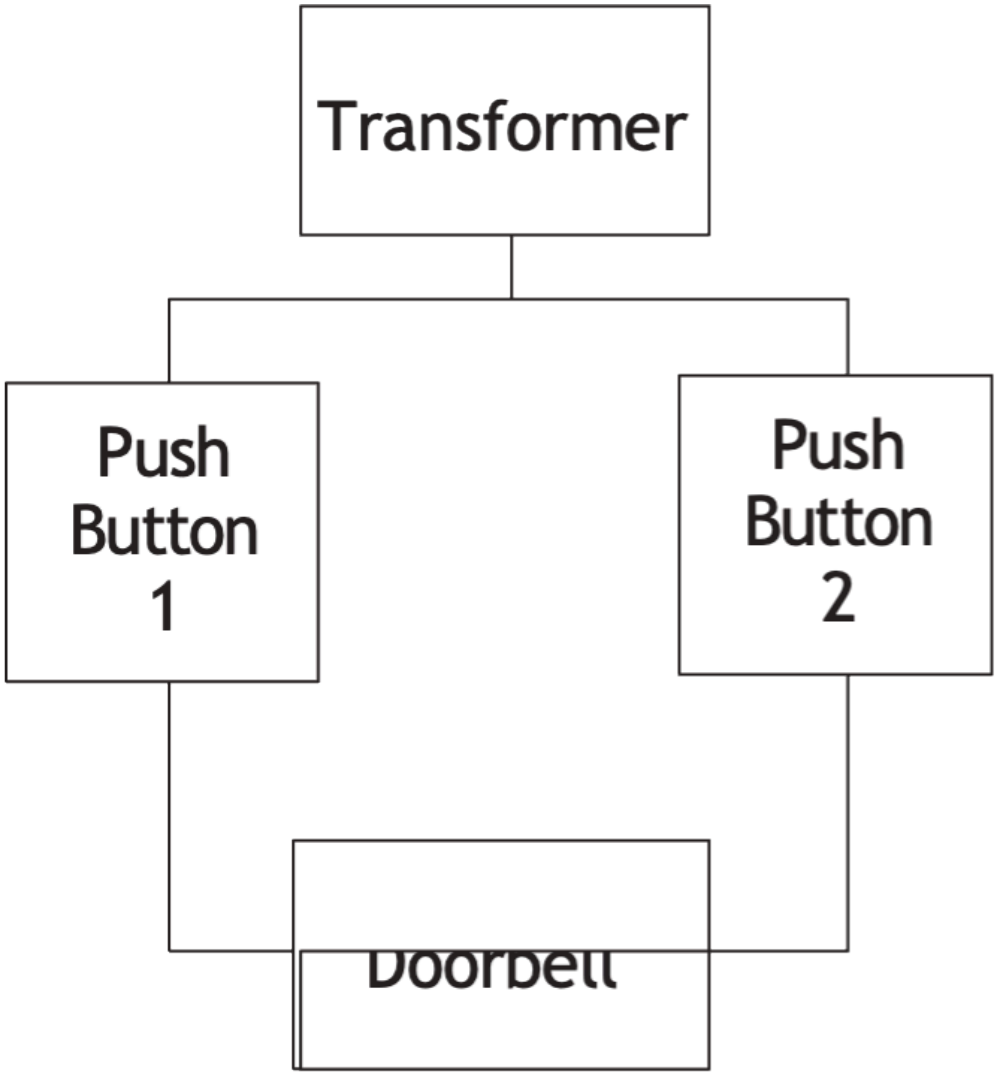


Figure 2 *Block and line diagram* (BC *Industry Training Authority*, 2019). CC BY-NC-SA 4.0

Wiring Diagrams

A ***wiring diagram*** shows the relative layout of the circuit components using the appropriate symbols and the wire connections (Figure 3). Although a wiring diagram is easy to use for wiring an installation, it is sometimes difficult to understand circuit operation because the components are shown as symbols. It is not as applicable for troubleshooting.

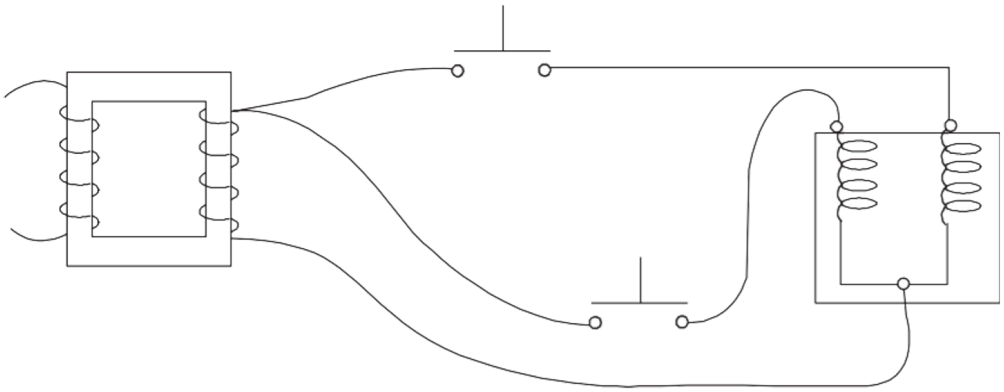


Figure 3 *Wiring diagram (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Schematic Diagrams

A ***schematic diagram***, often called a ***ladder diagram***, is intended to be the simplest, most orderly form of an electrical circuit. This diagram shows the circuit components as symbols on horizontal lines that resemble the rungs of a ladder, without regard to their physical location (Figure 4).

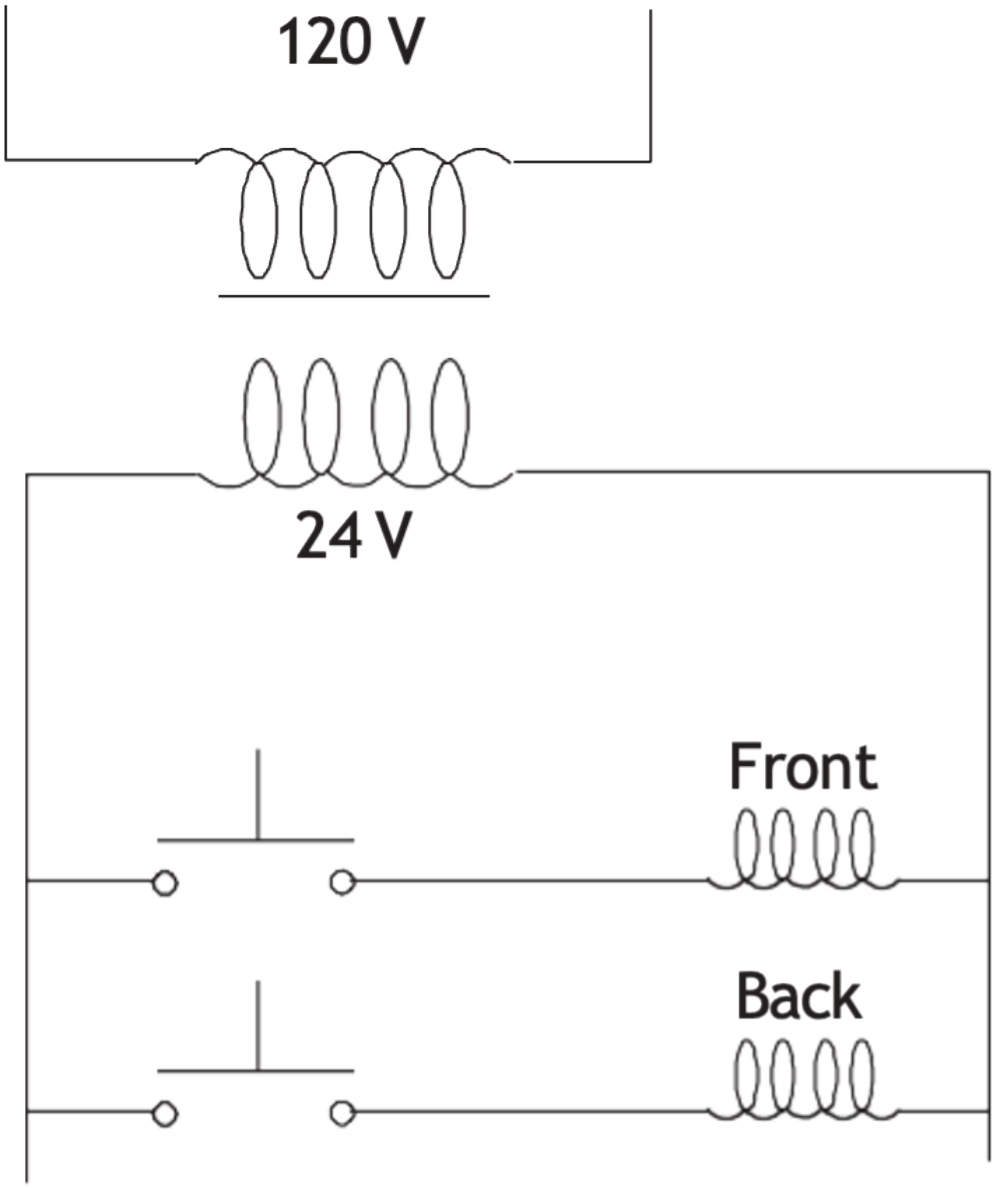


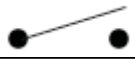
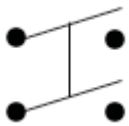
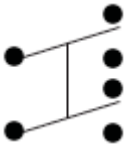
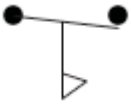
Figure 4 *Schematic wiring diagram (ladder diagram) (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

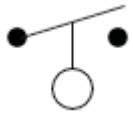
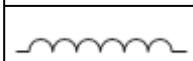
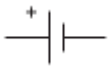
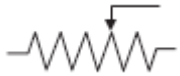
The power source lines of the circuit are parallel and form the rails or sides of the ladder. The loads and switches are drawn between the power source lines, forming the rungs of the ladder.

Ladder diagrams make it easier to tell which loads are wired in series and which are in parallel. As well, no two lines in a ladder diagram ever cross, so it is less likely to get wiring paths mixed up. However, using a ladder diagram requires more knowledge of electricity and ***electrical symbols*** and components than a ***pictorial diagram or schematic***. This is because they do not look like the real components. A service technician must be able to look at the diagram and relate it to the actual unit. They must know the unit components and their corresponding electrical symbols. On most diagrams, these symbols are keyed to a table that names the components.

Symbols

Electrical symbols are used as a shorthand method to represent the various electrical components of a circuit. The following are international schematic symbols for the most commonly used electrical devices.

Symbol	Name	Description
	Single pole, single throw switch (SPST)	Opens and closes one circuit
	Single pole, double throw switch (SPDT)	Opens and closes alternate circuits
	Double pole, single throw switch (DPST)	Opens and closes two separate circuits simultaneously
	Double pole, double throw switch (DPDT)	Opens and closes two alternate circuits simultaneously
	Flow switch	Closes on flow (normally open [NO])
	Flow switch	Opens on flow (normally closed [NC])
	Temperature switch	Opens a circuit when temperature rises
	Temperature switch	Closes a circuit when temperature rises
	Pressure switch	Closes a circuit when pressure rises
	Pressure switch	Opens a circuit when pressure rises
	Float switch	Closes a circuit when liquid level rises

	Float switch	Opens a circuit when liquid level rises
	Load	Typically represents a wire winding or coil (e.g., gas valve, light, motor)
	Relay	Typically represents a coil in a relay
	Wire winding/coil	Similar to “load” above
	Transformer	Transformers increase or decrease voltage between primary and secondary circuits
	Normally open (NO) relay contact	Disallows current flow unless relay coil is energized
	Normally closed (NC) relay contact	Allows current flow while coil is not energized
	Voltage source for direct current	Indicates a battery or other source of DC
	Resistor	Indicates a constant resistance in a circuit
	Variable resistor	Indicates a resistance that can be changed in a circuit
	Pump	The point of the shaded triangle indicates the direction of flow
	Fuse	Opens a circuit when too much current flows
	Fuse	Opens a circuit when too much current flows
	Ground (Earth)	A connection to the earth that has no voltage potential
	Wire connection	The dot indicates a connection between wires

Self-Test C-2.3: Wiring Diagrams and Symbols

Complete Self-Test C-2.3 and check your answers.

If you are using a printed copy, please find Self-Test C-2.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2459#h5p-31

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BCcampus. (n.d.). *Playlist: Tools and equipment videos*. BCcampus MediaSpace. https://media.bccampus.ca/playlist/details/0_3g8xp22x/categoryId/175673 Playlist Details – Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Plumber: Competency O-1 Use the Principles of Electricity
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- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

Camosun College. (2019). Line D: Tools and Equipment—Competency D-2: Apply Science Concepts to Trades Applications (Rev. ed.) [Learning guide]. BCcampus. https://collection.bccampus.ca/textbook/fkXxtNTn/

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https://collection.bccampus.ca/textbook/Nf7jVbAg/

Camosun College. (2015). *Line E – Electrical fundamentals competency E-2: Identify common circuit components and their symbols*. BCcampus.
https://collection.bccampus.ca/textbook/fGcTBtJh/

Camosun College. (2015). *Line E – Electrical fundamentals competency E-3: Explain Wiring Connections*. BCcampus.
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C-2.4 Measuring Electricity

Test Equipment

When you see lightning, you are not seeing electricity itself, but the release of electrical energy in the form of light. Electricity cannot be seen directly, so when an ***electrical circuit*** is not operating correctly, and unless you can see loose or damaged wire connections, you will need instruments that check for the absence or presence of electricity to discover what is wrong.

To measure the effect of electricity, you must use an ***electrical meter***. As electrical quantities vary, so do their effects on the meter. Meters come in a variety of designs, and you must be familiar with some of the most common types used during installation and servicing of hydronic equipment.

Because some electrical effects are very small, most meters are built with delicate operating mechanisms. Meters can be damaged easily, so they must be stored, handled, and used with great care.

Types of Electrical Meters

The most common types of electrical meters are:

- ***Ammeters***
- Voltmeters
- Ohmmeters

For economic reasons, you will most likely not have three separate meters but one unit that combines the functions of all three. This device is referred to as a ***multimeter***. A multimeter is able to measure volts, ohms, and low values of ***current (amps)***. Regardless of the type of meter used, it must be connected correctly to the circuit being tested to obtain accurate readings.

The two major types of meters, *analogue* and *digital* (Figure 1), perform the same functions but look different. The main difference is in the display unit. The key features are very similar and will be explained below.

Figure 1 *Digital multimeter and analogue multimeters (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Analogue Multimeters (VOMs)

Analogue multimeters, also called *volt-ohm-milliammeters* (VOMs) (Figure 2), are older-style meters that use a moving needle to display readings. While they are not commonly used in the piping trades today, it is important to be aware of them, as you may still encounter them in older equipment or training materials.

VOMs measure ***voltage***, ***current***, and ***resistance***, similar to modern digital multimeters. However, they require careful handling because the needle mechanism is delicate, and incorrect connections—especially when measuring ***direct current (DC)***—can damage the meter. They must also be properly zeroed before use and read from directly in front to avoid ***parallax error***.

In most modern applications, digital multimeters are preferred because they are easier to use, more accurate, and less prone to damage.

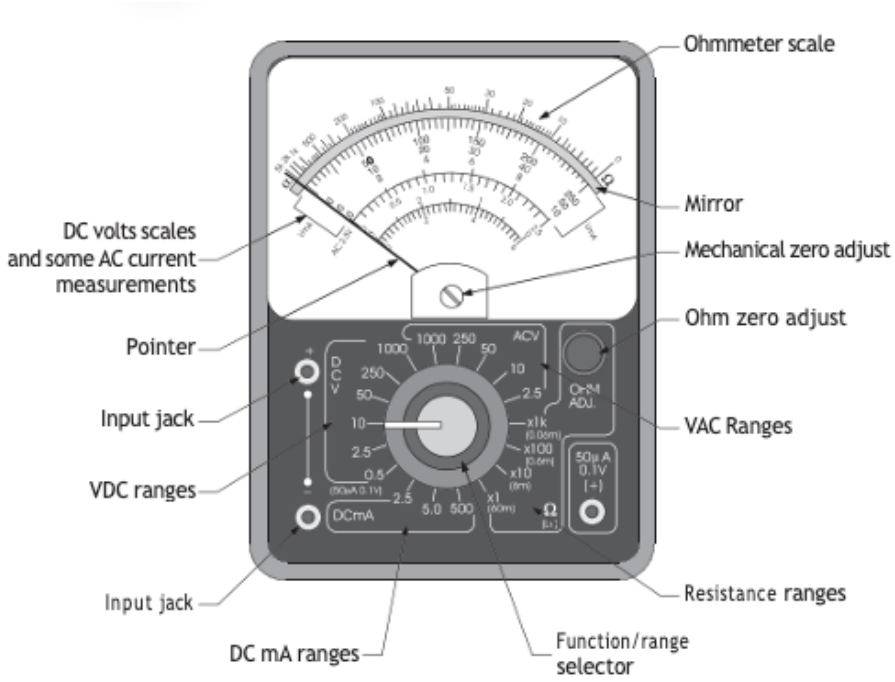

Figure 2 *Analogue VOM (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Measuring Voltage Using a VOM

When performing any tests, it is important to first confirm that the meter is adjusted and working properly. Before using a meter on AC or DC voltage, zero the meter, as shown in Figure 3. Use a blade screwdriver to position the needle directly over the "0" on the left of the scale.

Figure 3 *Mechanical adjustment of the zero reading (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Next, check the meter's operation by exposing it to a known source of voltage. Remember to correctly polarize the leads

if using a DC voltage such as a battery. This is done by performing a ***"tap" or "flash" test***: connect one meter lead to a test point and, with the function switch set to a higher DC voltage scale than the source being tested, tap the other lead to the second test point. This will cause the needle to deflect. If the deflection is in the wrong direction, simply reverse the position of the test leads. Then take a reading and confirm that it matches the expected value.

If you are checking the meter using an AC source, such as a wall receptacle, set the function switch to the highest AC setting and insert the two leads into the receptacle's jacks, in no specific position. ***Polarity*** does not matter for AC. Remember that the meter will automatically polarize the signal so the needle will deflect in the correct direction. If the reading matches the expected value, the meter is ready for use.

When measuring voltage, the meter is connected *in* ***parallel*** with the circuit being tested. This means no wires need to be removed from the circuit. The ***voltmeter*** reads the difference between the two test points.

Think of a voltmeter as operating in "subtraction mode"—it measures the difference in voltage between its two leads. This can create a safety hazard if misunderstood. For example, measuring across a closed switch in a live 120 V circuit may show 0 V, even though the circuit is energized.

Always verify circuit conditions before touching components.

Summary of using a VOM to test voltage:

- Zero the needle.
- Check the meter for operation first on a known voltage source.
- Start with the highest voltage scale first.
- Polarize the test leads if testing a DC circuit ("flash test").
- Connect the meter in parallel with the live circuit being tested.
- Interpret the reading and select a lower scale, if possible, for more accuracy.

Measuring Current Using a VOM

Using a VOM to measure *current (amperage)* requires connecting the meter ***in series*** with the circuit being tested. This means disconnecting a conductor and inserting the meter between the wire and the terminal. **This makes the meter part of the circuit**, so all current flowing through the circuit also flows through the meter, which creates a limitation in that the meter leads must be heavy enough to allow current flow, which causes heat, without burning up. Because of this, meter leads must carry current safely. Most multimeters are limited to measuring low current (***milliamps***) when using test leads.

Summary of using a VOM to test DC milliamperage:

- De-energize the circuit to be tested.

- Disconnect a wire and insert the meter in series with the circuit, observing the correct polarity of the test leads.
- Set the meter to the highest DC milliamp range.
- Energize the circuit and interpret the reading.
- Switch to a lower scale, if possible, for more accuracy.
- De-energize the circuit before removing the meter.
- Re-connect the circuit wiring and re-energize the circuit.

Digital Multimeters

All ***digital multimeters (DMMs)*** Figure 4) have similar features and are used in the same way as VOMs, except that the display is a numbered readout of digits rather than a pointer moving over numbered scales. Some digital meters have a function switch that must be set on the appropriate range just like with a VOM, whereas others are *self-ranging* or ***auto-ranging*** and are intuitive to the type of current or voltage that they are being exposed to. They do not differ from the VOMs in their inability to measure units of amperage and are likewise restricted to milliamps of current, but they are easier to read and generally more accurate than ***analogue meter***s.

Figure 4 *Digital multimeter (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Watch the following video by Afrotechmods (2010) on YouTube titled "THE BEST Multimeter tutorial (HD)" [4:35].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2461#oembed-1

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: THE BEST Multimeter tutorial (HD).

As mentioned, using a digital meter involves little or no interpretation as to the reading being registered and, for this reason, most technicians favour them over the VOM. One drawback of the DMMs is that they require a battery in good condition for all readings, whereas the analogue variety requires only a battery for resistance/continuity readings. One advantage of the DMMs is that they often have the ability to read current in the range of microamps. An analogue meter would have to be specifically designed for this range only.

Measuring Current Readings Above the Milliamp Range

Current readings above the milliamp range are taken with a ***clamp-on ammeter*** (Figure 5). These devices are usually digital and can be a stand-alone ammeter or can perform all the functions of a multimeter with the added capability of reading full amps. When measuring amperage, the spring-loaded jaws are opened and clamped around a single conductor in the circuit. Current running through a conductor creates an ***electromagnetic field*** around it, and the strength of the field is measured by the device and translated into a current reading. It is important to realize that the current flow through two conductors in a circuit can't be read together. In a two-wire circuit, the direction of the two electromagnetic fields is opposite to each other and will cancel each other out if the meter is clamped around both wires at once.

Figure 5 *Clamp-on ammeter (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Measuring Resistance Using a VOM

A VOM can be used to measure *resistance* or ***continuity*** in a circuit. In the same fashion as in testing for current flow, the meter must be installed in series with the circuit or individual component being tested, with one exception: **the circuit must not be live!**

A battery inside the meter will try to push a small amount of current out through one of the leads and expects to get it back through the other lead. The amount of resistance to this flow of current, measured in ***ohms***, will be read on the topmost scale of the meter. If there is no resistance at all, the needle should move to the far right side of the scale over the "0" mark, indicating no resistance in ohms. If the circuit is completely broken, or open, the needle will not move off the left side of the scale, where the symbol for *infinity* (∞) exists, meaning there is an infinite amount of resistance.

The ohms scale is therefore said to be non-linear in that halfway along the scale is not half of an infinite amount of resistance, because this number cannot be estimated. Because there is only one scale to interpret, it is important to note the reading on the scale and adjust it according to the function switch position. For example, with the function switch set to "×10" a reading of 15 on the scale would indicate a reading of $15 \times 10 = 150 \text{ ohms } (150\ \Omega)$. The same reading with the switch set to the 1K scale would indicate a reading of $15 \times 1,000 = 15,000 \text{ ohms } (15,000\ \Omega)$ (Figure 6).

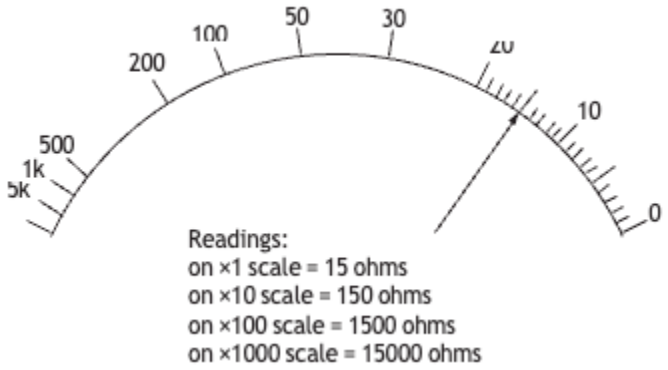

Figure 6 *Reading the ohms scale*

The ***ohmmeter*** must be zeroed before it can be used accurately (Figure 7). To do this, set the function switch to any of the ohms range settings and touch both leads together. The pointer should move to the far right side of the ohms scale and hover directly over the "0" mark. If it is off the mark to either side, use the Ohms Zero dial to correct the reading. The ohmmeter is now ready for use.

Figure 7 *Zeroing the ohms scale*

Measuring continuity is similar to measuring ohms in that the power to the circuit must be turned off. The multimeter sends out a small electrical current, and if it makes it through the circuit back to the meter, the circuit has *continuity*. Some meters emit an audible "beep" to indicate a continuous circuit.

It is important to also return the function switch to the "Off" position (if available) or to the highest AC volts range to ensure the battery doesn't drain during storage.

Summary of using a VOM to measure resistance:

- De-energize the circuit or component to be tested.
- Make sure that current from the meter can only flow through one circuit if there are two parallel circuits connected.
- Set the function switch to the highest range and ***"zero" the meter***.
- Touch the meter leads across the circuit or component and interpret the reading.
- Move to a lower range for more accuracy.
- When finished, turn the meter to "Off" or to the highest AC volts range.

Proper Handling and Storage

The proper care of test equipment and instruments is of utmost importance, whether they are analogue or digital. The length of time an instrument retains its original usefulness and accuracy depends largely upon the care it receives in the hands of the user. These precautions apply equally to digital and analogue meters:

- Do not drop any meter.
- Do not overload any meter. When in doubt, use a high range that you know will not be overloaded. You can always switch to a lower range, if necessary.
- Do not tamper with precision instruments. Let a competent instrument repair person service precision instruments.
- Before you connect a meter to a circuit, ensure that the range switch is set to an appropriate position.
- Carefully check circuit connections before applying power to meters.

Safety

Although electricity is vitally important in carrying out our daily functions, it can also be deadly if handled carelessly. One-tenth of an ampere of alternating current flowing through a vital organ can be fatal. Take safety precautions whenever working with electricity. Keep in mind the following precautions:

- Never cut off the third prong of a grounded plug. A grounded plug makes power tools and appliances safer to operate.
- Never touch any wire without making sure that it is not a live wire.
- Never turn an electrical appliance on or off while your skin is wet. Dry skin has a resistance of more than 100 000 ohms; wet skin's resistance drops to 1000 ohms.
- A current flow of 0.02 amperes is the maximum that a muscle can carry and still pull away from a conductor.
- Always disconnect the master switch or main disconnect before working on an electrical line or circuit.
- Always unplug an electrical appliance before working on it. Simply turning it off does not necessarily make it safe.
- Replace worn appliance cords.
- Unplug cords by pulling on the plug—not on the cord.
- Never turn an appliance on or off while standing in or touching a wet area.
- Notify the proper authorities whenever you find broken electrical wiring touching the ground. Do not attempt to touch the wire with another object.
- When working on electrical equipment that is live, try to use one hand only. If a person is shocked using one hand, current will probably flow through the hand and down through the feet. If a shock hits both hands, the electrical path would be through the heart, which could be fatal.

Self-Test C-2.4: Measuring Electricity

Complete Self-Test C-2.4 and check your answers.

If you are using a printed copy, please find Self-Test C-2.4 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2461#h5p-32

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- Plumber: Competency O-1 Use the Principles of Electricity
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- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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Camosun College. (2015). Trades Access Common Core Competency D-2: Apply Science Concepts to Trades Applications. Victoria, B.C.: Crown Publications. Download for free from the B.C. Open Textbook Collection (https://open.bccampus.ca/browse-ourcollection/find-open-textbooks/)

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Self-Test C-2.1: Electron Theory and Causes of Electricity

Complete Self-Test C-2.1 and check your answers.

1. What is an atom that contains only one valence electron known as?
    a. A conductor
    b. An insulator
    c. A semiconductor
    d. A positive ion
2. Which is the only source of electricity that produces alternating current?
    a. Heat
    b. Light
    c. Magnetism
    d. Chemicals
3. A thermocouple uses what form of energy to create electricity?
    a. Heat
    b. Light
    c. Magnetism
    d. Pressure
4. Where would piezoelectricity most commonly be used?
    a. To light a thermocouple
    b. To create electron flow through a light switch
    c. To light a main burner flame
    d. To create the spark in a BBQ lighter
5. Complete the flowing statement: “Electricity occurs when there is a flow of .”
    a. Ions
    b. Neutrons
    c. Electrons
    d. Protons
6. What is an atom that has an electrical charge known as?
    a. An ion
    b. A conductor
    c. An insulator
    d. An element
7. What is electricity that is created by friction known as?
    a. Thermoelectricity
    b. Triboelectricity
    c. Photoelectricity
    d. Piezoelectricity
8. What is the term given to 6.28 quintillion electrons?
    a. A coulomb of charge
    b. A neutron of potential

c. A volt of resistance
d. An ampere of ohms

9. Which term describes the force of the south poles of two magnets brought together?

a. Repel
b. Relate
c. Attract
d. Conduct

10. Which term best describes a materials readiness to be magnetized?

a. Saturation
b. Lines of flux
c. Permeability
d. Electromagnetism

11. Which term best describes the phenomenon associated with AC generated from hydroelectricity?

a. Saturation
b. Line of flux
c. Permeability
d. Electromagnetism

12. What are the four basic components of an electrical circuit?

a. Source, conductor, switch, load
b. Capacitor, cable, conductor, resistor
c. Battery, generator, motor, transformer
d. Voltage, amperage, resistance, magnetism

Answer Key: Self-Test C-2.1 is on the other page.

Answer Key: Self-Test C-2.1

1. What is an atom that contains only one valence electron known as?
    a. A conductor
2. Which is the only source of electricity that produces alternating current?
    a. Magnetism
3. A thermocouple uses what form of energy to create electricity?
    a. Heat
4. Where would piezoelectricity most commonly be used?
    a. To create the spark in a BBQ lighter
5. Complete the flowing statement: “Electricity occurs when there is a flow of .”
    a. Electrons
6. What is an atom that has an electrical charge known as?
    a. An ion
7. What is electricity that is created by friction known as?
    a. Triboelectricity
8. What is the term given to 6.28 quintillion electrons?
    a. A coulomb of charge
9. Which term describes the force of the south poles of two magnets brought together?
    a. Repel
10. Which term best describes a materials readiness to be magnetized?
    a. Permeability
11. Which term best describes the phenomenon associated with AC generated from hydroelectricity?
    a. Electromagnetism
12. What are the four basic components of an electrical circuit?
    a. Source, conductor, switch, load

Self-Test C-2.2: Electrical Circuits

Complete Self-Test C-2.2 and check your answers.

1. What are the four basic components of any circuit?

a. _____

b. _____

c. _____

d. _____

2. What is the function of a circuit breaker or fuse?
    a. To help maintain constant current flow within a circuit
    b. To create the polarity needed within a circuit
    c. To provide a path to ground for electricity
    d. To act as a switch that opens in the event of too much current flow
3. What is alternating current?
    a. Current that alternates between amps and ohms
    b. Current that alternates its direction
    c. Current that alternates amperage from high to low
    d. Current that creates alternate paths for current to flow
4. How is the formula for Ohm's law expressed?
    a. $E = I \times R$
    b. $I = E \div R$
    c. $R = E \div I$
    d. All of the above
5. If a circuit is powered by 120 volts and has a total resistance of 600 ohms, how much current is running through the circuit?
    a. 5 amps
    b. 120 amps
    c. 0.2 amps
    d. 0.5 amps
6. What is the voltage in a circuit that carries 0.5 amps with a resistance of 200 ohms?
    1. 1 volt
    2. 10 volts
    3. 100 volts
    4. 1000 volts
7. Which definition best describes a series circuit?
    a. There is only one path for electricity to flow through.
    b. There is a series of paths for electricity to flow through.
    c. There are between one and three paths for electricity to flow through.
    d. It is electricity flow created through the use of a series of resistors.
8. What is one advantage of using parallel circuits rather than a series circuit?

a. The ability to use an unlimited number of loads within the circuit
b. The ability to de-energize one leg of the circuit without affecting the others
c. The ability to alternate current through the different legs of the circuit
d. The ability to create different source voltages throughout the circuit

9. What would a three-way switch controlling a hallway light be an example of?

a. An SPST switch
b. An SPDT switch
c. A DPST switch
d. A DPDT switch

10. What is the term given to a coil of wire into which an iron armature is drawn?

a. A coil
b. A fuse
c. A circuit breaker
d. A solenoid

11. Which of the following best describes power?

a. Current flow
b. Inductive charge
c. Work performed
d. Voltage potential

12. Which two factors affect power?

a. Voltage and amperage
b. Resistance and capacitance
c. Magnetism and conduction
d. Induction and permeability

13. What kind of AC power supply would you expect to find in an industrial setting?

a. Inductive power
b. Single-phase power
c. Three-phase power
d. Direct current power

14. What voltage potential would you expect to find in a small shop with three-phase power supply?

a. 120 VAC
b. 208 VAC
c. 240 VAC
d. 775 VAC

15. Which of the following best describes why cities commonly use AC in public infrastructure?

a. AC provides ideal voltages for battery charging
b. AC is not commonly used in public infrastructure
c. AC is ideal for high-intensity carbon arced light sources
d. AC can be easily stepped up and transmitted over long distances

16. Which of the following statement best describes Kirchhoff's law when applied to voltage in a series circuit?

a. The voltage drop depends upon the available current.
b. Voltage available is equal to voltage drop over entire circuit.
c. All resistors in a Kirchhoff's circuit must have the same voltage ratings.
d. After the last resistor in a circuit, there must be voltage remaining to return to neutral.

17. Which of the following is both a load and a switch?

a. Relay
b. Resistor
c. Capacitor
d. Transformer

18. Which of the following best describes a transformer that reduces 120 VAC to 24 VACf?

a. Step-up
b. Isolation
c. Capacitive
d. Step-down

19. Which term best describes two metal plates separated by an insulative material for storage of a charge?

a. Farad
b. Ampacity
c. Capacitor
d. Transformer

Answer Key: Self-Test C-2.2 is on the other page.

Answer Key: Self-Test C-2.2

1. What are the four basic components of any circuit?
    a. Source, switch, load, conductors
2. What is the function of a circuit breaker or fuse?
    a. To act as a switch that opens in the event of too much current flow
3. What is alternating current?
    a. Current that alternates its direction
4. How is the formula for Ohm's law expressed?
    a. All of the above
5. If a circuit is powered by 120 volts and has a total resistance of 600 ohms, how much current is running through the circuit?
    a. 0.2 amps
6. What is the voltage in a circuit that carries 0.5 amps with a resistance of 200 ohms?
    1. 100 volts
7. Which definition best describes a series circuit?
    a. There is only one path for electricity to flow through.
8. What is one advantage of using parallel circuits rather than a series circuit?
    a. The ability to de-energize one leg of the circuit without affecting the others
9. What would a three-way switch controlling a hallway light be an example of?
    a. An SPDT switch
10. What is the term given to a coil of wire into which an iron armature is drawn?
    a. A solenoid
11. Which of the following best describes power?
    a. Work performed
12. Which two factors affect power?
    a. Voltage and amperage
13. What kind of AC power supply would you expect to find in an industrial setting?
    a. Three-phase power
14. What voltage potential would you expect to find in a small shop with three-phase power supply?
    a. 208 VAC
15. Which of the following best describes why cities commonly use AC in public infrastructure?
    a. AC can be easily stepped up and transmitted over long distances
16. Which of the following statement best describes Kirchhoff's law when applied to voltage in a series circuit?
    a. Voltage available is equal to voltage drop over entire circuit.
17. Which of the following is both a load and a switch?
    a. Relay
18. Which of the following best describes a transformer that reduces 120 VAC to 24 VACf?
    a. Step-down
19. Which term best describes two metal plates separated by an insulative material for storage of a charge?

a. Capacitor

Self-Test C-2.3: Wiring Diagrams and Symbols

Complete Self-Test C-2.3 and check your answers.

1. What is another term for a schematic diagram?
    a. Pictorial
    b. Wiring
    c. Ladder
    d. Block and line
2. Which diagram shows the relationship of the components with each other?
    a. Pictorial
    b. Wiring
    c. Ladder
    d. Block and line
3. Which diagram doesn't have any lines crossing each other?
    a. Pictorial
    b. Wiring
    c. Ladder
    d. Block and line
4. What does the following symbol represent?
    a. A pressure switch
    b. A float switch
    c. A transformer
    d. A resistor
5. What does the following symbol represent?
    a. A flow switch
    b. A low water cut-off
    c. A solenoid
    d. A relay

Answer Key: Self-Test C-2.3 is on the other page.

Answer Key: Self-Test C-2.3

1. What is another term for a schematic diagram?
    a. Ladder
2. Which diagram shows the relationship of the components with each other?
    a. Block and line
3. Which diagram doesn't have any lines crossing each other?
    a. Ladder
4. What does the following symbol represent?
    a. A float switch
5. What does the following symbol represent?
    a. A flow switch

Self-Test C-2.4: Measuring Electricity

Complete Self-Test C-2.4 and check your answers.

1. When measuring current in a circuit, what must you ensure when connecting the multimeter?
    a. That the power is off in the circuit
    b. That the multimeter is connected near the source
    c. That the multimeter is connected in series with the circuit
    d. That the multimeter is connected to source voltage
2. When testing for ohms, the power must be left on in the circuit.
    a. True
    b. False
3. When testing a circuit for voltage, how must the meter be connected?
    a. In parallel with the circuit
    b. In series with the circuit
    c. To a de-energized circuit
    d. With both leads grounded
4. When testing for continuity in a circuit, what must be ensured?
    a. That the circuit is powered
    b. That the meter is grounded
    c. That the source has a short circuit
    d. That the circuit is de-energized

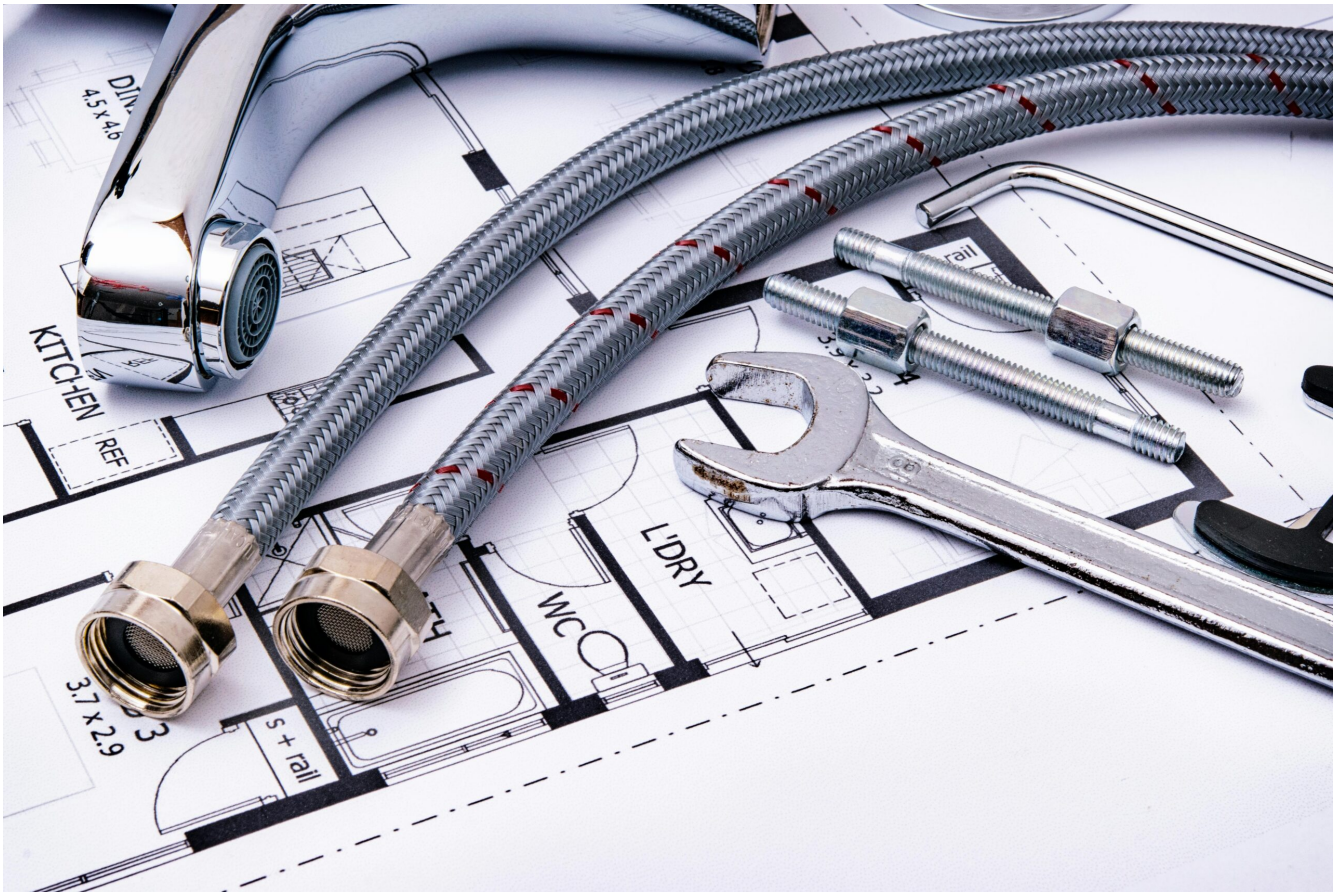
Answer Key: Self-Test C-2.4 is on the other page.

Answer Key: Self-Test C-2.4

1. When measuring current in a circuit, what must you ensure when connecting the multimeter?
    a. That the multimeter is connected in series with the circuit
2. When testing for ohms, the power must be left on in the circuit.
    a. False
3. When testing a circuit for voltage, how must the meter be connected?
    a. In parallel with the circuit
4. When testing for continuity in a circuit, what must be ensured?
    a. That the circuit is de-energized

C-3 DRAWINGS AND SPECIFICATIONS

Plumber Apprenticeship Program – Level 1



Close-up of plumbing tools and faucet on top of an architectural blueprint (AS Photograhy/Pexels) Pexels License

C-3 Drawings and Specifications Introduction

Drawings and specifications are essential tools in the pipe trades. They provide the information needed to plan, install, and maintain piping systems safely and accurately. Drawings show the layout, dimensions, and relationships between components, while specifications describe the materials, standards, and requirements that must be followed.

In this section, you will learn how to read and interpret common types of trade drawings, understand symbols and dimensions, and use basic drafting tools. These skills are critical for communicating with other tradespeople, following project requirements, and ensuring that work is completed correctly and efficiently.

Learning Objectives

After completing this section, you should be able to:

- Describe the drafting tools and materials.
- Use scale rulers to determine actual dimensions from a piping diagram.
- Describe piping and fixture symbols used in the pipe trades.
- Describe lettering and dimensioning of piping diagrams.
- Describe drawing projections.
- Use drawing projections.
- Use tools to sketch irregular shapes.

Topic areas covered in this publication are in alignment with SkilledTradesBC Harmonized 2018 Program Outlines.

You will be required to reference publications and videos available online at WorkSafeBC.

Supplementary Resources

- Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus by Camosun College.
  - Tape Measures
  - Understanding the Imperial Ruler
  - Chalk Lines

Terminology

The following terms may be used throughout this section. Note that some glossary terms may be in italics throughout the section content but are not included in this list. A complete list of terms for this section can be found in the **Glossary.**

- **compass:** A tool used to draw circles or curved lines. (Section C-3.1)
- **divider:** A tool with two sharp points used to measure or copy distances. (Section C-3.1)
- **drafting board:** A flat surface used for drawing plans and diagrams. (Section C-3.1)
- **French curve:** A tool with curved edges used to draw smooth curved lines. (Section C-3.1)
- **mechanical pencil:** A pencil that uses replaceable graphite sticks instead of wood. (Section C-3.1)
- **protractor:** A tool used to measure and draw angles. (Section C-3.1)
- **radian:** Another way to measure angles (used mainly in advanced math). (Section C-3.1)
- **scale rule:** A ruler used to measure and draw objects at a smaller or larger size. (Section C-3.1)
- **spline (flexible curve):** A flexible tool used to draw smooth curves. (Section C-3.1)
- **steel straightedge:** A straight metal ruler used to check if a line is perfectly straight. (Section C-3.1)
- **T-square:** A T-shaped tool used to draw straight horizontal lines. (Section C-3.1)
- **template:** A tool with cut-out shapes used to trace standard drawings. (Section C-3.1)
- **triangle (set-square):** A flat tool used in drafting to draw straight lines and angles. (Section C-3.1)

C-3.1 Describe the Drafting Tools and Materials Tools

Drafting is an essential skill in the piping and plumbing trades. Whether you are preparing a simple sketch for a jobsite layout or reading detailed construction drawings, the ability to understand and create accurate drawings ensures that work is completed safely, efficiently, and to specification. Before you begin drafting, it is important to become familiar with the tools and materials used to produce clear and precise drawings.

This section introduces the most common drafting tools—such as *drafting boards*, *T-squares*, *triangles*, and *scale rules (or scales)*—and explains how to select, maintain, and use them correctly. A good understanding of these tools will help you develop accuracy and consistency in your drawings and prepare you for more advanced drafting tasks later in your training.

Drafting Board or Table

Figure 1 *Drafting Table (Czapp Árpád/Pexels) Pexels License*

The surface of the ***drafting board*** should be smooth. It should have a true, flat surface, with no warps or twists. The surfaces of most drafting boards are covered with vinyl because it is smooth and even. To allow the vinyl to expand and contract, fasten it only at the top and on one side.

The drafting board or table should have two parallel outside working edges, made of either hardwood or steel. The working edges should be tested for straightness with a***steel straightedge***. If the edges are not parallel or straight, they should be corrected before you use the board.

Most drafting table tops can be set at different heights from the floor and at any angle from vertical to horizontal. Other drafting tables may not have the same adjustments and can be raised only from a horizontal position to a low slope.

To reduce back strain, use an adjustable drafting stool when working at a drafting table. Tables or boards should be a minimum of 1.2 m (4 ft) in width and 0.9 m (3 ft) in height.

T-Square

The fixed head ***T-square*** is used for most work. It should be made of durable materials and have a transparent edge on the blade. To do accurate work, the blade must be perfectly straight. To check the straightness of the blade, mark two points on a sheet of paper. Then, draw a line to join the two points using the blade of the T-square as your guide. Turn the blade over and draw another line to join the same two points (Figure 2). Both lines should be directly over each other if the blade is perfectly straight. T-squares typically have blades that are 0.75 m (30″) to 1 m (42″) long.

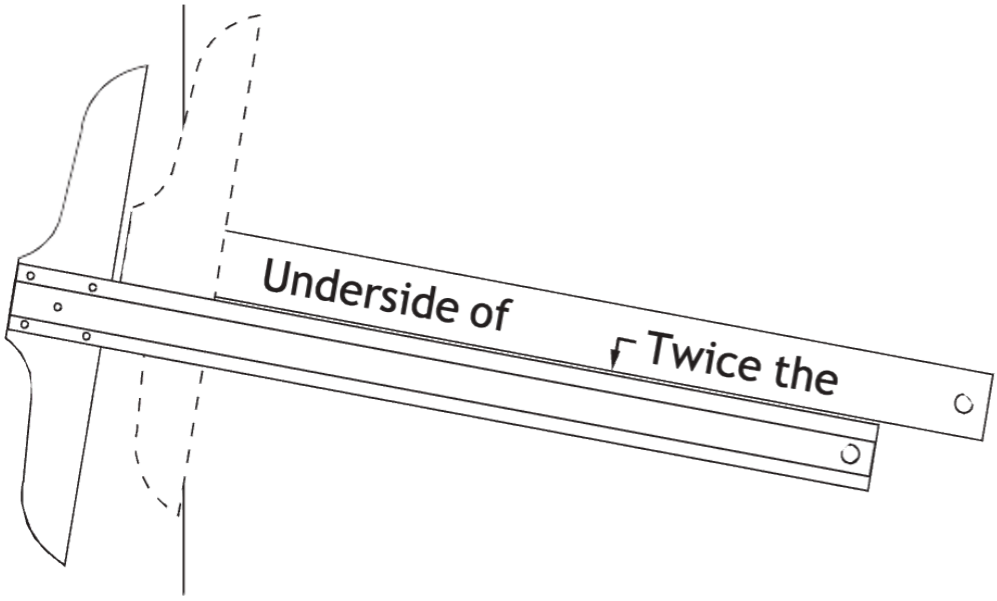


Figure 2 *Testing the straightness of a T-square* (*BC Industry Training Authority*, 2019). CC BY-NC-SA 4.0

The T-square is used to draw horizontal lines on paper. For right-handed people, it is held tightly against the left edge of the drawing board and moved up and down as required. When making close adjustments, place the fingers of your left hand on top of the square and use your thumb to control the T-square's movement.

When drawing horizontal lines, incline your pencil in the direction of the line. Hold the pencil point as close as possible to the blade and roll the pencil between your fingers to prevent the point from becoming flat on one side.

Triangles

Triangles (set-squares) are made of a clear plastic with ***rabbeted edges*** (Figure 3), so that when you draw lines, the edge raised from the tracing paper. This helps prevents smudges and ink blotches.

Triangles are available in 45°—90°—45° or 30°—60°—90° combinations. For most work, triangles should be about 200 mm to 250 mm (8–10″) long. Triangles should be stored flat to prevent warping and should not be placed under other objects. This prevents any pressure put on them, which will cause them to deform.

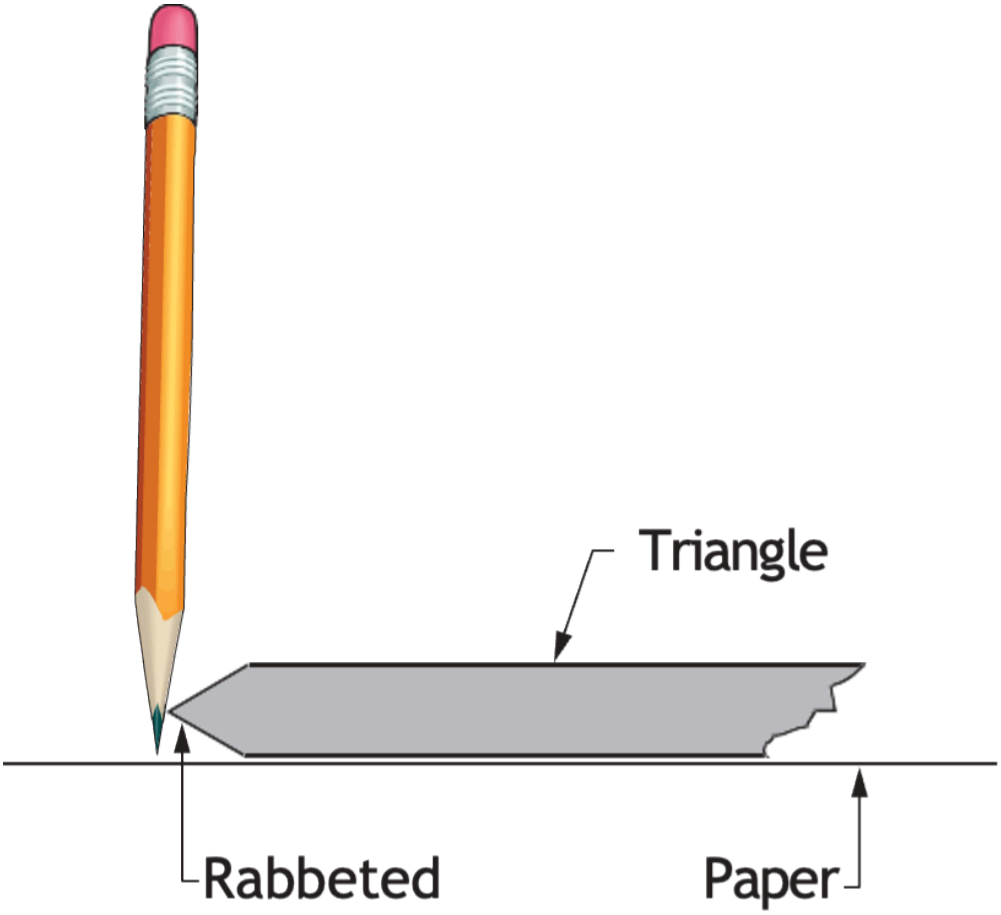


Figure 3 *Rabbeted edge (side view) (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

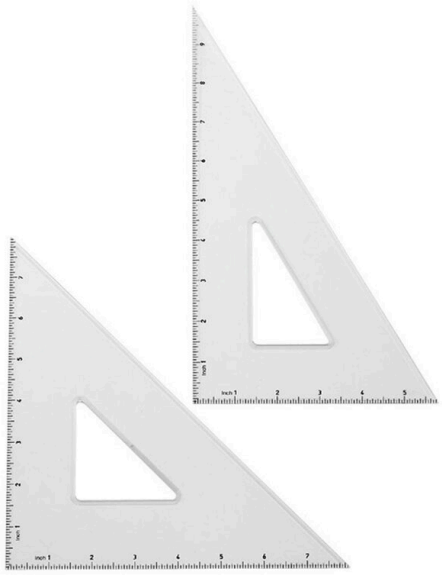


Figure 4 *Triangle30-60 (Cletzrodt/ Wikimedia Commons) License*

Triangles are used to draw vertical lines and other lines at set angles. Rest the triangle on the T-square blade and slide it along the blade to the desired location. Draw the full length of the vertical line in one pass if possible. Hold the blades of the T-square and the triangle together firmly to prevent any movement when you are drawing. Hold the pencil point as close as possible to the triangle when you are drawing.

Check a triangle for accuracy by drawing a perpendicular line, then reversing the triangle and drawing another perpendicular line (Figure 5).

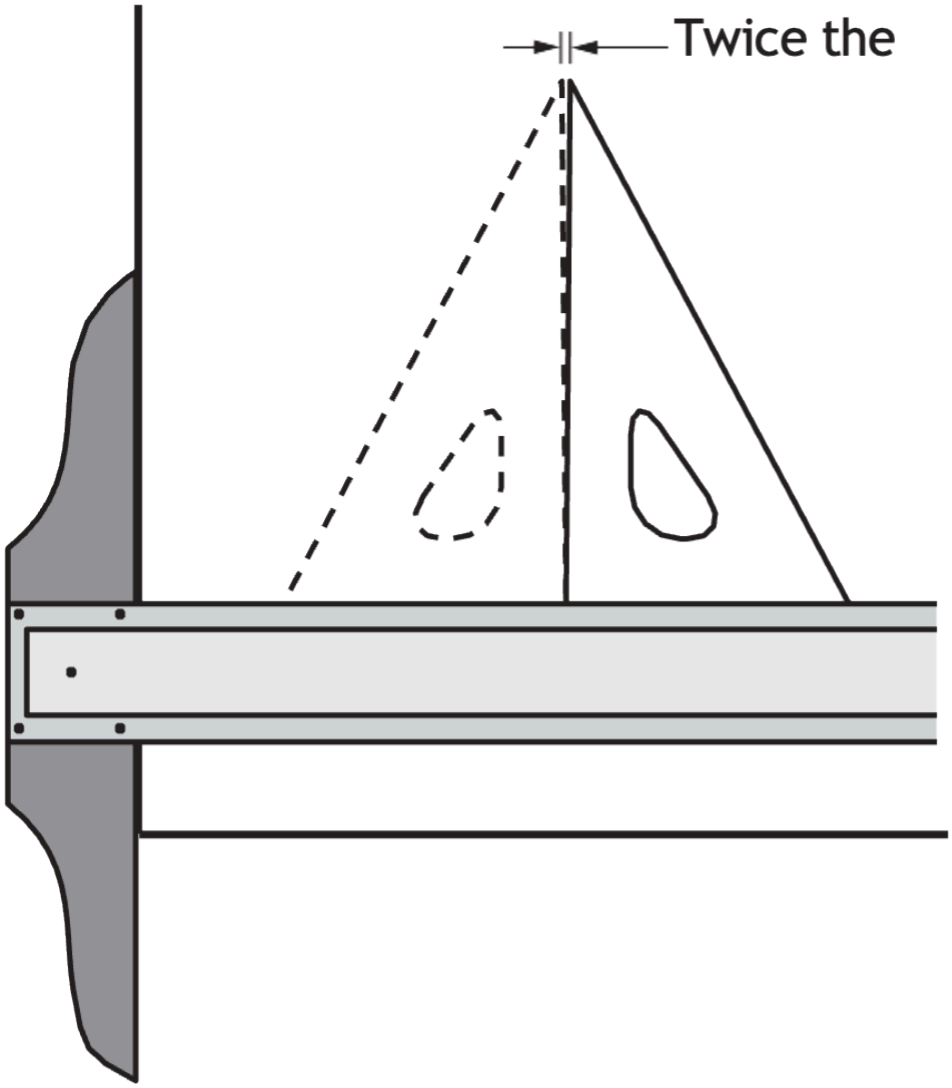


Figure 5 *Testing the straightness of a T-square (BC Industry Training Authority, 2019).CC BY-NC-SA 4.0*

You can also draw 15° and 75° angles by using both a 45°—90°—45° and a 30°—60°—90° in combination. Figure 6 shows how triangles are placed to draw angles that are every multiple of 15°.

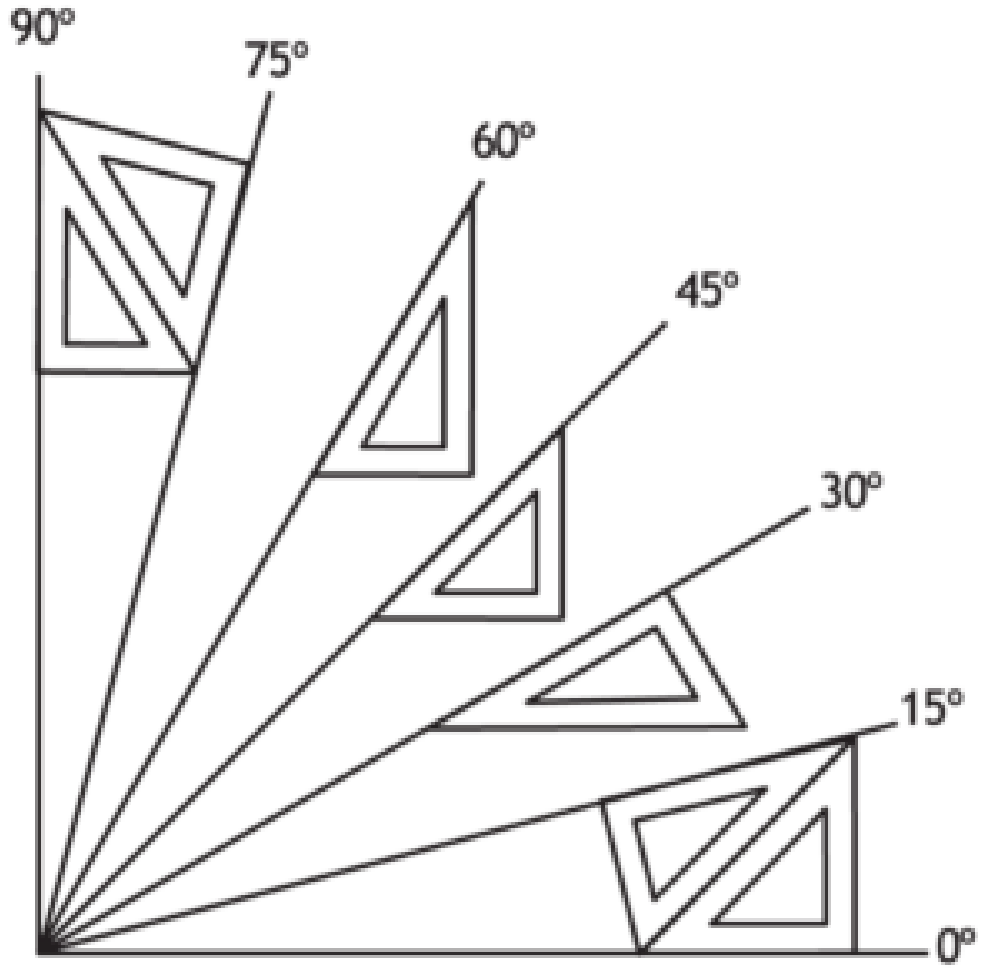


Figure 6 *Drawing angles with one or two triangles (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Protractor

A ***protractor*** is a square, circular, or semicircular tool, typically made of transparent plastic or glass, for measuring angles. Most protractors measure angles in ***degrees*** while some measure in ***radians*** (Figure 7).

Protractors are used for a variety of mechanical and engineering-drafting applications to transfer angles to the drawing sheet. Some protractors are simple half-discs, while others, such as the ***bevel protractor***, have one or two adjustable swinging arms, which can be used to measure angles more precisely.

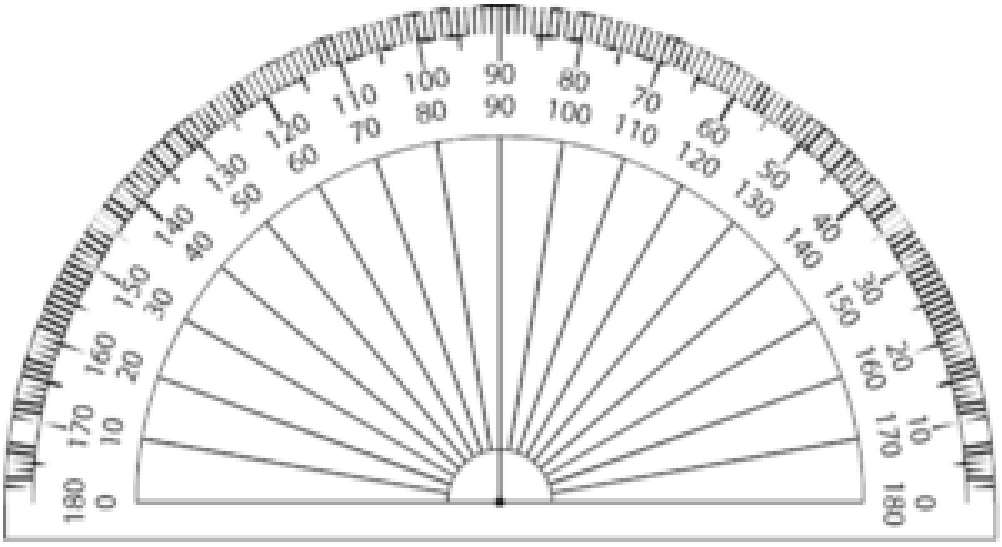


Figure 7 *Protractor (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

French Curves and Splines

A ***French curve*** (Figure 8) is a plastic or metal template designed to help you draw curves. It is often used in the design of cars and dresses. The French curve contains many different curve shapes, but each one is represented over a very short distance only. The French curve allows you to draw and connect curves together so they fit together perfectly without using mathematics calculations.

To use a French curve, align one section with the two points you want to connect, then trace along the edge of the French curve with your pencil. One radius of the curve blends into another radius. It takes a lot of practice to use French curves effectively!

Figure 8 *French curve (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A ***spline***, or the more modern term, *flexible curve* (Figure 9), can be used instead of a French curve to draw most curves.

A spline is a bendable plastic or rubber rod that is reinforced with metal. To use a spline, bend it to the shape of the curve you need and draw along its edge. The design of the spline lets you hold a pencil against an edge and draw an accurate line without smudging. A spline cannot be used to draw tight curves that have a very short radius because the spline will not bend sharply enough. Sometimes a spline is temporarily held in position with small weights.

Figure 9 *Spline (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Drawing Pencils

Manufacturers grade drawing pencils by numbers and letters. These range from 6B (very soft and black) to 9H (the hardest). From 6B the pencils progress through 5B, 4B, 3B, 2B, B and HB, and then to F, the medium grade. After that, they move to the harder graphite: H, 2H, 3H, 4H, 5H, 6H, 7H, 8H and finally 9H. The softer grades are used for sketching and rendering (shading and texturing) drawings. The harder grades are used for more precise instrument drawings.

Mechanical pencils are made to hold leads that are bought separately. (Although they are called leads, they are made of graphite.) Most draftspeople use four or five different mechanical pencils with a different lead grade in each. Pipe trades workers are likely to find a 0.7 mm pencil handy. Most mechanical pencils come in different colours so that you can keep track of which lead is in each.

Special pencil sharpeners are used to sharpen wooden pencils and mechanical pencils (Figure 10). However, thin-lead mechanical pencils, with leads as small as 0.5 mm, are available in different grades of lead and do not require sharpening.

Figure 10 *Wood and mechanical pencils (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Eraser Shields

An ***erasing shield*** is a thin metal tool used to erase small areas precisely. It has cut-out shapes that allow you to erase only the desired section without affecting surrounding lines. Figure 11 shows two erasers and an erasing shield.

Figure 11 *Erasers and erasing shield (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Scale Rules

Scale rules enable you to draw diagrams of piping systems and other objects at a reduced scale and measure distances on scaled drawings.

Scale rules come in a variety of types to meet the requirements of many different kinds of work. Most scale rules have three sides and six different scales. The scales are read from either end of the rule.

Common metric scales are expressed in ratios of 1:1, 1:2, 1:5, 1:10, 1:20 and 1:50, or 1:100, 1:200, and 1:500. Because metric units are based on multiples of 10, they are easy to convert between scales to suit your purpose (Figure 12).

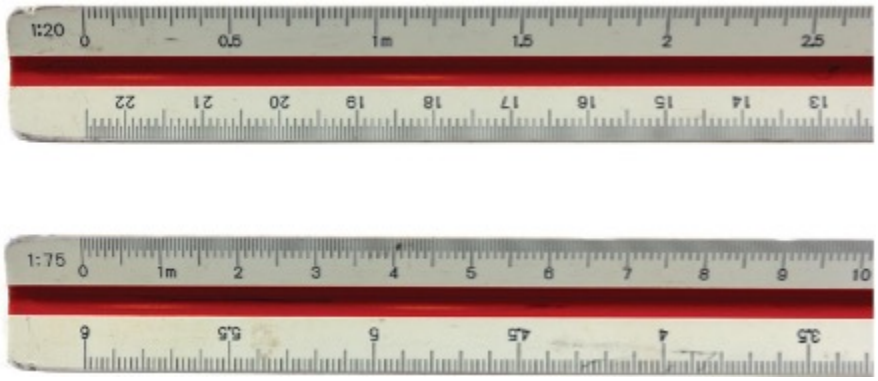


Figure 12 *Metric scale rule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Imperial scale rules may be an *architect's rule*, a *mechanical engineer's rule* or a *civil engineer's rule* (Figure 13); each uses different units. The architect's scale rule is in inches and fractions of inches. A mechanical engineer's scale rule comes in inches and decimals of inches. A civil engineer's scale rule comes in feet and decimals of feet. The most common scale rules are the metric and architect's scales.

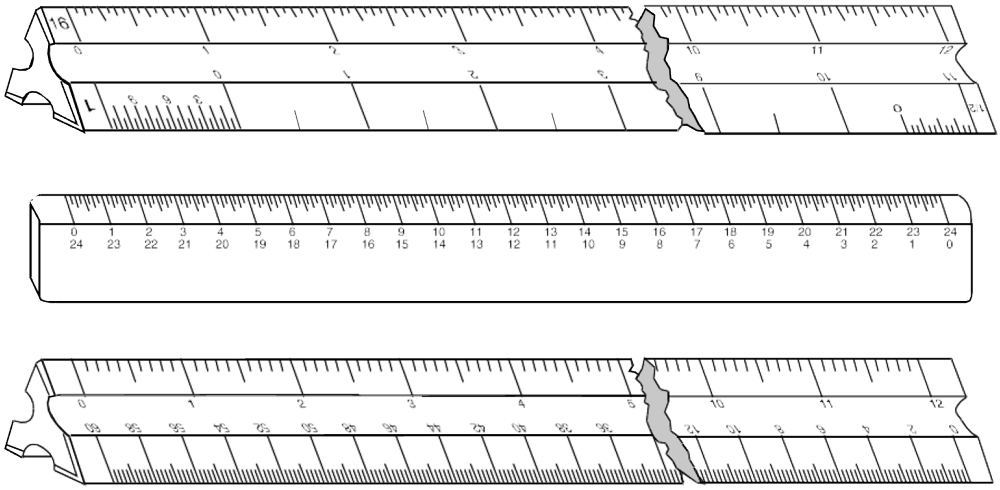


Figure 13 *Inch-feet scale rules (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Templates

Templates are thin plastic tools with cut-out shapes. They are used to draw standard symbols and fixtures that are commonly used in a trade. These cut-outs make it easy to trace shapes onto drawing paper quickly and accurately.

Templates contain pre-dimensioned holes in the right scale to accurately draw a symbol or sign. They are available in many forms and sizes, including circles, geometric shapes, and trade-specific symbols such as plumbing fixtures.

Circle templates are used for drawing circles and circle-arcs of certain dimensions. Models are also available for other geometric shapes such as squares and ellipses, as well as many specialized varieties for other purposes.

There are also specific templates that contain the most common symbols in use in different branches of designing. For

example, architect templates can be used to draw different sized doors with their opening arcs, building and equipment symbols, plumbing fixtures, and furniture. The templates also provide the symbols for thermal insulation.

There are templates available for many different trades. Templates that are used by pipe trades workers are the isometric, plumber's and heating templates (Figure 14).

Figure 14 *Templates (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Compasses

For larger circles and arcs that cannot be drawn with the circle template, you can use a ***bow, wing*** or a ***friction compass***. For very large circles, you can use a ***beam compass***. These four types of compasses are shown in Figure 15.

Most compasses can be fitted with leads, pens, or points. For best results, adjust the lead so that it is about 1/32″ shorter than the needle. Both legs will be the same length when the needle penetrates the paper. Fit the ***compass*** with lead that is one grade softer than the pencil used to make the drawing. The lead must be kept sharp.

Figure 15 *Four types of compasses (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

To set the compass to size, draw a line on a piece of clean scrap paper and measure off the required radius. Set the compass on this line. Avoid setting a compass on a scale. Sticking the compass needle into the scale will eventually destroy its accuracy. When using the compass, tilt it in the direction of movement as you draw the line, as shown in Figure 16.

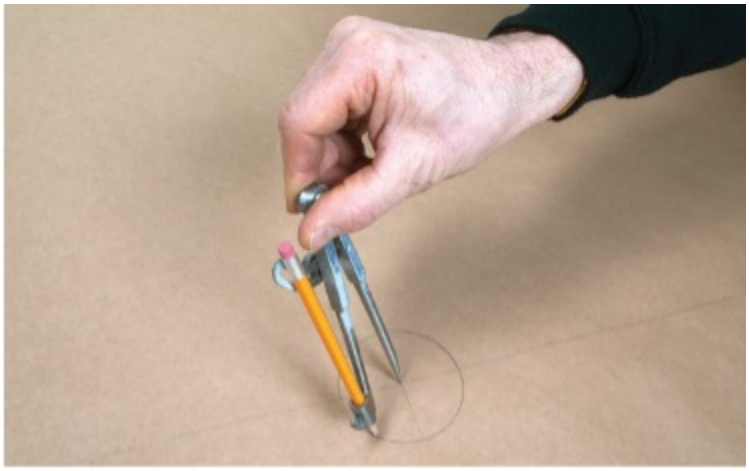


Figure 16 *Drawing circles with a compass (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Dividers

A ***divider*** is an instrument used for measuring, transferring, or marking off distances. It consists of two straight, adjustable legs hinged together and ending in sharp points (Figure 17). It is used principally in drafting for accurate transfer of dimensions from a drawing sheet to a measuring device, such as a ruler.

Figure 17 *Divider (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Self-Test C-3.1: Describe the Drafting Tools and Materials Tools

Complete Self-Test C-3.1 and check your answers.

If you are using a printed copy, please find Self-Test C-3.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2413#h5p-33

References

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BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Plumber: Competency C-2 Interpret Drawings and Specifications
- Steamfitter: Competency C-2 Interpret Drawings and Specifications
- Sprinkler Fitter: Competency C-2 Interpret Drawings and Specifications

Camosun College. (2019). Line D: Tools and Equipment—Competency D-3: Competency D-3: Read Drawings and Specifications (Rev. ed.) [Learning guide]. BCcampus. https://collection.bccampus.ca/textbook/yxJ3AwTa/

Camosun College. (2015). Trades Access Common Core Competency D-3: Competency D-3: Read Drawings and

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C-3.2 Use Scale Rulers to Determine Actual Dimensions from a Piping Diagram

In the piping trades, most of the drawings you work from are not shown at their actual size. Buildings, mechanical rooms, and piping systems are far too large to fit on a page, so designers reduce the size of the drawing while keeping every part in proportion. To understand these drawings and to correctly determine the real-world lengths of pipe and the locations of ***fittings***, you must be able to use a ***scale ruler***.

A scale ruler allows you to read measurements that have been reduced by a certain ratio, such as 1/4″ = 1′-0″ in imperial units or 1:50 in metric. When you understand how these ratios work, you can accurately interpret piping diagrams, estimate material lengths, and verify ***dimensions*** on both imperial and metric plans.

This section will teach you how to read and use ***architect's (imperial) scales*** and metric scales, how to convert scale measurements into real-world dimensions, and how to avoid common mistakes when measuring from drawings. By the end, you will be able to confidently obtain approximate pipe lengths directly from a drawing whenever written dimensions are not provided.

Scale drawings are accurate and convenient visual representations made and used by engineers, architects, and people in the construction trades. The accuracy is achieved because the drawing is ***proportional*** to the real object. The convenience comes from the reduced size of the drawing. It is large enough to provide the desired detail but small enough to be manageable.

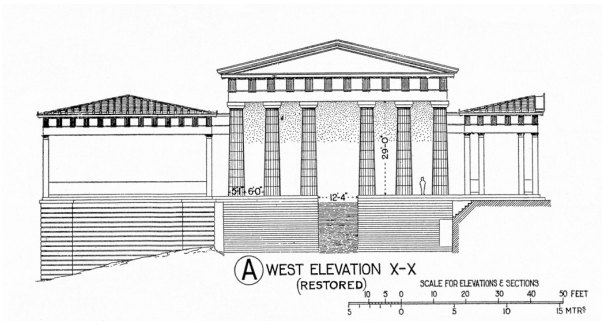

Figure 1 *House numeric labels (Mnesicles, Flickr) CC BY-NC 2.0*

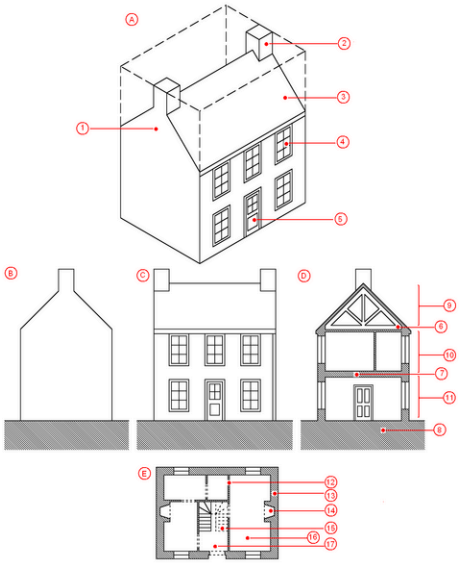

Figure 2 *House Numeric Labels (Cmdrjameson, InfoCan/Wikimedia Commons) CC BY-SA 3.0*

The flexibility to draw proportionally in different sizes is provided by the use of scales. Since piping systems are large compared to piping drawings, we will only be concerned with ***reduction scales***. Reduction scales make the drawing smaller than the object. The kinds of rules we will typically use to make scaled drawings are the architect's scale and the metric scale, both shown in Figure 3.

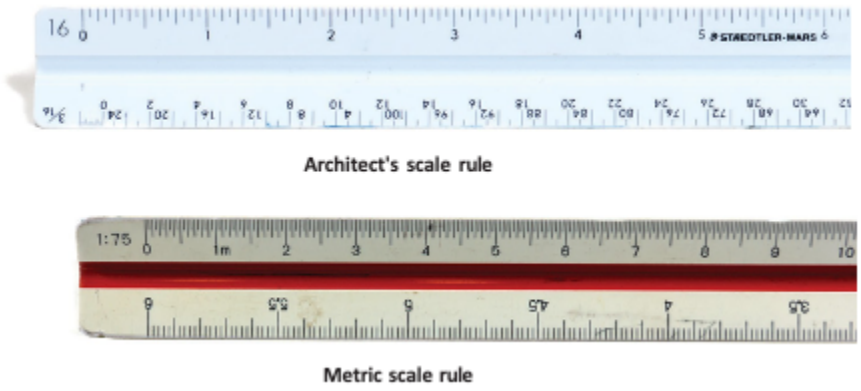

Figure 3 *Architect's and metric scale rules (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Proportional Scaling

The scale of the drawing is always written on the drawing. The ***scale*** is the ratio of the size of the drawing to the object. For drawings smaller than the object, the ratio will be that of a smaller distance to a larger one.

Architect's scales use ratios of inches to a foot. The most common architect's scale used is $\frac{1}{4}$„ to the foot, written on drawings as:

$$\text{Scale } \frac{1}{4}\text{”} = 1\text{’} - 0\text{”}$$

This means that a line $\frac{1}{4}$„ long on the drawing represents an object that is 1 foot long. At the same scale, a line $1\frac{1}{2}$„ long represents an object 6′ long, because $1\frac{1}{2}$„ contains six quarter-inches.

Metric scale ratios use the same units in both ratio terms, resulting in an expression of how many times smaller than the object the drawing is. For example, the standard metric scale ratio that approximately corresponds to $\frac{1}{4}\text{”} = 1\text{’} - 0\text{”}$ is written on drawings as:

$$\text{Scale } 1{:}50$$

This means that the object is actually 50 times as large as what's shown on the drawing, so 50 mm on the object is represented by 1 mm on the drawing. For another example, 30 mm on the drawing represents 50×30

$$= 1{,}500 \text{ mm (or 1.5 metres) on the object}$$.

Table 1 lists the scale ratios commonly used for building plans and construction drawings in both metric and the equivalent architectural scale ratios.

Table 1 ***Preferred Scales for Building Drawings***

Type of Drawing	Common Metric Ratios	Use	Imperial Equivalents and Ratios	
Site Plan	1:500 1:200	To locate the building, the services and reference points on the site.	1″ = 40′-0″ $\frac{1}{16}$„ = 1′-0″	(1:480) (1:192)
Sketch Plans General Locations Drawings	1:200 1:100 1:50	To show the overall design of the building. To indicate the juxtaposition of the rooms and locate the positions of piping systems and components.	$\frac{1}{16}$„ = 1′-0″ $\frac{1}{8}$„ = 1′-0″ $\frac{1}{4}$„ = 1′-0″	(1:192) (1:96) (1:48)
Construction Details	1:20 1:10 1:5 1:1	To show the detail of system components and assemblies.	$\frac{1}{2}$„ = 1′-0″ 1″ = 1′-0″ 3″ = 1′-0″ Full size	(1:24) (1:12) (1:4) (1:1)

Architect's (Imperial) Scales

Traditional architectural measurements of length are written very precisely in feet and inches using the appropriate symbols for feet and inches, separated by a hyphen (e.g., $4' - 3\frac{1}{2}"$ and $7' - 0"$). This is the way that all imperial measurements should be written on construction drawings.

Listed below are the scales found on the architect's triangular scale rule.

1. $\frac{3}{32}" = 1' - 0"$
2. $\frac{3}{16}" = 1' - 0"$
3. $\frac{1}{8}" = 1' - 0"$
7. $1" = 1' - 0"$
8. $\frac{1}{2}" = 1' - 0"$
9. $1\frac{1}{2}" = 1' - 0"$

4. $\frac{1}{4}$” $= 1’ - 0”$

5. $\frac{3}{4}$” $= 1’ - 0”$

6. $\frac{3}{8}$” $= 1’ - 0”$

10. $3” = 1’ - 0”$

11. $1” = 1’ - 0”$ (full size - use the scale labelled ”16”)

Figure 4 shows the ends of one face of an architect’s imperial triangular scale rule. There are two edges on each face, and each edge contains two scales that run in opposite directions. At each end of an edge, a number or fraction indicates the distance in inches that represents 1 foot. The top edge is in eighths of an inch from left to right and in quarters of an inch from right to left. Note that on a full rule the 1/8″ scale from 0 to the right end represents 95 feet and the 1/4″ scale from 0 to the left end represents 47 feet.

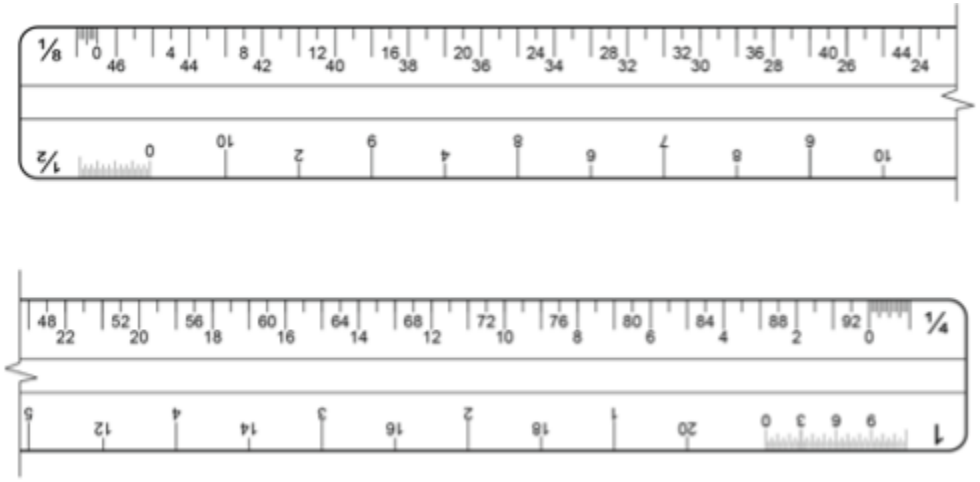

Figure 4 *One face of an architect’s rule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Watch the following video by MTCopeland (2020) on YouTube titled “How to Use an Architect Scale Ruler” [3:40].

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If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: How to Use an Architect Scale Ruler

At each end, between the zero and the number indicating scale, the length representing 1 foot is subdivided into 6, 12, 24 or more parts to indicate inches and, in some scales, fractions of an inch. For example, each of the six marks on the $\frac{1}{8}$" scale represents 2 inches, while each mark equals a quarter of an inch on the 1″ foot-reduction scale and 1 inch on the $\frac{1}{4}$" scale.

Now look at the $1\frac{1}{2}$" scale in Figure 5. The subdivided foot unit is divided into inches and fractions of an inch. Reading left from the zero, notice the figures "3", "6" and "9," which represent measurements of 3″, 6″ and 9″. From the zero to the first long mark represents 1 inch. Between the zero and the 1-inch mark there are four lines, each of which represents one quarter of an inch.

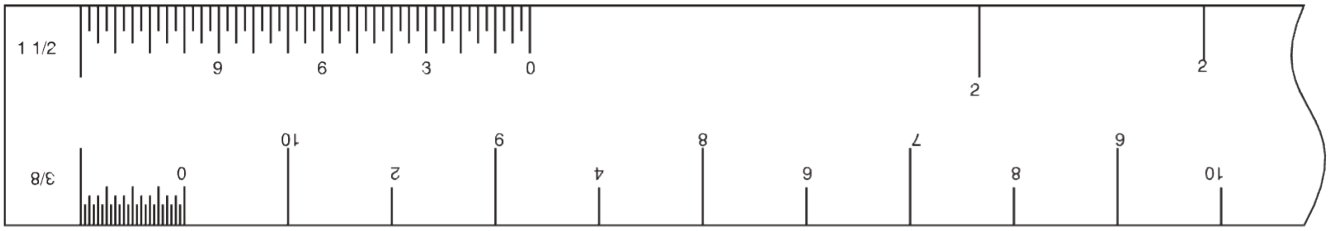

Figure 5 *Units on an architect's scale rule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Piping drawings usually use a $\frac{1}{8}$" scale for larger buildings, a $\frac{1}{4}$" scale for smaller buildings and houses and a $\frac{1}{2}$" scale for details.

Each drawing will state in the ***title box*** the scale that is used. Sometimes when special details are given, the scale is placed directly under the detail.

To draw or measure a length to scale, first find the edge of the rule containing the scale. One end of the length will rest exactly on one of the foot marks of the scale, and the other end should rest either on the zero marker or somewhere on the inch subdivision of the scale. The length can then be marked and drawn or read off from a drawing.

Figures 6 and 7 demonstrate this manner of reading dimensions from four of the ratios on the architect's scale.

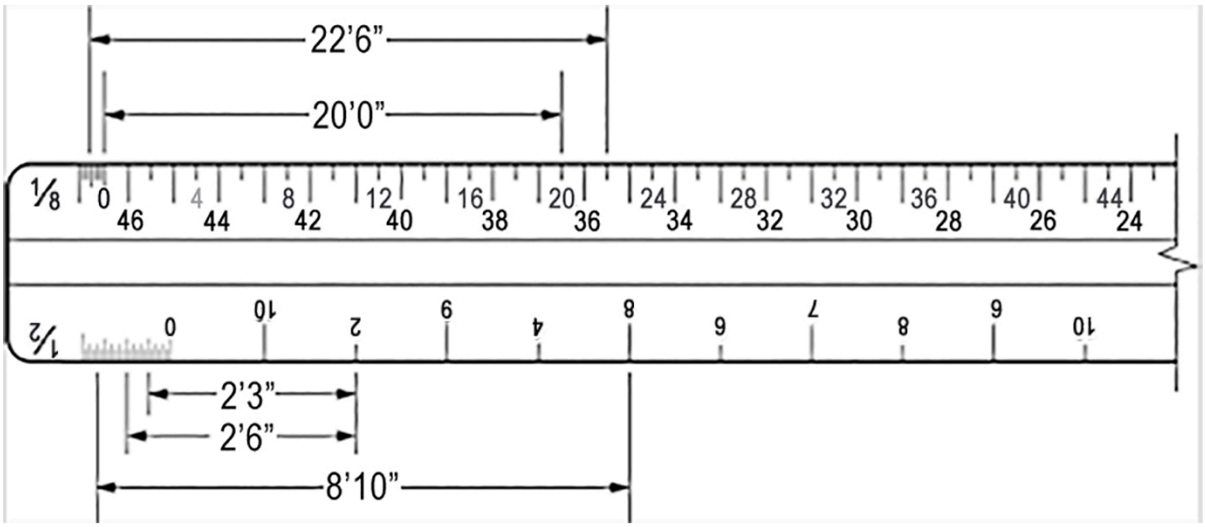

Figure 6 *Reading dimensions using an architect's scale rule ([adapted] BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

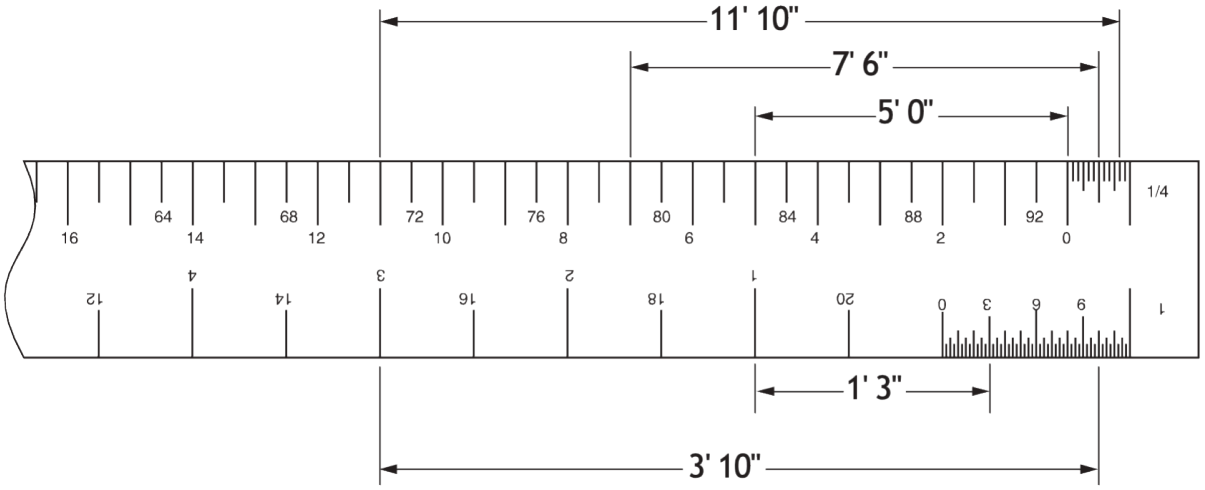

Figure 7 *Reading dimensions using an architect's scale rule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Architectural units have feet divided into inches, whereas engineering units divide feet into tenths and hundredths. Engineer's scales are not used to make piping drawings.

Metric Scales

A ***triangular metric scale*** is similar to the architectural scale in that it has six edges, but it has only one scale ratio per edge. The ratio is marked at the left end of the scale. For example, the scale of 1:50 means that 1 mm on the drawing represents 50 mm on the object. This means that the object is 50 times larger than the drawing of it. An object 450 mm long would be represented by a line 9 mm long $(\frac{450\text{ mm}}{50})$.

Figure 8 shows one of the three sides of a ***metric scale***. The scale labelled 1:50 is read from left to right, from 0 to 15 m. The scale labelled 1:2 can also be read from left to right (0 to 600 mm) by turning the scale around.

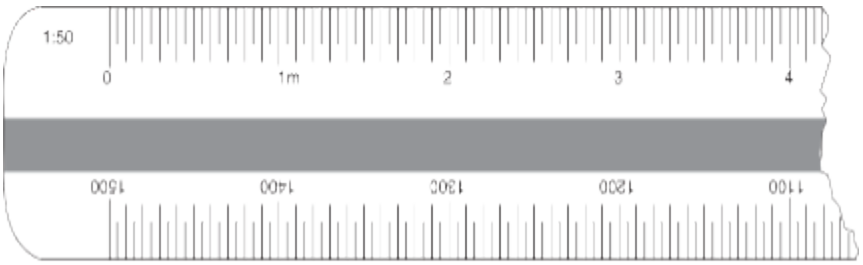

Figure 8 *One side of a metric scale rule (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Watch the following video by Steve Bailes (2012) on YouTube titled "Metric Scale" [2:07].

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If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Metric Scale

If the ratio is 1:1, it means that 1 mm on the drawing represents 1 mm. In other words, the object in the drawing is being drawn to its actual size.

The ratios most often used in piping drawings are 1:100 for larger buildings, 1:50 for smaller buildings, and 1:20 for details.

You will notice that all the edges on a metric scale are marked with spaces that are 1 mm apart, similar to a metric tape measure. The difference is that each edge is marked off or labelled according to a different ratio, so that proportionate lengths are read directly from the scale. This eliminates the need to calculate dimensions.

Figure 9 shows common metric scales for comparison. Notice that all the scales shown are labelled in metres and that 0.5 m = 500 mm. All the scales in Figure 9 are marked at the scaled position of 250 mm.

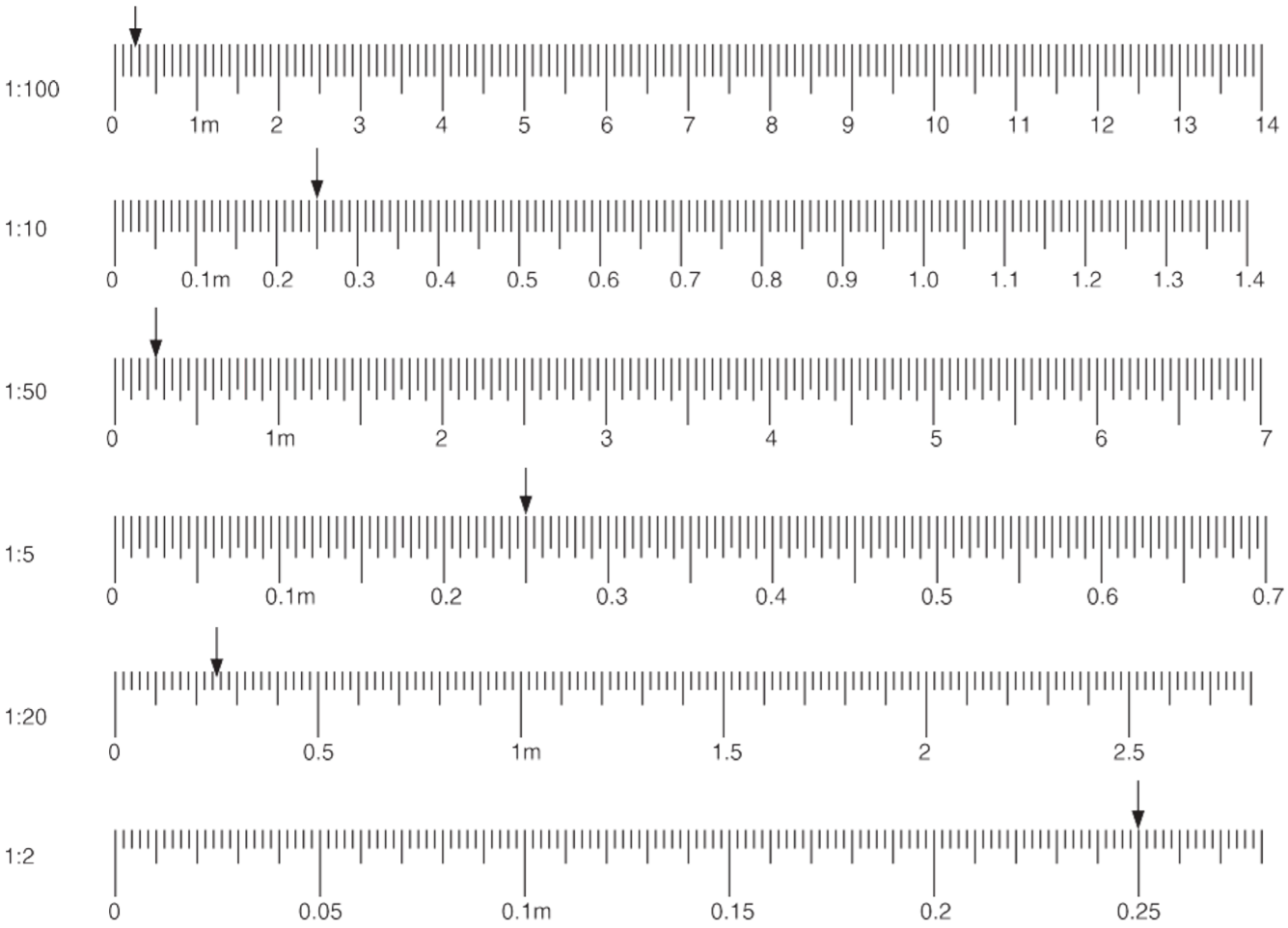

Figure 9 *Metric scales marked at 250 mm (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The length of an object represented on a drawing in a metric scale is found by measuring the drawn object with a metric rule of the proper scale. You can also measure the drawing with any metric tape measure and multiply the result by the scale ratio.

Obtain Dimensions From Drawings

The best way to get exact dimensions from drawings is to use the explicit dimensions (in millimetres or in feet and inches) written between the dimension lines. Any measurements that you need should be somewhere on the drawings. Drawings normally only give each dimension once. If there are a number of parallel lengths, only one will have a measurement. To find the dimension you need, you may need to refer to other views, or you may have to add or subtract other dimensions.

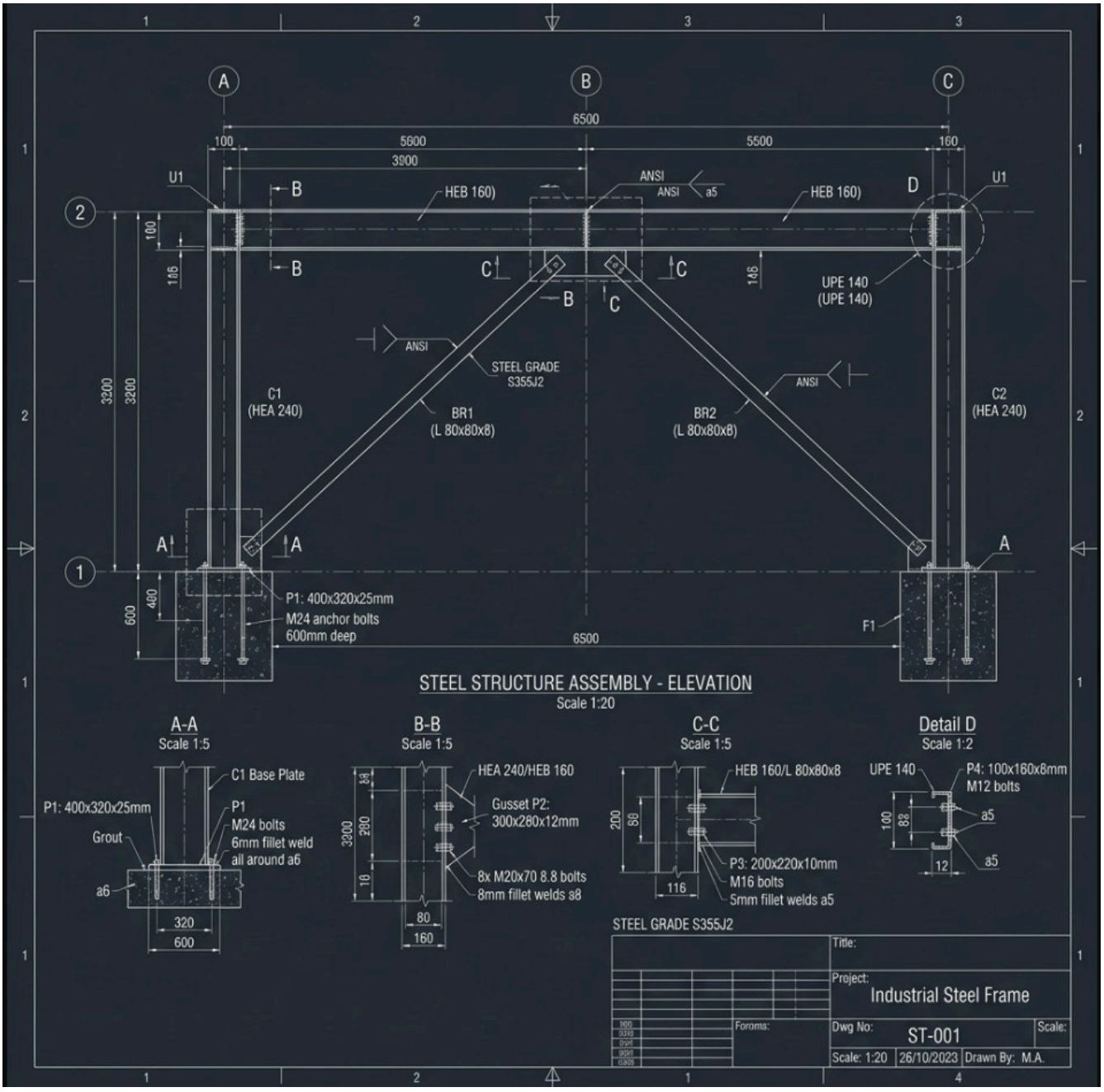

Figure 10 *Detailed 2D Steel Structure CAD Drawing with 1:20 scale [Model: Nano Banana 2] (Easy-Peasy.AI) CC BY 4.0 License*

Measuring lines of a drawing to determine the measurement is not an accurate way to extract dimensions. This is because the drawing is only a representation and may not be exact. Photocopies and reproductions of drawings also may not be to the scale of the original.

The scale of the drawing and lack of attention in measuring can lead to inaccuracies. For example, if the scale of a drawing is $\frac{1}{8}" = 1' - 0"$, an error of $\frac{1}{32}"$ in measuring the plan amounts to 3″ of error in the actual object measured. Detail drawings permit more exact precision because they are proportionately larger. However, details often *require* more exactness and usually contain any needed dimensions.

When accuracy is not required and approximate dimensions are adequate, measuring plans is a quick method of taking off material for estimating the cost of a job. In such cases, about 10% is usually added for cut-off and waste allowance.

Measuring plans to scale is not accurate enough for measuring pipe for cutting and installation purposes.

If you use the scale of the drawing, it will be simple to read off the measurements. However, in the field you will often need approximate measurements and the only measuring tool at hand will be a ***measuring tape***.

A ***steel pocket tape measure*** has a movable hook on the end that allows accurate measuring, either when butted against a surface or when hooked on the end of an object (Figure 11). The end of the flexible tape itself is shortened to allow for the hook.

Figure 11 *Tape measure with movable hook (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

To avoid any error, and to place the tape flat on the drawing, use a convenient unit mark, such as 100 mm as the starting point for measuring, as in Figure 12.

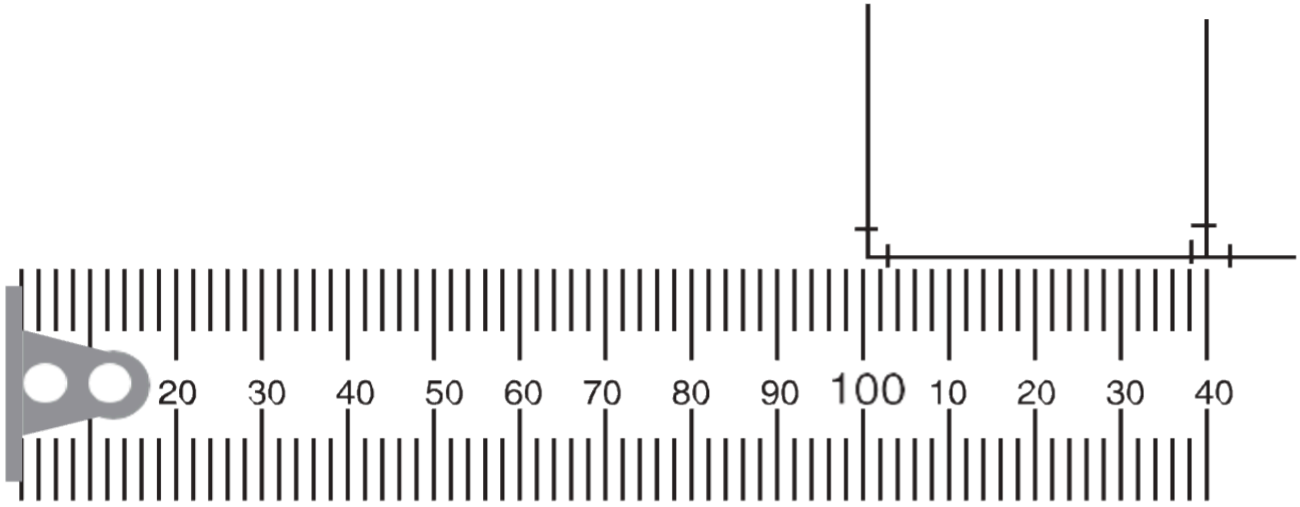

Figure 12 *Measuring metric drawings (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The distance between the dimension lines is 40 mm. Since the scale is 1:50, the centre-to-centre length is:

$$40 \text{ mm} \times 50 = 2,000 \text{ mm}$$

If the scale had been 1:100 the length would be $40 \text{ mm} \times 100 = 4,000 \text{ mm}$.

Determining approximate piping lengths from imperial scale drawings follows the same procedure. An imperial tape measure is used in the same way to find a length on the drawing in inches. As an example, suppose the length is $7\frac{1}{2}$".

To find the length represented, use the scale of the drawing.

In every case, if you divide the length on the drawing by the scale fraction or number, you will be calculating the length in feet. Since dividing by a fraction is the same as multiplying by its reciprocal, you multiply the drawn length in inches by:

- 4 when the scale is $\frac{1}{4}" = 1' - 0"$
- 8 when the scale is $\frac{1}{8}" = 1' - 0"$
- 2 when the scale is $\frac{1}{2}" = 1' - 0"$

Helpful tip! The reciprocals of all standard scales used by architects are shown in Table 2.

Table 2 ***Reciprocals of Standard Scales***

Scale	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$ $(\frac{3}{2})$	3
Reciprocal	$\frac{32}{3}$	8	$\frac{16}{3}$	4	$\frac{8}{3}$	2	$\frac{4}{3}$	1	$\frac{2}{3}$	$\frac{1}{3}$

The $7\frac{1}{2}$" length on a drawing scaled $\frac{1}{4}" = 1' - 0"$ would represent:

$$7\frac{1}{2}" \times 4 = 30'$$

On a scale of $\frac{3}{8}" = 1' - 0"$, the same $7\frac{1}{2}$" drawing length represents:

$$7\frac{1}{2}" \times \frac{8}{3} = 20'$$

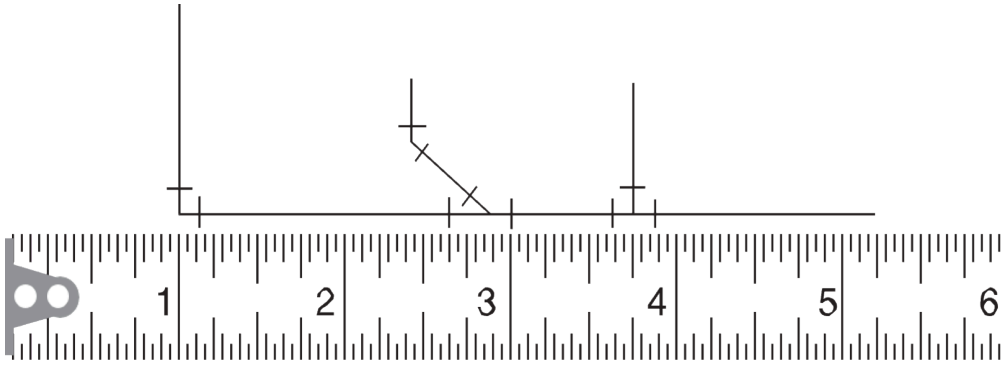

Figure 13 *Reading lengths of piping runs (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Figure 13 is part of a piping run drawn to the scale of $\frac{1}{8}" = 1' - 0"$. The total length of the run is:

$4\frac{1}{4}" \times 8 = 34'$.

Self-Test C-3.2: Use Scale Rulers to Determine Actual Dimensions from a Piping Diagram

Complete Self-Test C-3.2 and check your answers.

If you are using a printed copy, please find Self-Test C-3.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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- Sprinkler Fitter: Competency C-2 Interpret Drawings and Specifications

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MTCopeland. (2020). *How to use an architect scale ruler* [Video]. YouTube. https://www.youtube.com/watch?v=-0g7BwFhWW8&t=5s

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- **Figure 1** Acropolis, Propylaea: reconstruction elevation from the west, by Mnesicles on Flickr is used under the CC BY-NC 2.0 license.
- **Figure 2** House Numeric Labels , by Cmdrjameson (adapted original by İnfoCan) on Wikimedia Commons is used under the CC BY-SA 3.0 license.
- **Figure 10** Detailed 2D Steel Structure CAD Drawing [Model: Nano Banana 2] is from Easy-Peasy.AI and is used under a CC BY 4.0 license.

C-3.3 Describe Piping and Fixture Symbols Used in the Piping Trades

Symbols

In the piping trades, drawings are a universal language. Before any pipe is cut, assembled, or installed, the entire system is communicated through symbols that represent pipes, fittings, valves, and fixtures. These symbols allow designers, plumbers, inspectors, and other trades to understand a piping layout quickly without needing detailed written explanations.

Because every symbol has a specific meaning, using the correct one is essential. A single incorrect symbol on a drawing can lead to wrong materials being ordered, improper installation, or costly delays. For this reason, piping symbols are intentionally simple, standardized, and easy to draw accurately.

This section introduces the different types of piping symbols—single-line, double-line, and symbols that identify specific pipe materials. Understanding these symbols is a foundational skill for anyone working in the piping trades, as they appear in virtually every plan, sketch, schematic, and installation drawing you will encounter.

Single-Line Symbols

Piping systems are usually drawn with single-line symbols because they are quick and easy to draw yet convey a great deal of information. The single-line symbol represents the centre line of the pipe and fittings as seen from the side. Figure 1 shows the same piping run represented by double- and single-line symbols.

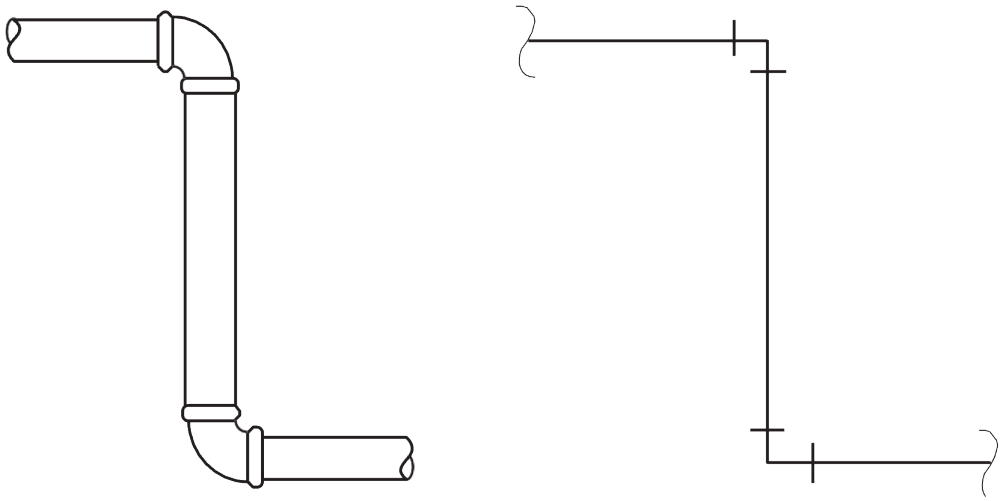


Figure 1 *Double- and single-line drawings*

Single-line symbols are often used on drawings:

- when speed of execution is important
- of extensive piping systems that have long runs
- when the size of the piping is less than NPS 12″
- that only show processes or principles of operation (“diagram drawings” or “flow charts”)
- that are produced in order to make materials lists

On single-line drawings, the piping run lengths may or may not be drawn to scale, but the sizes of the valves or fittings are always drawn to scale. The exception is the flow chart.

Double-Line Symbols

A double-line drawing is used when accurate scale and a more realistic appearance are needed. In this method, two lines that are spaced to scale represent both the length of each pipe and its nominal pipe size.

Double-line drawings are usually made for the purpose of giving more detailed information than can be shown on single-line drawings of smaller scale. Many companies use single-line drawings for piping smaller than NPS 12″ and double-line drawings for NPS 12″ pipe and larger.

Double-line symbols may be used for fittings, such as tees and elbows, making them look very real. Valve bodies are often drawn exactly like the single-line symbol and do not look real.

On double-line drawings, flanged and welded fittings and valves are drawn to scale with respect to both fitting run length and the perpendicular flange length. Threaded fitting and valve lengths are scaled only if there are close clearances.

Figure 2 illustrates some of the common symbols used in double-line pipe drawings. Note that threaded fittings are drawn to a close approximation of the actual shape of the fitting. The valve is strictly symbolic.

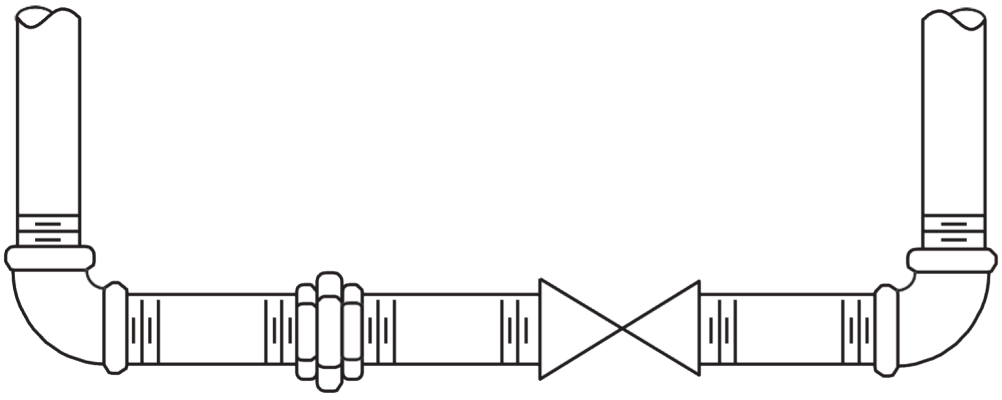


Figure 2 *Double-line drawing*

Due to the more intricate details of double-line drawings, do not use a scale smaller than 1:50 ($\frac{1}{4}" = 1' - 0"$) unless

the pipe sizes are large enough to show up well on the drawing. $\frac{3}{8}" = 1' - 0"$ is the standard process area pipe drawing scale.

Symbols for Pipe Process Type

Letters or dash symbols can be placed in convenient locations along the drawing of a pipe to identify the fluid that it will carry. Table 1 shows some examples. A legend that looks like Table 1 should be added to the drawing to identify the symbols used.

Table 1 *Pipes identified for intended fluid*

Symbol	Description	Abbreviation
	Cold water	CW
	Hot water (140°F)	HW
	Hot water return (140°F)	HWR
SP	Automatic fire sprinkler	SP
G	Gas - low pressure	G
A	Compressed air	A
MA	Medical compressed air	MA
V	Vacuum	V
O	Oxygen	O
AC	Acetylene	AC
LPG	Liquified petroleum gas	LPG
	Flow - in direction of arrow	
	Pitch - in direction of arrow	

Piping Break Lines

Piping break lines indicate the termination of the drawing of a piping run, although the piping does not end. Break lines are illustrated in Figure 3.

Figure 3 *Piping break lines*

Piping breaks may be used where a pipe runs past the end of a drawing or to show piping that is hidden behind another piping run (Figure 4). When the drawing is complex, as in an isometric drawing of a complete system, the break lines may be omitted. A small gap is used to indicate that the piping run behind does not connect with the piping run in front.

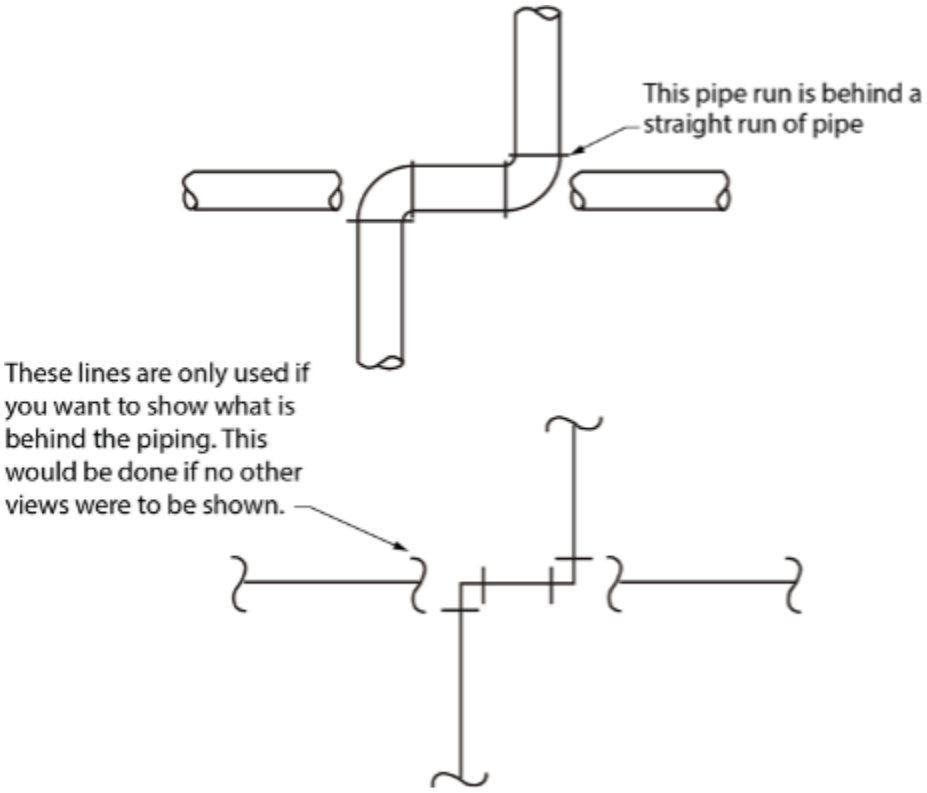


Figure 4 *Piping break lines*

Piping Joints

Some common piping joints include:

- screwed
- welded
- flanged
- soldered

In single-line drawings, a short line has traditionally been used to indicate a screwed pipe joint. It is drawn at right angles (perpendicular) to and centred on the piping run (Figure 5). This symbol is now used for almost any kind of pipe joint in single-line drawings, except that flanged and welded joints may use their own symbols. Figure 5 illustrates the various methods of drawing pipe joints in both single- and double-line forms, using a 90° elbow as an example.

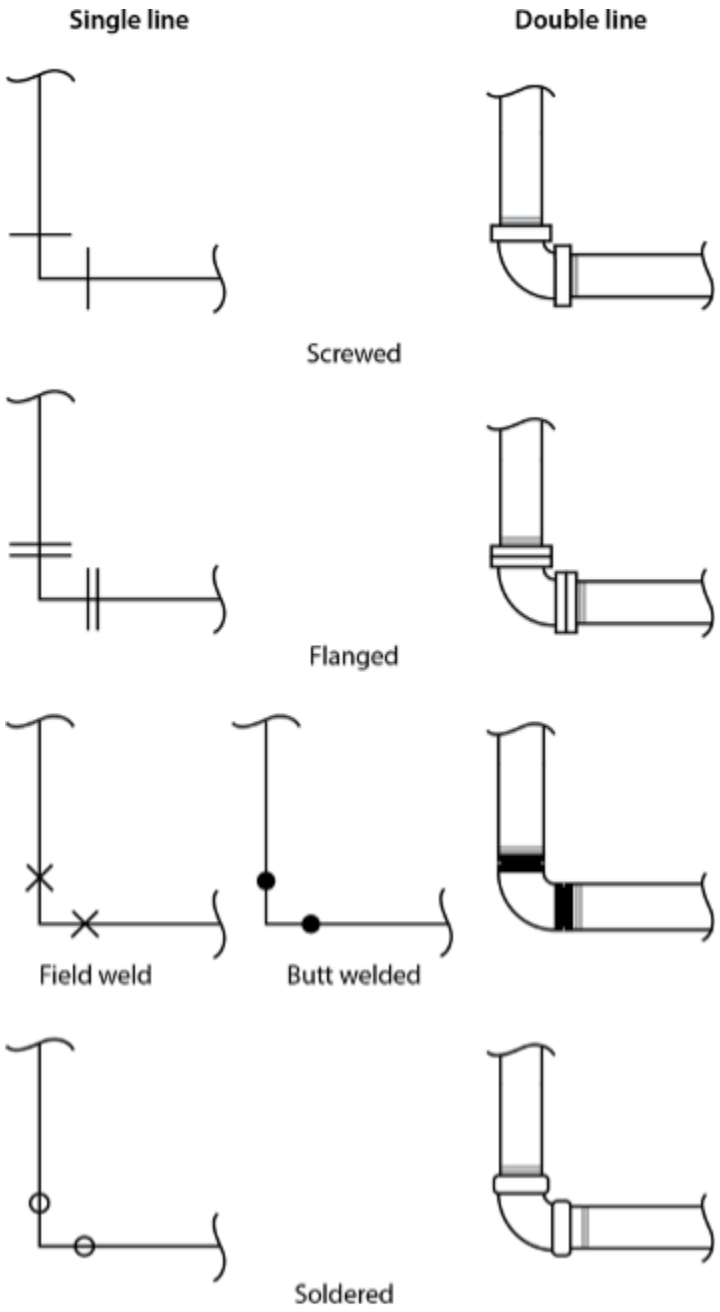


Figure 5 *Piping joint symbols*

Drawing Views

The appearance of a fitting changes when it is viewed from a different direction. The piping symbols are different for every view to reflect the change in their appearance.

For example, the front view of an elbow and its joining pipes (Figure 6) is at right angles (perpendicular) to both pipes. The symbol is drawn with single lines, and the joints are drawn with short, straight lines. The short, straight line represents the viewed edge of the fitting. The application is the same for both single- and double-line drawings.

Figure 6 *Front view of elbow and symbol*

If the elbow is viewed from the right side, the vertical pipe is perpendicular to the line of sight, but the horizontal pipe is viewed on end. The corresponding view symbol represents the vertical pipe by a vertical line and the joint by a short crossing line, as expected.

Figure 7 *Right view of elbow in Figure 6*

The end view of the fitting is represented by a circle (Figure 7). The circle is the true appearance of the edge of the fitting. The back of the elbow is shown by the centre line continuing to the centre of the circle.

Figure 8 *Left view of elbow in Figure 6*

The left view is shown in Figure 8. This view faces the pipe and an open end of the fitting, which is represented by a dot at the centre of the circle, as if it were a hole. Again, the circle appears like the true edge of the fitting.

Occasionally, pipes and joints are viewed neither on end nor perpendicular but receding at an angle (usually 45°). In those cases, the symbol for the near edge of the fitting is a curved line (Figure 9). Note that the curve is the true appearance, as if the far edge were obscured by the pipe or fitting.

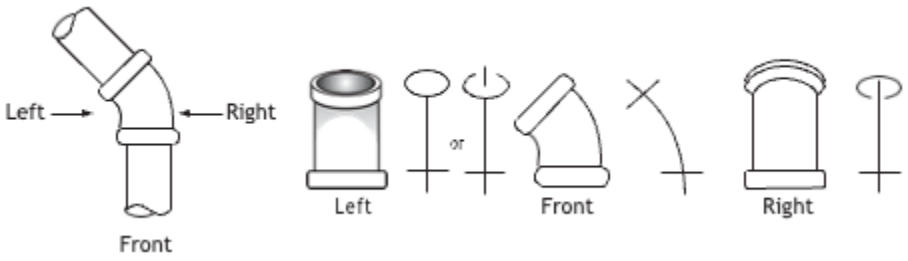


Figure 9 *Views of a 45° elbow*

One end of a 90°elbow angled at 45° (Figure 10) will also use the curved symbol on one end.

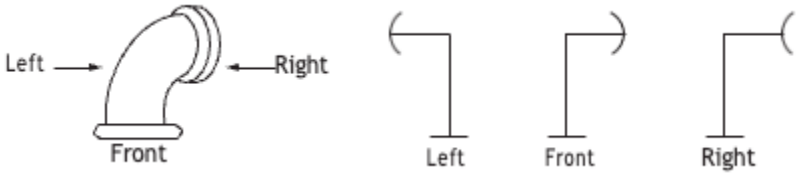


Figure 10 *90° elbow at 45° view*

This example of views for drawing fitting symbols should help you recognize the symbols for single-line and double-line drawings presented in Table 2.

Name	Single Line			Double Line		
	Left	Front	Right	Left	Front	Right
90 elbow						
45 elbow						
Tee						
Wye						
Cross						

Table 2 *Fitting symbols*

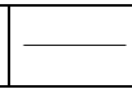
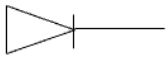
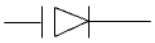
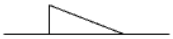
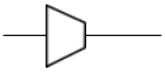
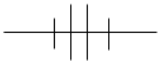
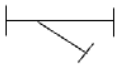
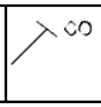
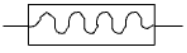
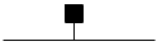
Name	Single Line
	FRONT
Cap	
Plug	
Reducing bushing	
Eccentric reducer	
Concentric reducer	
Union flange (screwed)	
Union (flanged)	
Expansion joint	
Strainer	
Fire department connection	
Cleanout	
Floor cleanout	
Pipe anchor	
Pipe guide	
Flexible connector	
Water hammer arrestor	

Table 3 *Specialized single-line symbols*

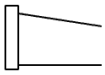
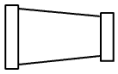
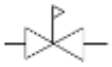
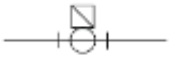
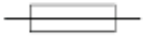
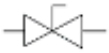
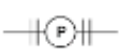
Name	Double Line
	FRONT
Cap	
Eccentric reducer	
Concentric reducer	
Union flange (screwed)	

Table 4 *Specialized double-line symbols*

Symbols for Valves, Air Eliminators, Pumps and Other Components

Valves, air eliminators, pumps and other components are generally shown on drawings by their symbols, even when double-line piping drawings are used. Table 5 shows some of the most common symbols.

Type of component	Symbol	Type of component	Symbol
Gate		Motor operated*	
Globe		Pressure reducing	
Check*		Pressure relief	
Angle		Pressure-temperature relief	
Butterfly		Flow switch	
Hose (utility)		Pressure switch	
Fire hose		Control valve	
Post indicator		Vacuum relief	
Backwater		Pressure gauge with gauge cock	
Backflow preventer*		Thermometer	
Gas cock		Automatic air vent	
Balancing*		Air vent	
Pump			
PRV			

*specify type in legend or specifications

Table 5 *Types of components and examples of their symbols*

Check Valves

The symbol for a check valve is positioned to indicate the direction of flow (Figure 11). It is important to draw the symbol in the correct position or the diagram could be misinterpreted, leading to the valve being installed incorrectly. The

symbols are typically used without the arrows shown in Figure 11, which are shown here to help you understand the correct orientation of the symbol. Specifications or notations on the drawing will indicate what type of check valve is needed (i.e., swing check, lift check, etc.).

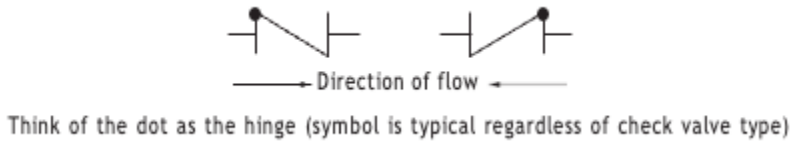


Figure 11 *Symbol for check valve showing direction of flow*

These are just a few commonly used symbols for piping fittings, valves and other components. Symbols for other components may be more or less standard or may be modified as required. Such modifications should be labelled with a reference legend that identifies the symbol.

Symbols for Plumbing Fixtures

Plumbing fixtures are generally shown on plan and elevation drawings by their actual size and shape according to the drawing scale (Figures 12 to 18). This is required to determine if the fixture location in the building is in compliance with Building Code clearances to walls and other fixtures.

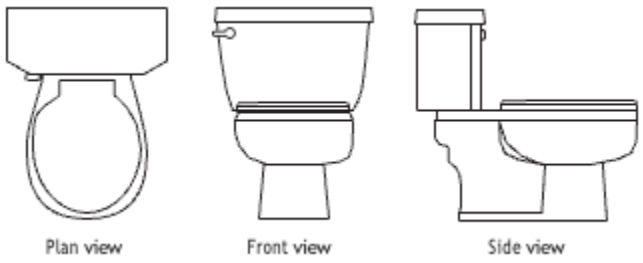


Figure 12 *Floor mounted water closet*

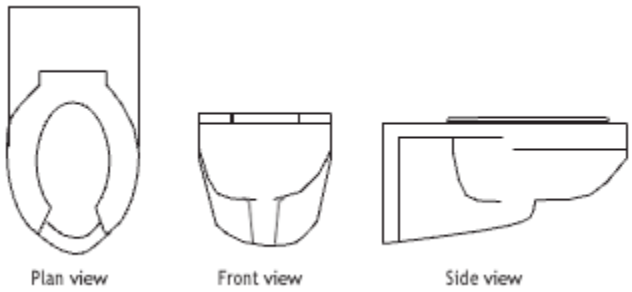


Figure 13 *Wall-hung water closet*

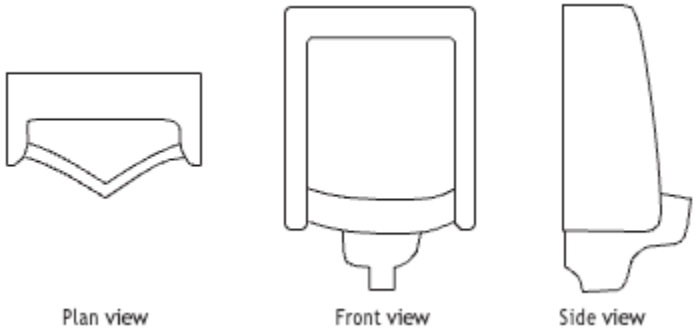


Figure 14 *Wall-hung urinal*

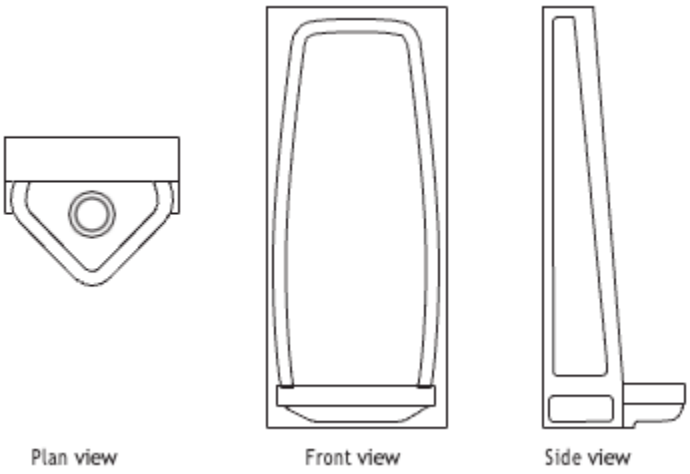


Figure 15 *Floor mount (stall) urinal*

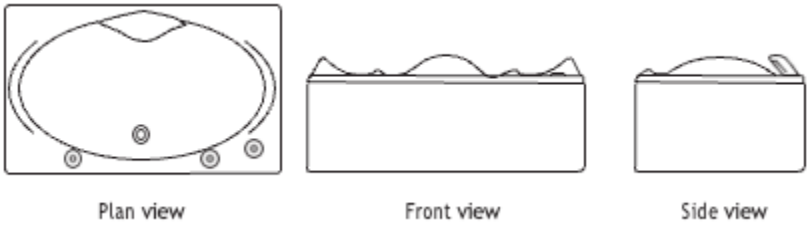


Figure 16 *Roman bathtub*

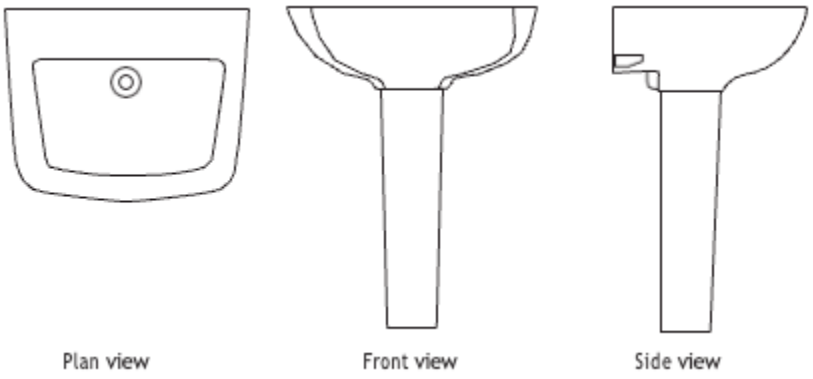


Figure 17 *Pedestal basin*

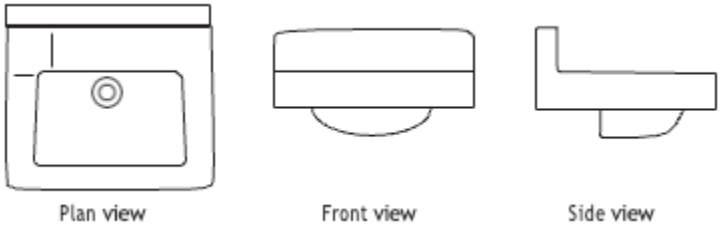


Figure 18 *Wall-hung basin*

Unlike free-standing fixtures, cabinet-mounted fixtures would only be represented in plan view (Figure 19). In elevation views only the cabinet that houses the fixture would be shown, as the fixture itself is recessed.

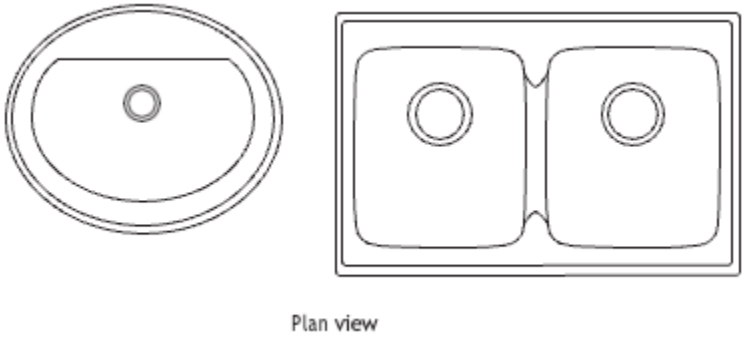


Figure 19 *Plan views of vanity basin and kitchen sink*

Self-Test C-3.3: Describe Piping and Fixture Symbols Used in the Piping Trades

Complete Self-Test C-3.3 and check your answers.

If you are using a printed copy, please find Self-Test C-3.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2465#h5p-35

References

BCcampus. (n.d.). *Playlist: Tools and equipment videos*. BCcampus MediaSpace. https://media.bccampus.ca/playlist/details/0_3g8xp22x/categoryId/175673 Playlist Details – Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Plumber: Competency C-2 Interpret Drawings and Specifications
- Steamfitter: Competency C-2 Interpret Drawings and Specifications
- Sprinkler Fitter: Competency C-2 Interpret Drawings and Specifications

Camosun College. (2019). Line D: Tools and Equipment—Competency D-3: Competency D-3: Read Drawings and Specifications (Rev. ed.) [Learning guide]. BCcampus. https://collection.bccampus.ca/textbook/yxJ3AwTa/

Camosun College. (2015). Trades Access Common Core Competency D-3: Competency D-3: Read Drawings and Specifications. Victoria, B.C.: Crown Publications. Download for free from the B.C. Open Textbook Collection (https://open.bccampus.ca/browse-ourcollection/find-open-textbooks/).

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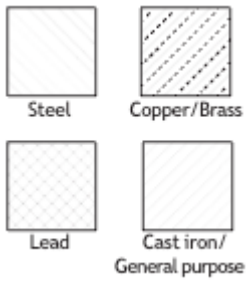
C-3.4 Describe Lettering and Dimensioning of Piping Diagrams

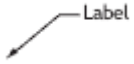
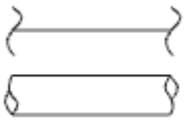
Standard lines for drawings have been developed so that lines in every drawing or sketch convey the same meaning or information. In order to convey that meaning, the lines used in technical drawings have both a definite pattern and a definite thickness. Some lines are complete and others are broken. Some lines are thick and others are thin. A *visible line*, for example, is used to show the edges (or *outline*) of an object and to make it stand out for easy reading. This line is made thick and dark. A *centre line*, on the other hand, which locates the precise centre of a hole or shaft, is drawn thin and made with long and short dashes. This makes it easily distinguishable from the visible lines.

Study the standard line thicknesses (or *line weights*) shown in Figure 1 and practise making them. Use a fairly sharp pencil when you draw. Maintaining an even, consistent pressure will make it easier for you to produce acceptable lines.

In computer drafting, the line shape remains the same, but line thickness may not vary as in manually created drawings. Some lines, such as centre lines, may not cross in the same manner as in a manual drawing. For most computer drafting, line thickness is not important.

Table 1: Standard line weights

Type	Weight	Line	Description
Object line Margin line	Heavy	———	Solid line to show visible shape, edges and outlines.
Hidden body line	Medium	- - - - - - - - - - - - - - - - - -	Broken line of short dashes to show hidden object lines not visible to the eye.
Phantom line	Light	----------	Broken line of short dashes to show alternate positions or movement of a part.
Section line	Light		Unbroken lines arranged in a pattern, usually straight and at a 45° diagonal.
Projection line	Light	———	Unbroken lines that extend away from the object or feature for emphasis.
Centre line	Light	- - - - - - - - - - - - - - - - - -	A broken line of long and short dashes to show the centre of an object.
Extension line/ Dimension line	Light		Extension lines are small lines that extend outward from an object or feature. Dimension lines span between the extension lines with arrow heads and a given dimension.

Leader line	Light		Unbroken line usually drawn at an angle often with a “dogleg” and an arrowhead. A dot is used in place of an arrowhead where a surface is referenced. Usually accompanied by a label.
Cutting plane line	Heavy		A broken line of one long and two short dashes to show an imaginary cross-section. The arrowheads show the direction from where the cross-section is viewed. A corresponding image will show the view of A.
Break lines for wood and metal	Heavy		Unbroken freehand or straight zig-zag lines to abbreviate longer spans of wood or metal.
Break lines for piping	Heavy		Curled lines to abbreviate a longer span of pipe.

When you are able to consistently reproduce lines of equal blackness and thickness, study Figure 1, which shows the nature of each line and explains how they are used in a technical drawing. You must be able to identify each line by name and describe its application.

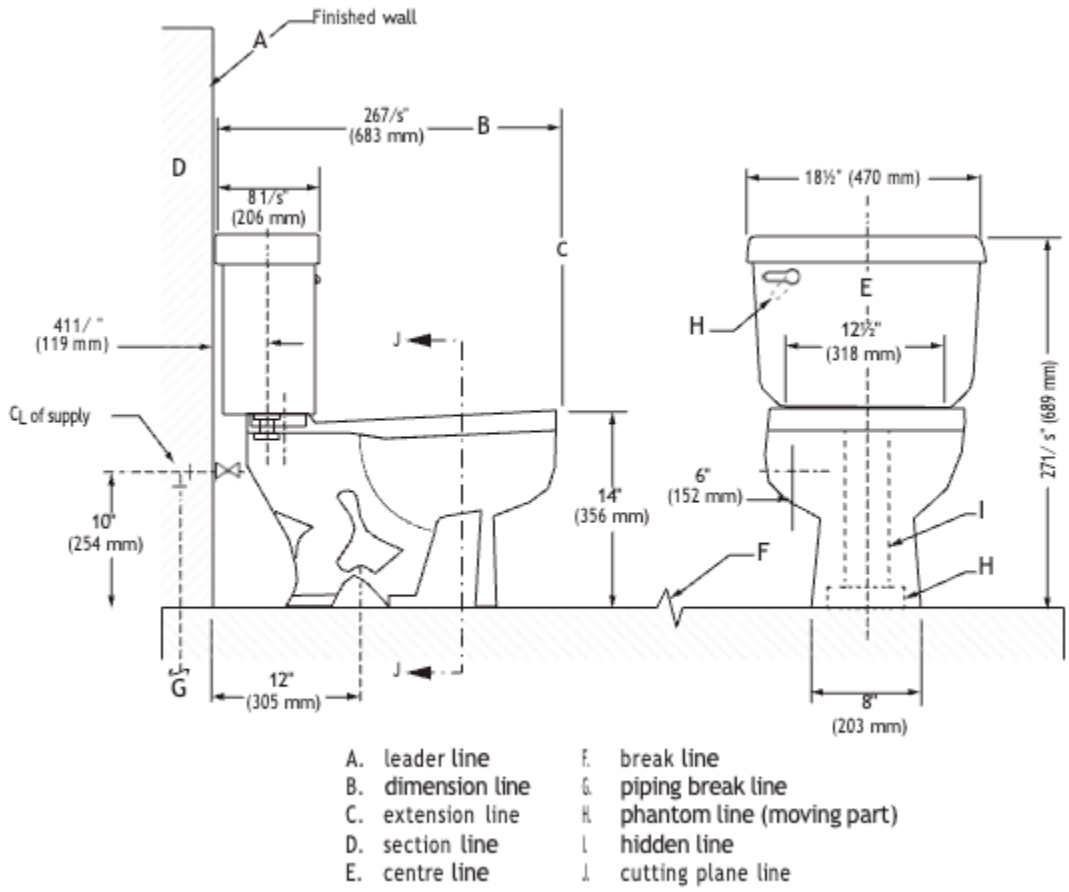


Figure 1 *Use of standard lines*

Standard Lettering

The letters and numbers on a drawing or sketch are as important as the lines. Scribbled, smudged or badly written letters and numbers can become impossible to read. This may lead to time- consuming and costly errors. Lettering is necessary to describe:

- the name or title of a drawing
- when it was made
- the scale
- who sketched it
- the dimensions
- the special notations that describe the size
- the materials to be used
- the construction methods

In making drawings and sketches, there is a need for simplicity, uniformity and speed of execution.

The American standard vertical letters have become the most accepted style of lettering used in the production of

manual drafting (Figure 2). Font styles and sizes may vary in computer drafting. Note that all letters are written as capital (or *uppercase*) letters. Practise these characters, concentrating on forming the correct shape. Remember that letters and numbers must be black so that they will stand out and be easy to read.

Lettering and figures should have the same weight and darkness as hidden lines.

Figure 2 *American standard vertical letters*

Figure 3 shows a simple drawing. Notice that the dimensions are given between arrows that point to extension lines. By using this method, the dimensions do not get in the way of the drawing. One extension line can be used for several dimensions. Notice also that the titles require larger letter sizes than those used for dimensions and notations. It is important that the title and sketch number on your sketches stand out, as shown in Figure 3. When you begin lettering, you may wish to use very light lettering guide lines to ensure uniformity in lettering size and alignment.

Typically, drawings are placed on the page within containment lines called a border. The border lines help bring the drawing together and give it a professional feel.

On an $8\frac{1}{2}" \times 11"$ sheet of paper, borders are drawn approximately 1 cm from the edge for the top and sides, but approximately 2 cm from the bottom to compensate for an optical illusion that occurs when the border is equal around all four sides. Unless the bottom border is larger, the eye is drawn to the bottom of the page because the border appears too short.

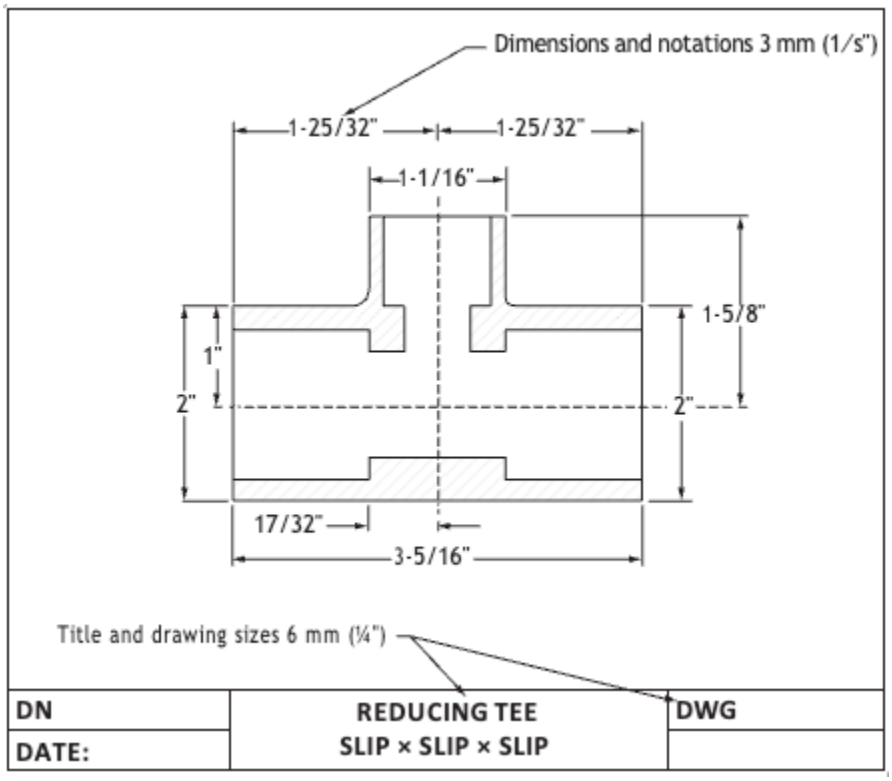


Figure 3 *Standard lettering sizes*

Self-Test C-3.4: Describe Lettering and Dimensioning of Piping Diagrams

Complete Self-Test C-3.4 and check your answers.

If you are using a printed copy, please find Self-Test C-3.4 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2467#h5p-36

References

BCcampus. (n.d.). *Playlist: Tools and equipment videos*. BCcampus MediaSpace. https://media.bccampus.ca/playlist/details/0_3g8xp22x/categoryId/175673 Playlist Details – Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

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C-3.5 Describe Drawing Projections

You need accurate information to complete a piping installation, no matter how simple or complex the system.

Information for a project is provided by mere drawings or by drawings and specifications. Drawings provide dimensions and details of materials of construction. Specifications give details on installation procedures and the standards required for materials. Some installations may have the specifications and all other pertinent information on the drawings in the form of notes.

These drawings are known as *working drawings*. Working drawings are sometimes referred to as *blueprints*, a term that is a carry-over from when all prints had a blue background and the lines and lettering were in white.

Types of Views Used in Drawings

The two main types of views (or *projections*) used in drawings are:

- pictorial
- orthographic

Pictorial Views

Pictorial views show how something should physically look when completed. There are three types of pictorial views:

- perspective
- isometric
- oblique

Perspective View

A *perspective view* presents a building or an object just as it would look to you. A perspective view has a *vanishing point*: that is, lines that come together in the distance as they move away from you. For example, in Figure 1, we see a road and line of telephone poles. Even though the poles get smaller in their actual measurement, we recognize them as being the same size, but more distant.

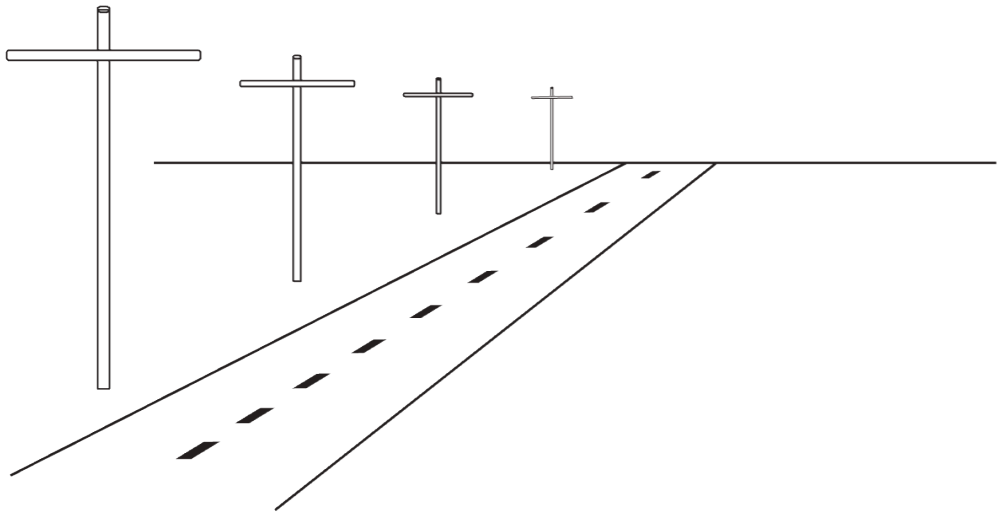

Figure 1 *Perspective view*

Isometric View

An *isometric view* is a three-dimensional view. The plumb lines are vertical. The horizontal lines are set at 30° angles from a line parallel to the bottom of the page. Isometric views have no vanishing point, so the objects do not appear as they would in a perspective view. Lengths are exact on isometric drawings only when the item is parallel to one of the axes of the drawing. Figure 2 shows an isometric view of a simple object, as well as the lines that represent the three dimensions.

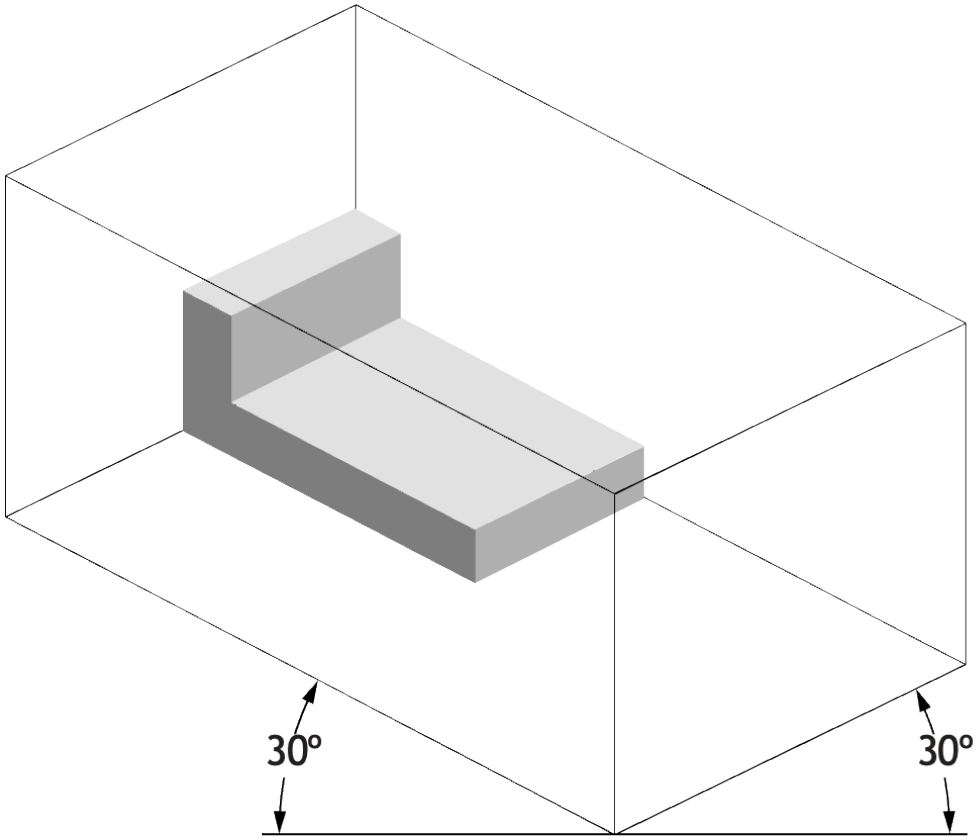

Figure 2 *Isometric view*

Oblique View

An *oblique view* is similar to an isometric view, except that the face or front view is drawn to exact scale and the oblique lines are extended at a 30° to 45° angle to create a three-dimensional representation (Figure 3).

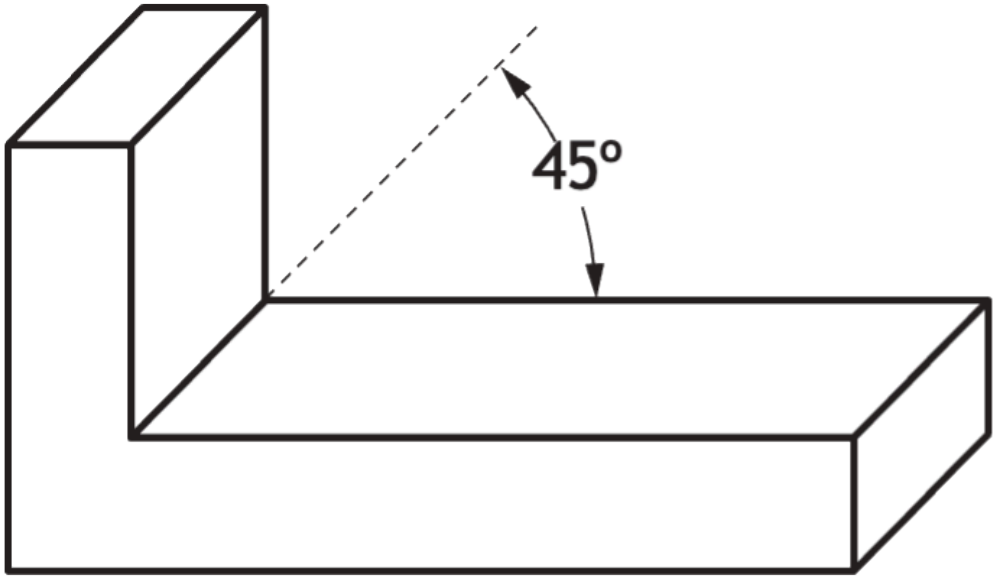

Figure 3 *Oblique view of the object in Figure 2*

Orthographic Views

Orthographic views (or *orthographic projections*) are the most common views used for working drawings. Each projection is a view that shows only one face of an object, such as the front, side, top or back. These views are not pictorial. Orthographic views are used in all fields of architecture and engineering. Figure 4 shows how the pictorial view from Figure 2 is opened to produce six orthographic views. Figure 5 shows how the same views are drawn.

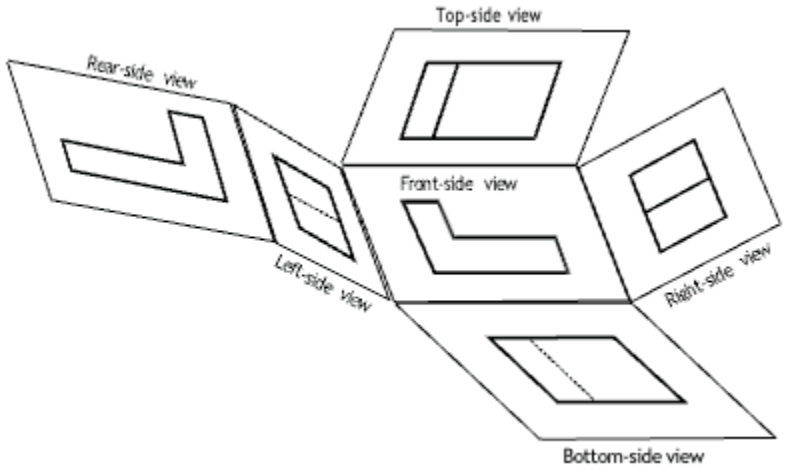

Figure 4 *How a pictorial view is opened to produce orthographic views*

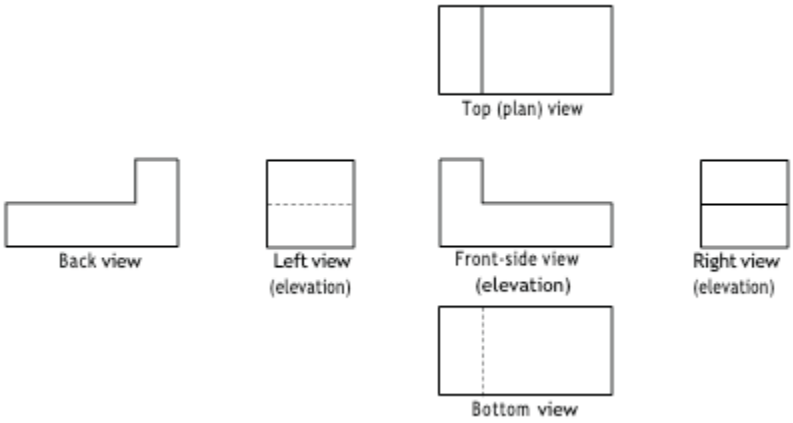

Figure 5 *Orthographic views of the object in Figure 2*

Unless the object is very complex, only the front, top and right-side views are necessary. If the object has a uniform thickness, only two views are necessary. The front, left, back and right views are also referred to as *elevations*.

Piping systems normally require two or three orthographic views, either a *plan view* and one elevation drawing or a plan view and two elevation drawings. Some systems may be illustrated with a three-dimensional (isometric) drawing or with three orthographic drawings.

The plan (top), the front and the side views are the three usual orthographic views from which you should choose the views to represent piping systems. If the side view shown is not specified, the right side is normally used. Bottom and back views are used less often.

Floor Plan

The floor plan is an orthographic view of a building that is commonly the most important projection for the pipe trade worker because it gives the most pertinent information about the building. Floor plans identify room names and numbers, place them within the building as a whole, and provide the following relevant info:

- room dimensions
- size, location, and swing of doors
- size and location of windows
- size and spacing of beams and floor joists

Floor plans show the location of:

- plumbing fixtures
- tub drains
- appliances
- cabinets, closets and shelves

Figure 6 *Floor plan*

Elevation View

An elevation view is a front, side, or back orthographic projection of a building, that contains important information such as:

- finished grade or ground level
- exterior details, including material, dimensions roof pitch -see figure 7
- scale

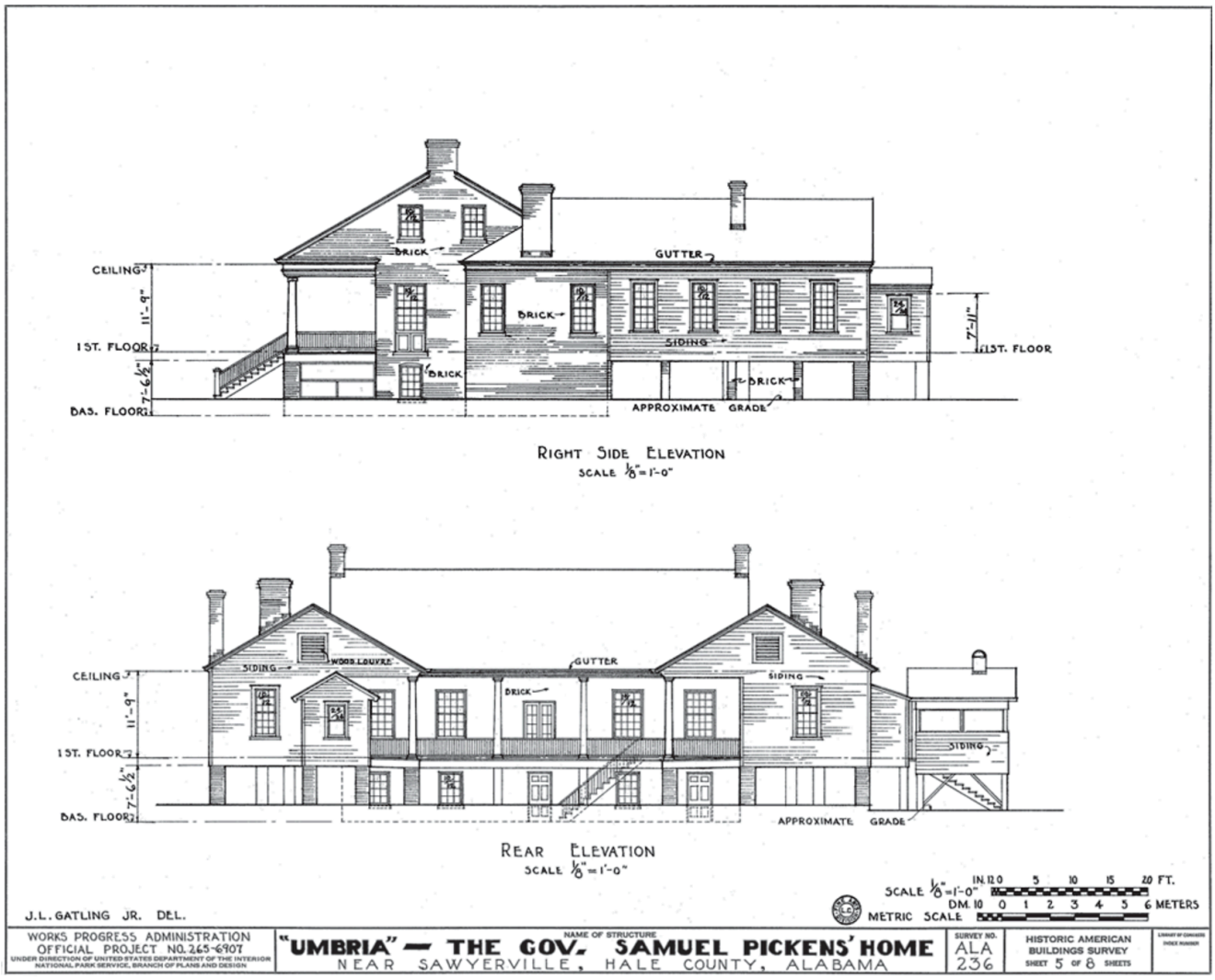

Figure 7 *Elevation view (Public domain image from Library of Congress, Prints and Photographs Division, AL-236)*

Section Plan

A section drawing provides details on a cross-section of a building or wall. The section drawing is usually quite detailed, showing scale, material selection, dimensions and typical construction choices.

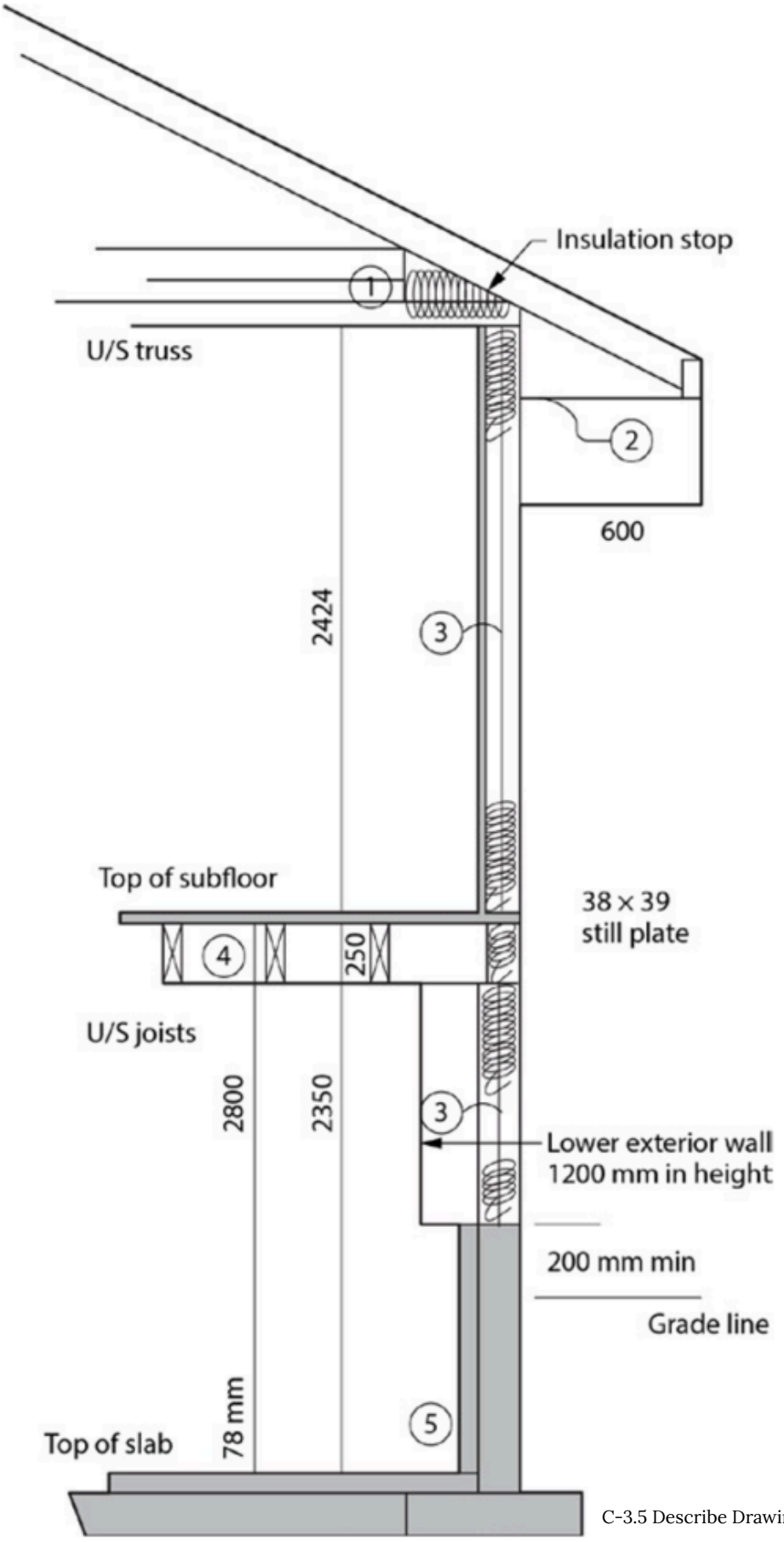
Insulation stop
1
U/S truss
2
600
2424
3
Top of subfloor
38 × 39
still plate
4
250
U/S joists
2800
2350
3
Lower exterior wall
1200 mm in height
200 mm min
Grade line
78 mm
5
Top of slab

Figure 8 *Section drawing*

Self-Test C-3.5: Describe Drawing Projections

Complete Self-Test C-3.5 and check your answers.

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C-3.6 Use Drawing Projections

Orthographic Fitting Symbols

To help you recognize piping symbols in different orthographic views, the following fittings are shown first in a pictorial drawing (Figure 1) then as three orthographic views (Figure 2).

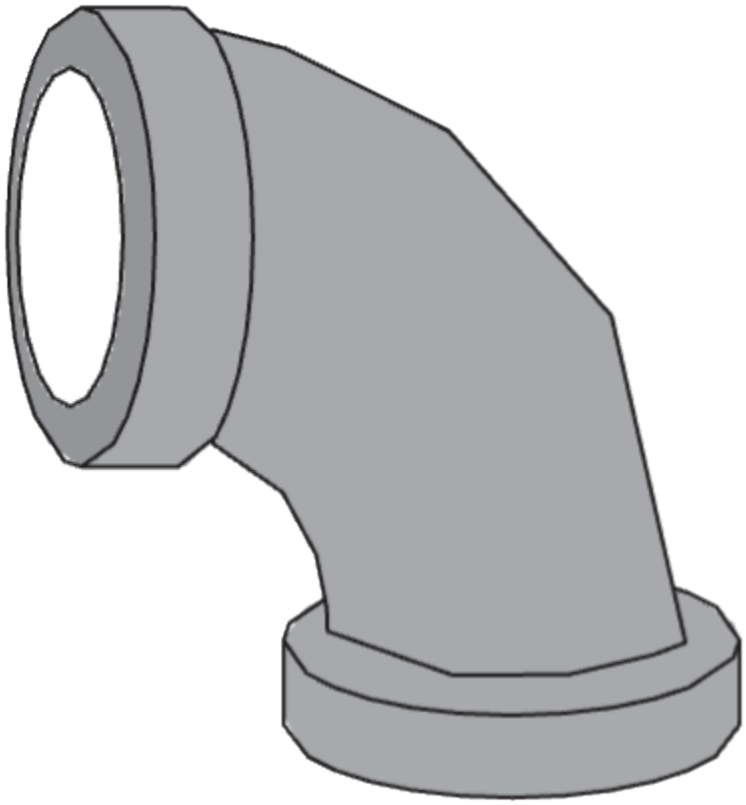

Figure 1 *Pictorial drawing*

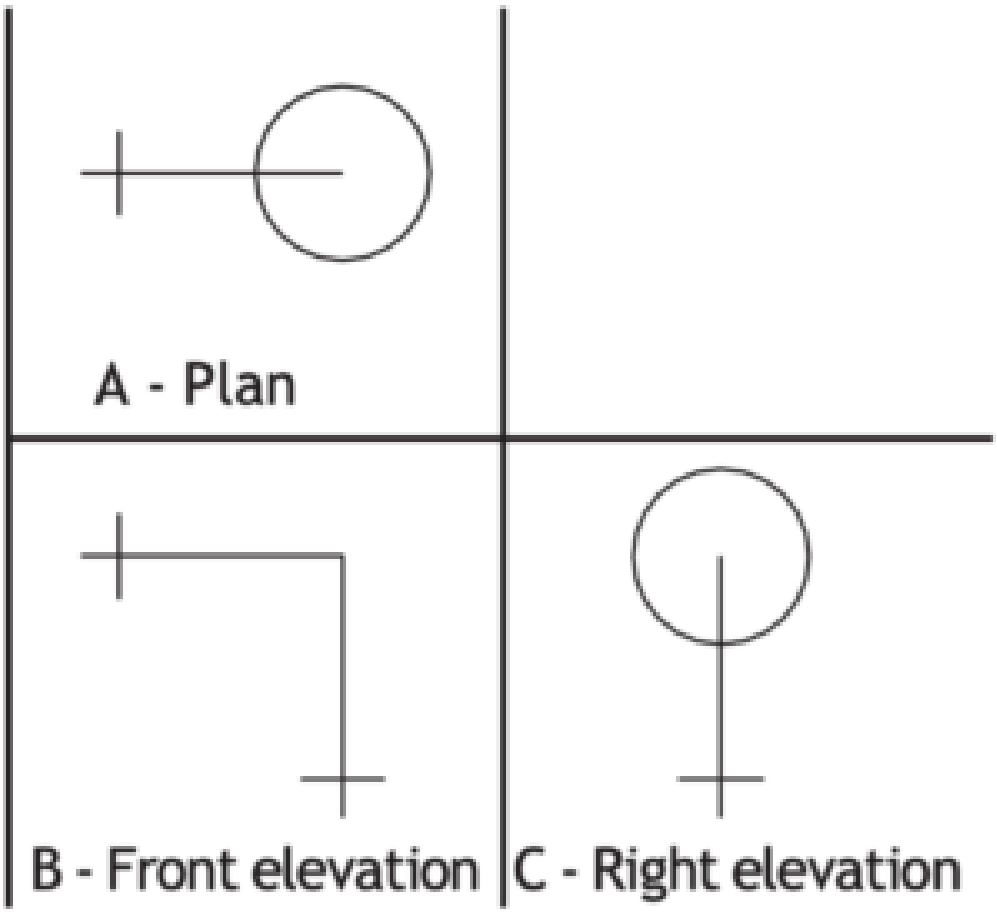

Figure 2 *Orthographic views*

In Figure 3, the same elbow is shown from the opposite side. Figure 4 reflects the corresponding changes to the orthographic views.

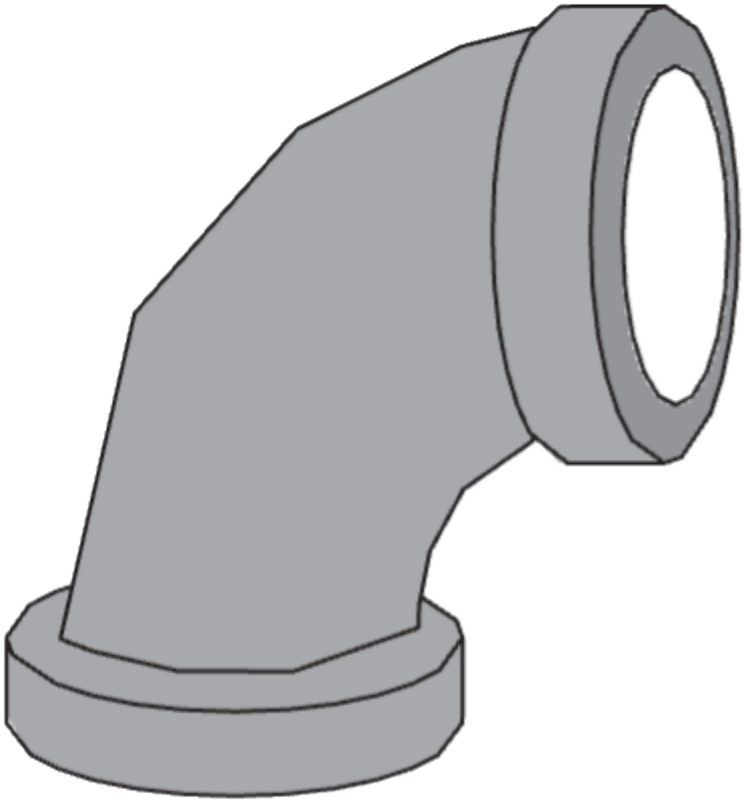

Figure 3 *Pictorial drawing*

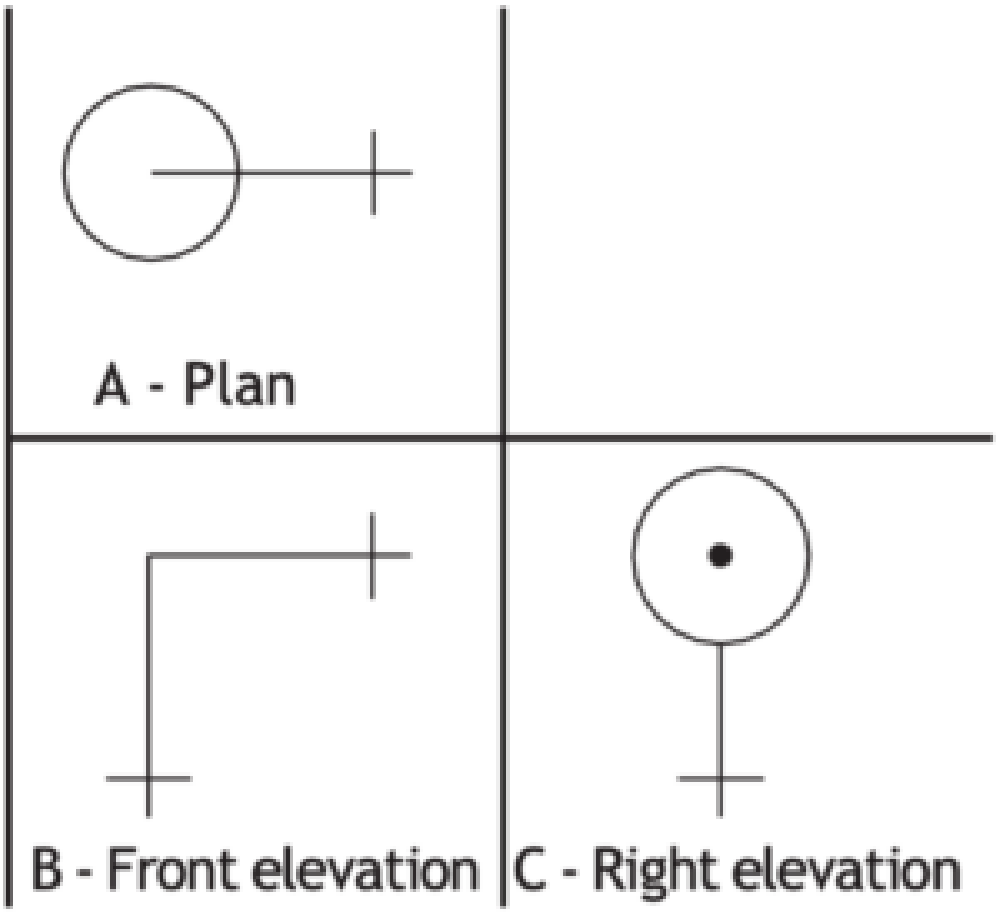

Figure 4 *Orthographic views*

As stated previously, side and front views are normally called elevations and at times are referred to as *sections*, especially if the drawing only contains part of a piping system.

Figure 5 shows a drawing of a tee and the three standard orthographic views. Notice that the right view, facing the end of the tee, cannot be distinguished from the same view facing the end of a 90° elbow. This is why multiple views of an object are preferred for clarity.

The frontal drawing of a 45° elbow in Figure 6 is shown with the corresponding standard orthographic views. Notice the curved fitting lines dictate that part of the fitting is not at right angles in the view.

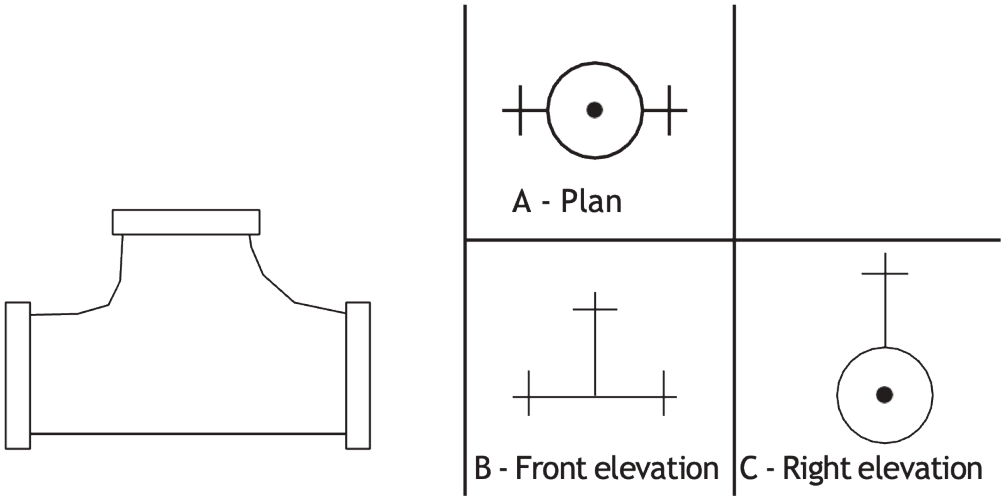

Figure 5 *Front elevation and single-line orthographic views of a tee*

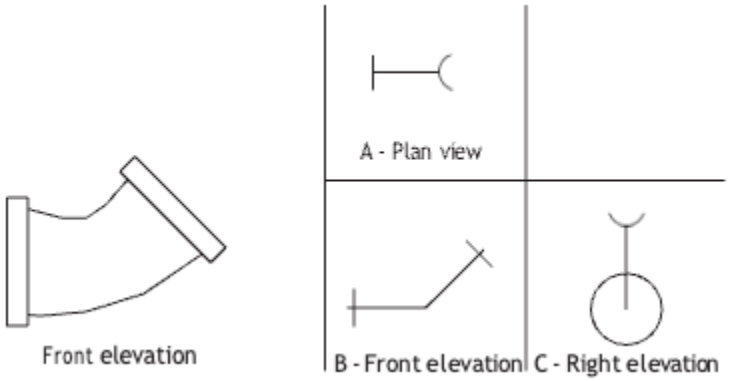

Figure 6 *Front elevation and single-line orthographic views of a 45° elbow*

Each fitting has a different appearance depending on the direction from which it is viewed. With practice, you will be able to quickly draw three orthographic views for any fitting. If you know what the fitting is and see one view of it, with practice, you will be able to draw the remaining views.

Example

Cover the answer on the right and draw in the remaining views of the tee for which the plan view is given in Figure 7.

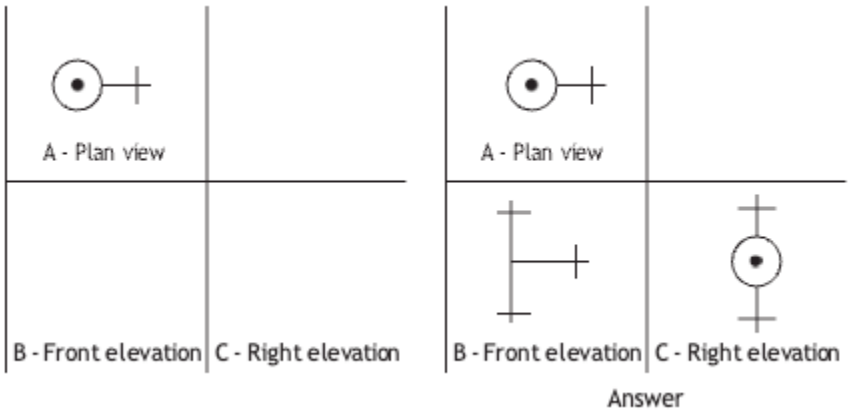

Figure 7 *Remaining views of a tee*

Use Orthographic Piping Drawings

As we have discussed, when orthographic projections are used, three views of an object are usually shown. These are typically the plan view, the front view and a side view.

The two or three orthographic views used for piping drawings are usually shown grouped together in typical fashion. All views are required for a complete understanding of the piping system. It is not unusual to find only one orthographic view of a two- or three-dimensional piping run. A single view would only be used when the second view would convey little or no information. For example, the plan view of a horizontal drainage piping system is often shown without any accompanying elevation drawings, as there may be no elevation changes (other than the pipe's slope).

The chief advantage of orthographic drawings is that they can be used to pinpoint the exact location of components. For example, orthographic piping layouts drawn on building plans show the exact relationship between the piping system and the building's features. Any lengths that are on the drawing are considered to be accurate. Because orthographic drawings are so often used to show exact component locations, they are usually drawn to scale.

Orthographic drawings have limitations. They are not suitable for complicated systems that have many overlapping pipes, valves and fittings. An orthographic drawing of an intricate piping system can confuse even the most experienced blueprint reader. Orthographic drawings of complicated piping systems are generally accompanied by an isometric diagram that shows the system in one clear view.

Figures 8 to 15 show various orthographic views of simple piping systems. Be sure to allow for hidden items when considering different views. In each case, two of the three views are enough to depict clearly the piping layout. For example, if the front views were not chosen in Figures 8 and 9, the figures could appear to depict two tees and two elbows, respectively.

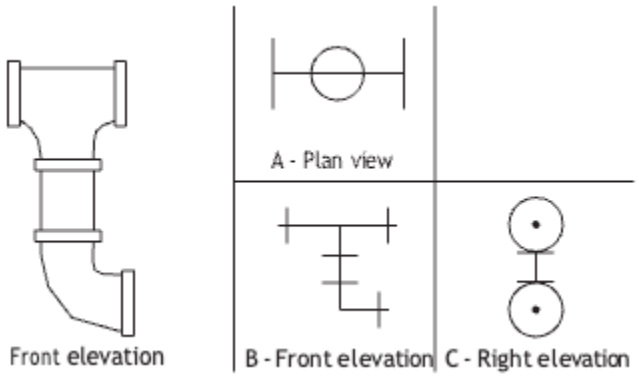

Figure 8 *Single-line orthographic views of a tee and 90° elbow*

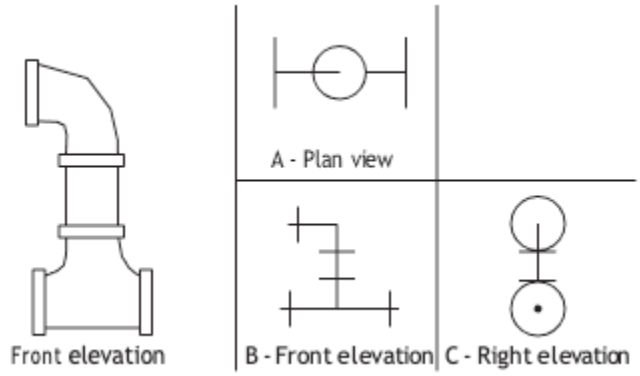

Figure 9 *Single-line orthographic views of a tee and 90° elbow*

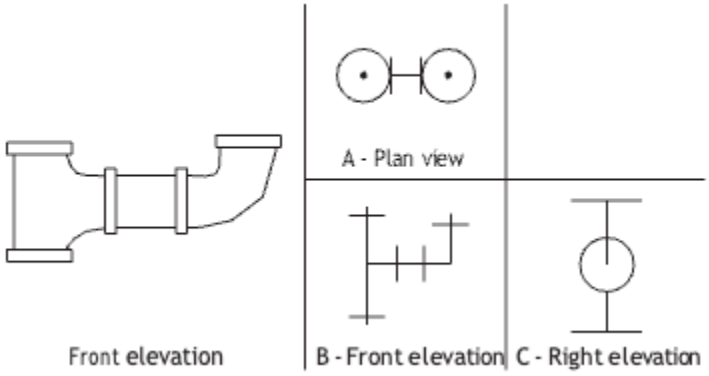

Figure 10 *Single-line orthographic views of a tee and 90° elbow*

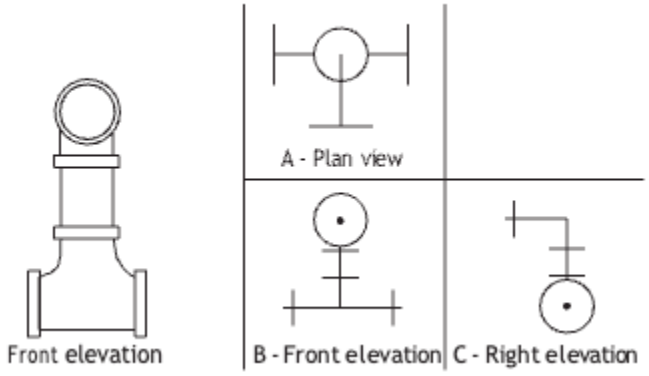

Figure 11 *Single-line orthographic drawings of a tee and 90° elbow*

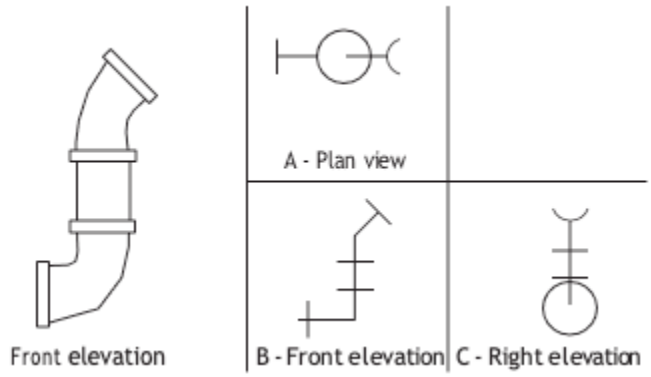

Figure 12 *Single-line orthographic drawings of a 90° and 45° elbow*

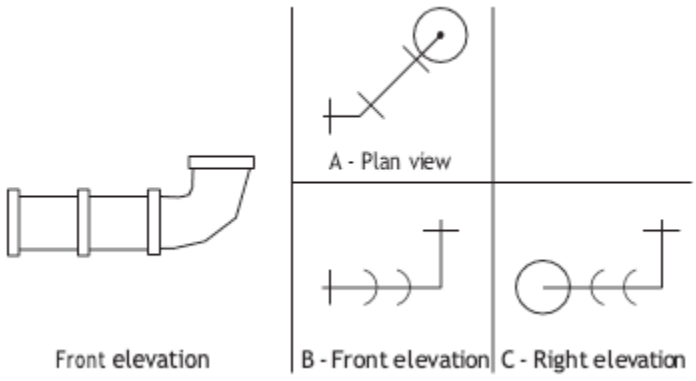

Figure 13 *Single-line orthographic drawings of a 90° and 45° elbow*

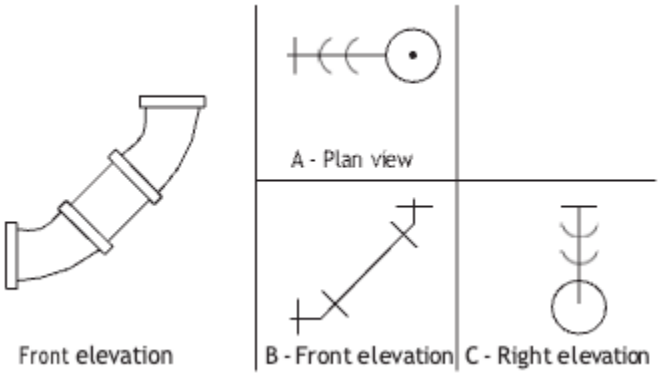

Figure 14 *Single-line orthographic drawings of two 45° elbows*

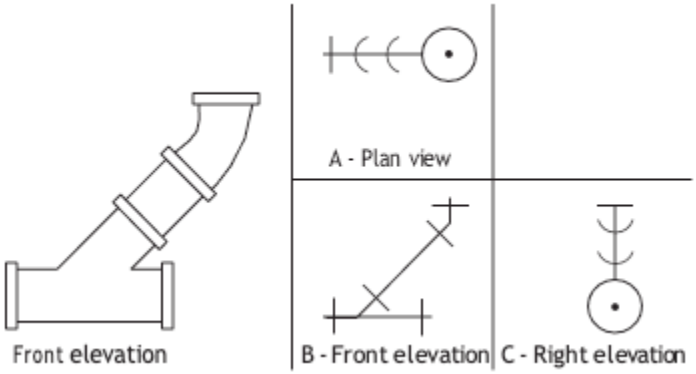

Figure 15 *Single-line orthographic drawings of a wye and 45° elbow*

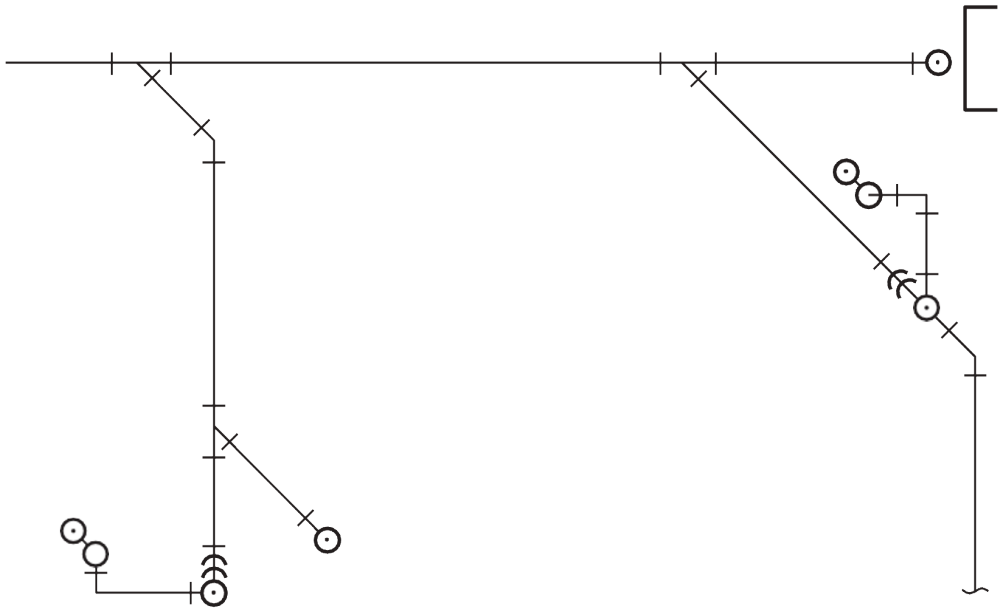

Figure 16 *Drainage plan*

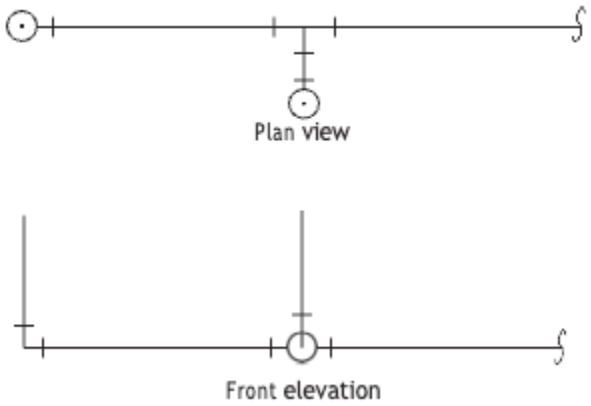

Figure 17 *Orthographic views of a simple pipe assembly*

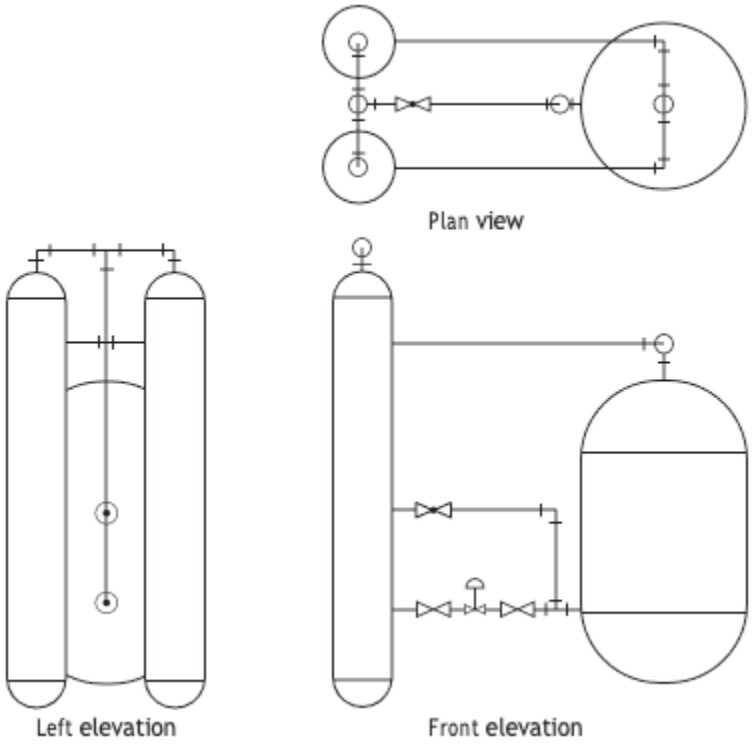

Figure 18 *Orthographic drawing, plan and elevation views*

Note that in Figure 18, the plan view is unable to show the control valve and isolation valves. A supplementary elevation view is therefore required to understand the piping arrangement.

Once you can distinguish which view of a piping system is depicted, you will be able to read and understand the drawing.

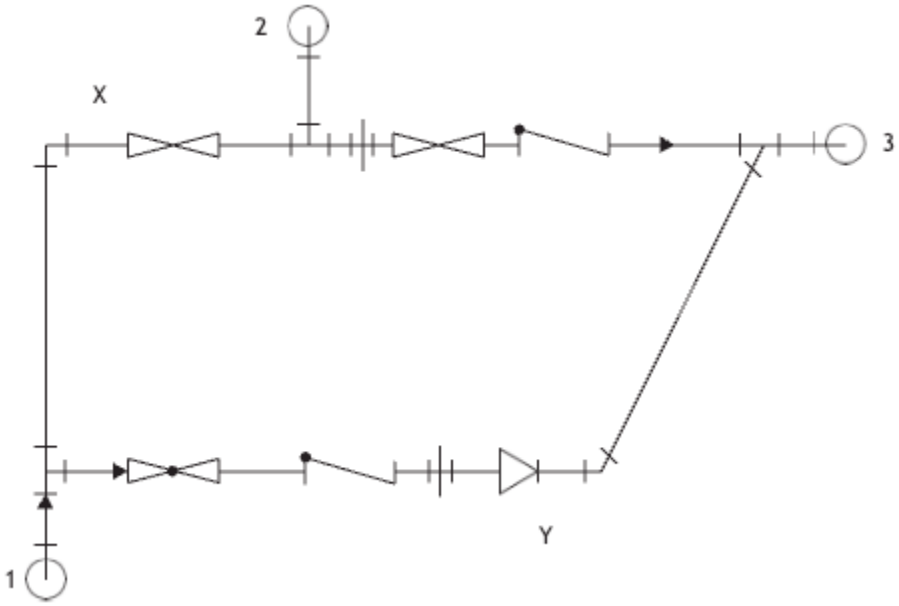

Figure 19 *Piping system*

Figure 19 shows an orthographic plan view of a portion of a piping system, incorporating standard graphic piping symbols. The small solid arrowheads placed on the pipeline indicate the direction of flow. The flow originates from below point 1. The direction of flow is through section X to point 2 and on to point 3. Point 3 is also supplied by flow through piping section Y when the bypass globe valve is open. Note also the direction of flow indicated by the check valve symbols.

Self-Test C-3.6.1: Use Drawing Projections

Complete Self-Test C-3.6.1 and check your answers.

If you are using a printed copy, please find Self-Test C-3.6.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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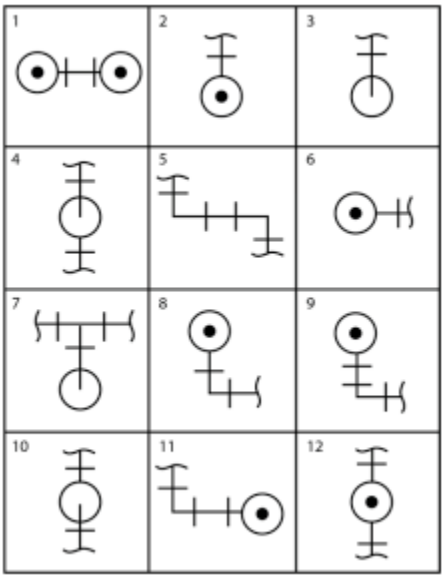


Figure 1 *Symbol table for questions* 19-23

Use Isometric Piping Drawings

Isometric drawings are used because they clearly represent both simple and complicated piping arrangements. This clarity comes from using angular lines to represent the three dimensions, much like a picture. The three dimensions of

length, width and height are drawn along the isometric axes shown in Figure 20. The lengths of objects running parallel to these axes can be drawn to scale.

Lines at other angles will not be to scale.

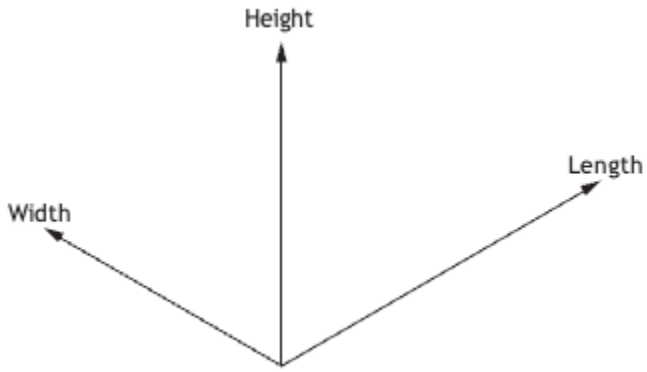


Figure 20 *Isometric axes—all lines along these axes can be drawn to scale*

The two vertical directions (up and down) are represented by vertical lines. The four horizontal directions (front and back; left and right) are represented by lines at 30° from the horizontal. These six directions are parallel to the three isometric axes, as shown in Figures 21 and 22.

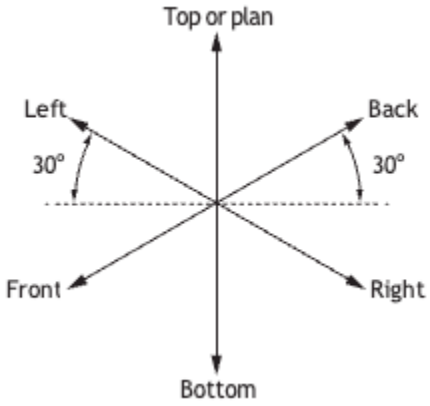


Figure 21 *Isometric axes for a front-right view*

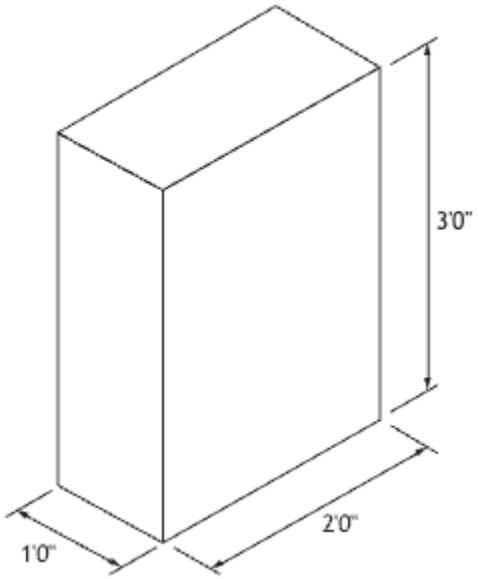


Figure 22 *A box drawn isometrically*

Most piping is installed parallel to these directions, so the piping can be drawn along the isometric lines. Lines that are not isometric on scaled drawings will not be to scale. Notice the clarity of the piping layout shown in Figure 23.

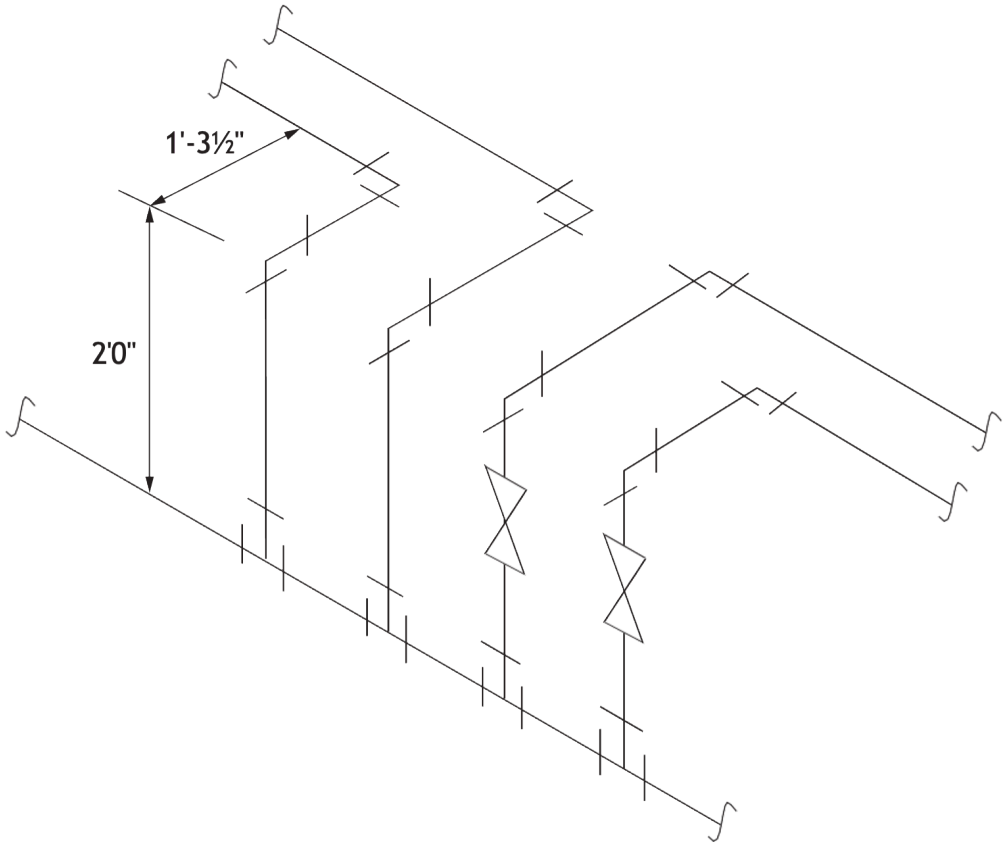


Figure 23 *Isometric piping drawing at a scale of 1 = 1′–0″*

This type of drawing of a piping layout can be easily drawn with practice. The drawing style is useful for taking off materials such as the type and number of fittings and the lengths of pipe required. This can only be done accurately if the drawing is to scale or dimensions are provided.

Isometric lines are parallel to the three isometric axes. They are also drawn parallel to one of the three edges of the isometric plane. Figure 24 shows the isometric lines that correspond to the isometric axes. Notice that the pipes, fittings and lines indicating fittings, joints or connections are all parallel to the edges of the plane of view.

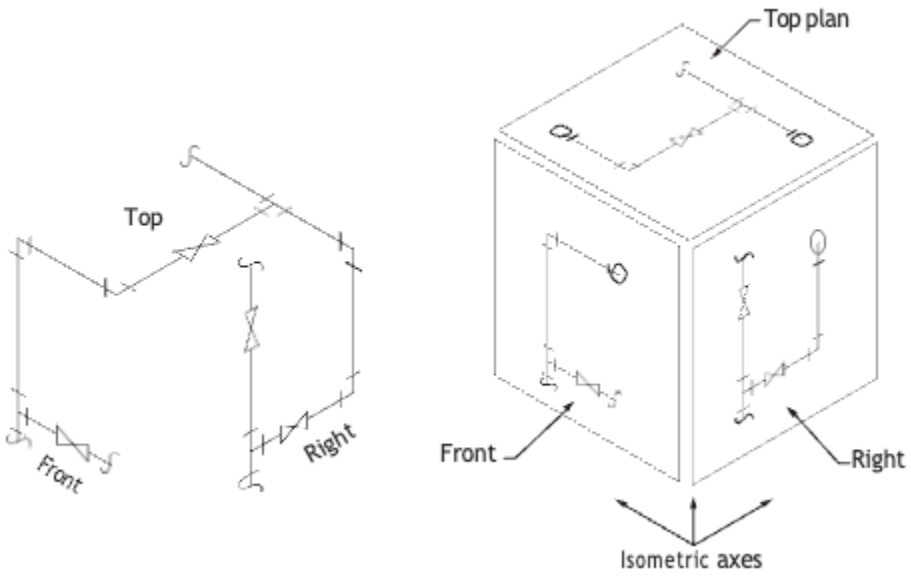


Figure 24 *Isometric planes and isometric axes*

All the piping connected to a fitting is in the same plane. This determines how the fitting is drawn. The runs and joints are parallel to the edges of the plane. Figure 25 shows two tees on the same vertical pipe. Notice how the joints are drawn differently because the horizontal parts are in different planes. The upper tee faces the left, but the lower tee faces the back.

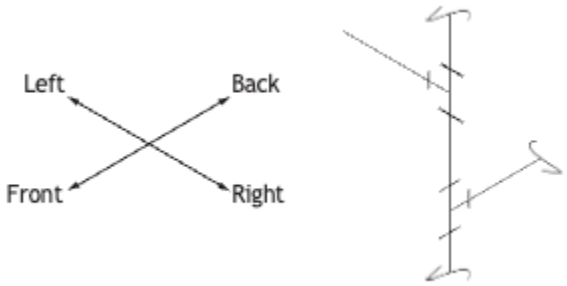


Figure 25 *Tees on a vertical pipe*

Piping runs that are not parallel to the isometric axes will not be to scale. Two examples of lines that will not be to scale are the 45° run from one end of a 45° elbow and the branch of a 45° wye fitting. Such runs are drawn by proper orientation to the isometric axes, and the joint is drawn perpendicular to the pipe it crosses (Figure 26). The pipe between the two 45° elbows is non- isometric, and the joints are perpendicular to the pipe.

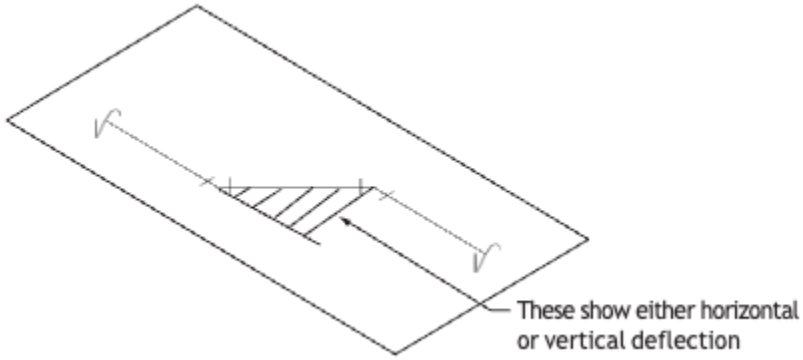


Figure 26 *Two horizontal 45° elbows*

Figures 27 and 28 show objects drawn both orthographically and isometrically. Notice that the isometric drawing is three dimensional and shows height, width and depth in one view. This typically makes isometric drawings easier to interpret than orthographic drawings. Figure 28 contains piping in only one plane, so only the vertical axis and the left-right axis are needed for the isometric drawing. The isometric drawing in Figure 29 is three-dimensional and uses all three isometric axes.

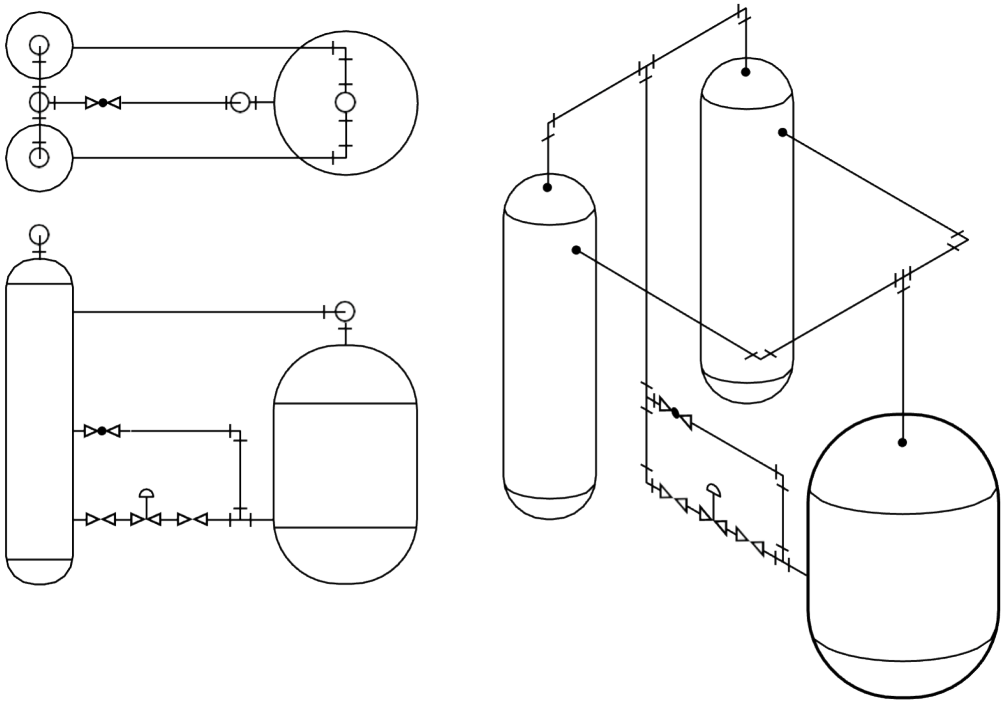


Figure 27 *Objects drawn orthographically and isometrically*

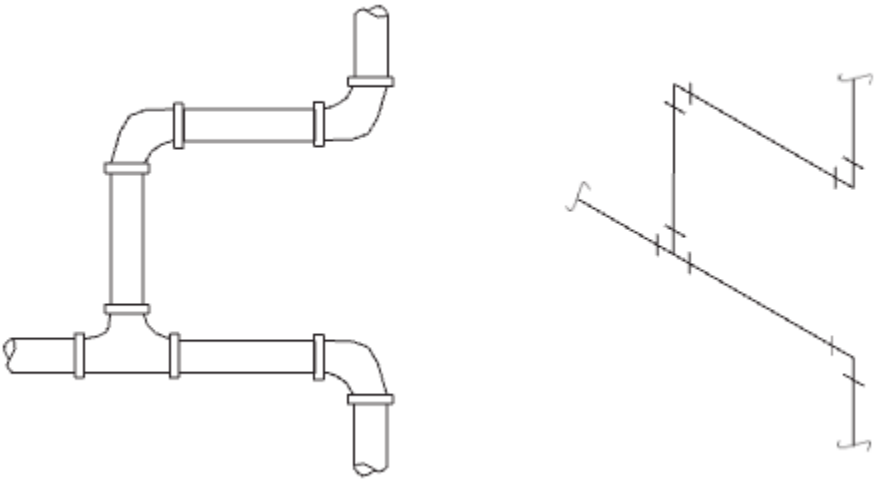


Figure 28 *Orthographic and isometric drawings of piping in one plane*

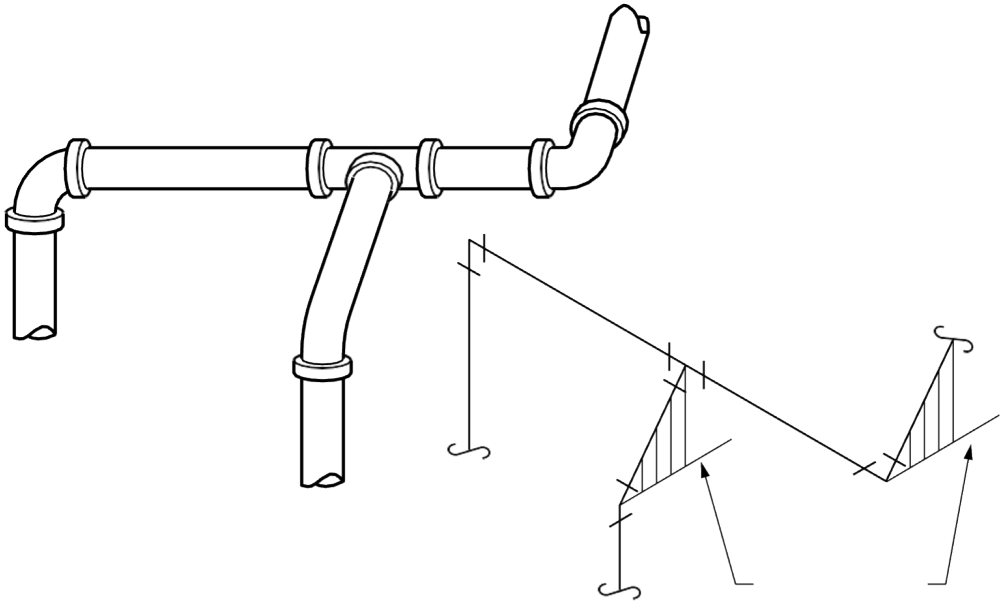


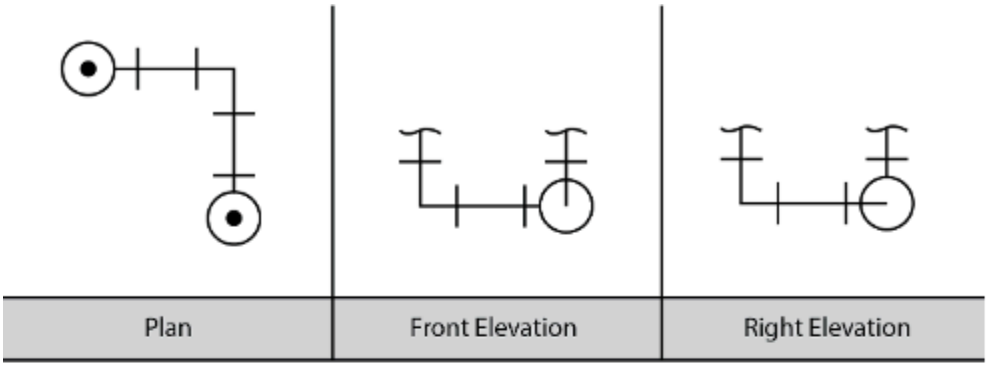
Figure 29 *Pictorial and isometric drawings of a three-dimensional piping system*

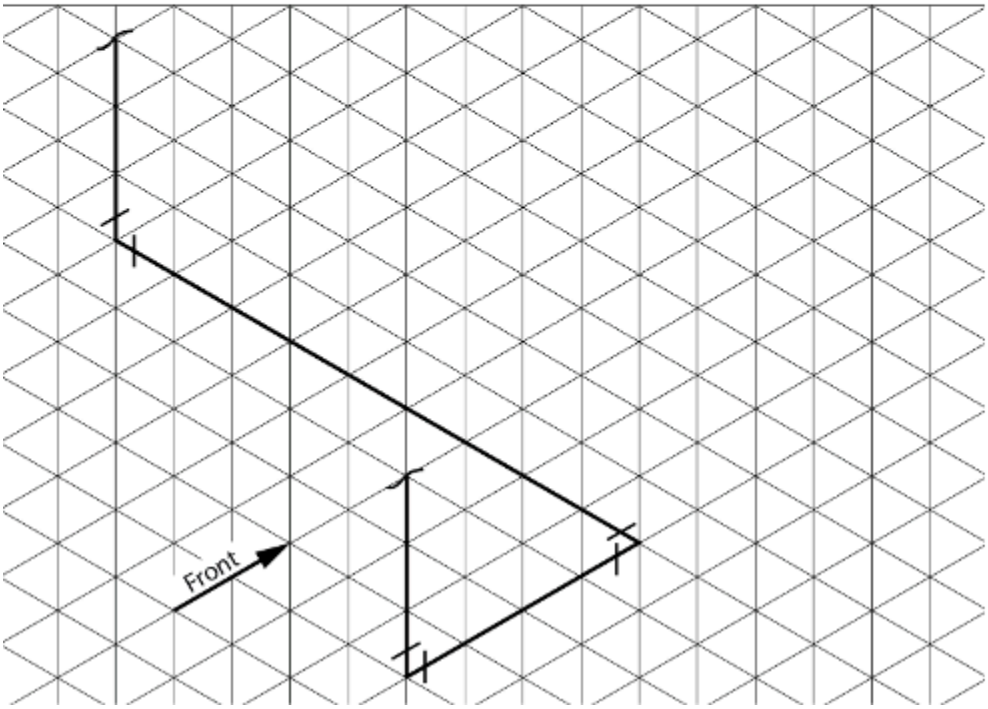
Conversion Between Orthographic and Isometric Drawings

To convert a multi-view orthographic projection to a three-dimensional isometric projection is quite simple. Orient the isometric grid to match the side of the orthographic projection. In this case use the front view.

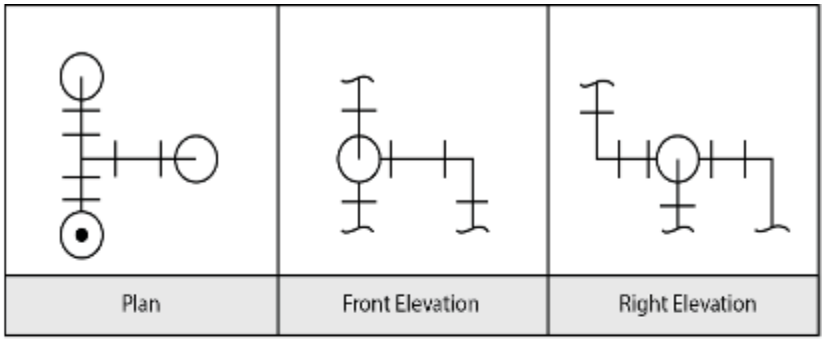
Remember that the two vertical directions (up and down) are represented by vertical lines. The four horizontal directions (front and back; left and right) are represented by lines at 30° from the horizontal. Plot the line segments at the proper orientation, as shown in the examples.

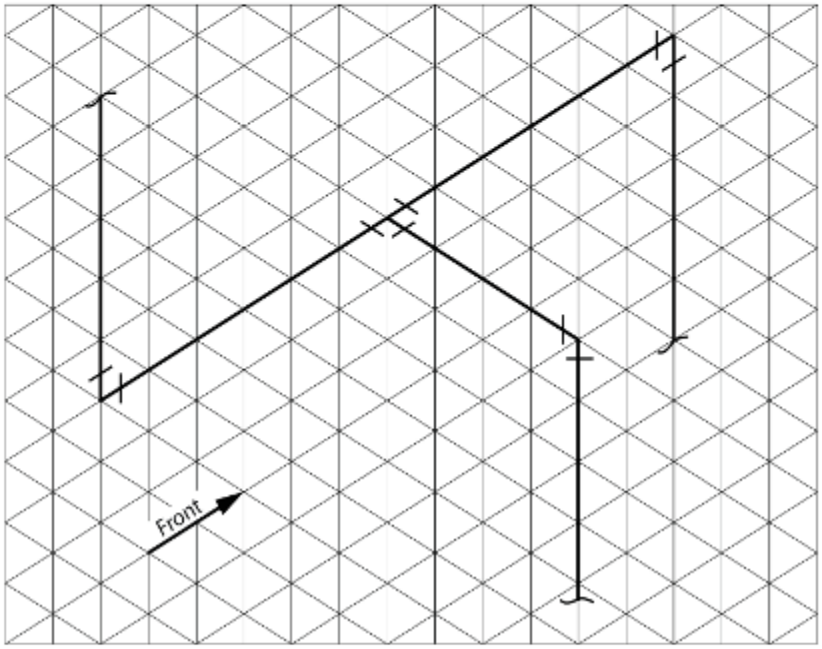
Example 1





Example 2





Self-Test C-3.6.2: Use Drawing Projections

Complete Self-Test C-3.6.2 and check your answers.

If you are using a printed copy, please find Self-Test C-3.6.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2471#h5p-39

References

BCcampus. (n.d.). *Playlist: Tools and equipment videos*. BCcampus MediaSpace. https://media.bccampus.ca/playlist/details/0_3g8xp22x/categoryId/175673 Playlist Details – Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Plumber: Competency C-2 Interpret Drawings and Specifications
- Steamfitter: Competency C-2 Interpret Drawings and Specifications
- Sprinkler Fitter: Competency C-2 Interpret Drawings and Specifications

Camosun College. (2019). Line D: Tools and Equipment—Competency D-3: Competency D-3: Read Drawings and Specifications (Rev. ed.) [Learning guide]. BCcampus. https://collection.bccampus.ca/textbook/yxJ3AwTa/

Camosun College. (2015). Trades Access Common Core Competency D-3: Competency D-3: Read Drawings and Specifications. Victoria, B.C.: Crown Publications. Download for free from the B.C. Open Textbook Collection (https://open.bccampus.ca/browse-ourcollection/find-open-textbooks/).

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Self-Test C-3.1: Describe Drafting Tools and Materials

Complete Self-Test C-3.1 and check your answers.

1. What material is used to provide a smooth surface on drafting boards and tables?
    a. Hardwood
    b. Vinyl
    c. Plastic
    d. Rubber
2. What would you use a hard lead pencil for?
    a. Writing reports
    b. Instrument drawings
    c. Sketching
    d. Drafting
3. What would you use a soft lead pencil for?
    a. Writing reports
    b. Instrument drawings
    c. Sketching
    d. Drafting
4. What is an erasing shield used for?
    a. To erase mistakes
    b. To hold an eraser
    c. To keep erasures within a desired area
    d. To prevent the need for erasures
5. What do you use a T-square for?
    a. To draw horizontal lines
    b. To draw vertical lines
    c. To place the paper squarely on the drafting table
    d. To draw horizontal and vertical lines
6. What can you use to draw complex curves besides a French curve?
    a. A spline
    b. A triangle
    c. A circle template
    d. A compass
7. A 1:50 scale would likely be found on a(n)
    a. Metric scale
    b. Architect's scale
    c. Mechanical engineer's scale
    d. Civil engineer's scale
8. A $\frac{1}{4}$" to 1′ scale would likely be found on a(n)

a. Metric scale
b. Architect's scale
c. Mechanical engineer's scale
d. Civil engineer's scale

9. Which triangle is of most use to a plumber?

a. 15°—75°—90°
b. 30°—60°—90°
c. 45°—90°—45°
d. 60°—60°—60°

10. What is the name given to the drafting tool used in the design of cars and dresses?

Answer: _____

11. What name is given to the drafting tool that contains pre-dimensioned holes in the right scale to accurately draw a symbol for equipment?

Answer: _____

12. When adjusting the pencil lead on a compass, how much shorter than the needle should the lead be?

Answer: _____

13. What is the more modern name given to the drafting tool known as a spline?

Answer: _____

Answer Key: Self-Test C-3.1 is on the other page.

Answer Key: Self-Test C-3.1

1. What material is used to provide a smooth surface on drafting boards and tables?
    a. Vinyl
2. What would you use a hard lead pencil for?
    a. Instrument drawings
3. What would you use a soft lead pencil for?
    a. Sketching
4. What is an erasing shield used for?
    a. To keep erasures within a desired area
5. What do you use a T-square for?
    a. To draw horizontal lines
6. What can you use to draw complex curves besides a French curve?
    a. A spline
7. A 1:50 scale would likely be found on a(n)
    a. Metric scale
8. A $\frac{1}{4}$" to 1′ scale would likely be found on a(n)
    a. Architect's scale
9. Which triangle is of most use to a plumber?
    a. 30°—60°—90°
10. What is the name given to the drafting tool used in the design of cars and dresses?
    a. French curve
11. What name is given to the drafting tool that contains pre-dimensioned holes in the right scale to accurately draw a symbol for equipment?
    a. Template
12. When adjusting the pencil lead on a compass, how much shorter than the needle should the lead be?
    a. $\frac{1}{32}$"
13. What is the more modern name given to the drafting tool known as a spline?
    a. Flexible curve

Self-Test C-3.2: Use Scale Rulers to Determine Actual Dimensions from a Piping Diagram

Complete Self-Test C-3.2 and check your answers.

1. List the correct measurements for the lettered dimensions in Figure 1.

a: _____ f: _____

b: _____ g: _____

c: _____ h: _____

d: _____ i: _____

e: _____ j: _____

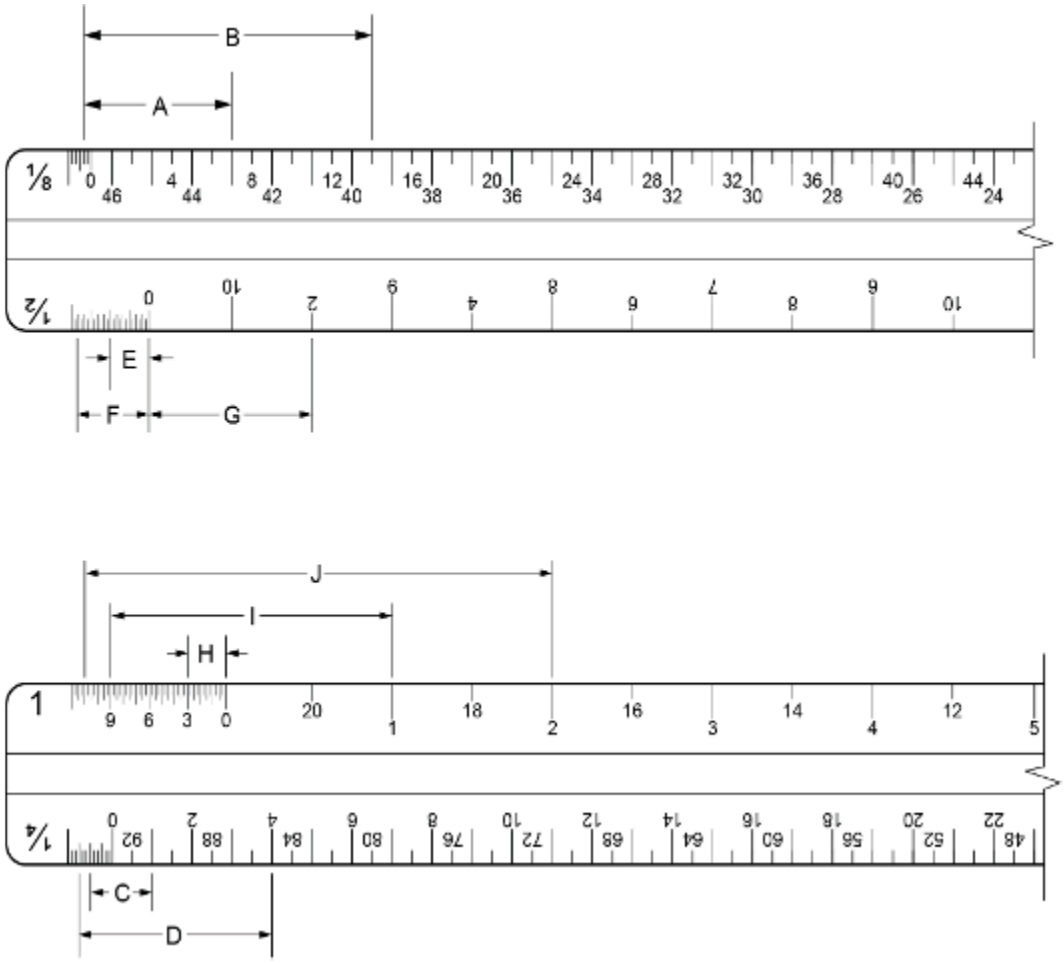


Figure 1 *Illustration for question 1*

2. Find the lengths of the sections of pipe (Figure 2), centre to centre, using an architect's rule. Scale $\frac{3}{4}" = 1' - 0"$. **measurements may vary from answer key with different printed versions**

a: _____

b: _____

c: _____

d: _____

e: _____

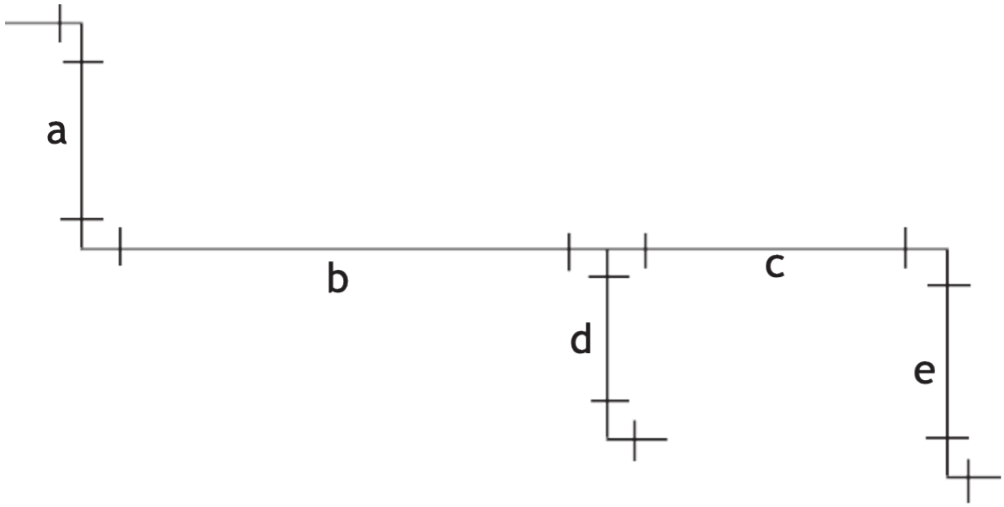
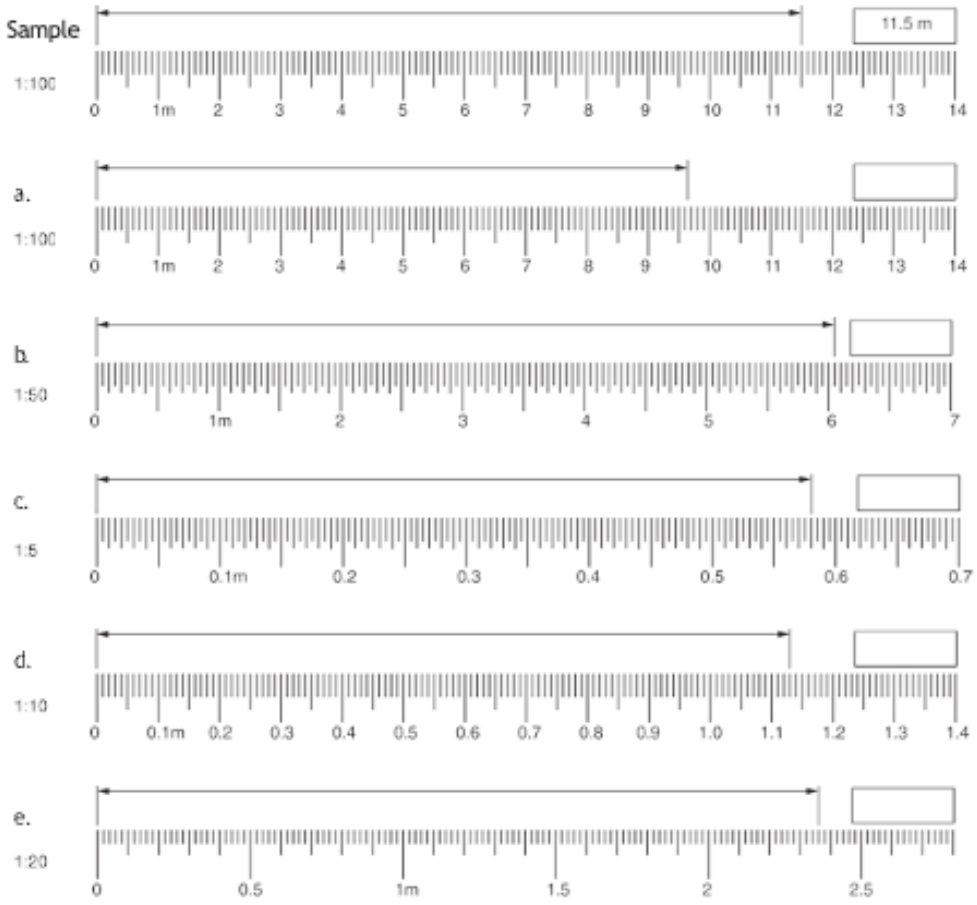
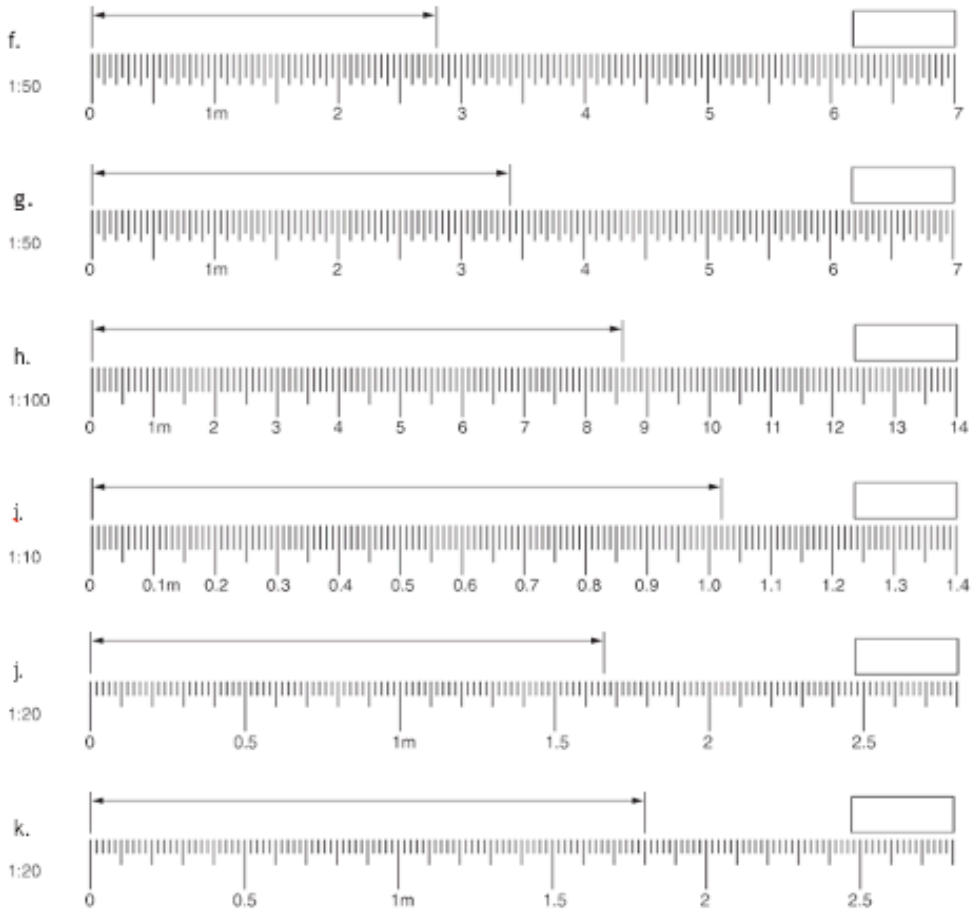


Figure 2 *Illustration for question 2*

3. Write the correct measurement of the dimensions shown below in the box at the right:


Sample
1:100
11.5 m
0 1m 2 3 4 5 6 7 8 9 10 11 12 13 14
a.
1:100
0 1m 2 3 4 5 6 7 8 9 10 11 12 13 14
b.
1:50
0 1m 2 3 4 5 6 7
c.
1:5
0 0.1m 0.2 0.3 0.4 0.5 0.6 0.7
d.
1:10
0 0.1m 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
e.
1:20
0 0.5 1m 1.5 2 2.5



4. Using Figure 3 give the C—C (centre to centre) lengths of each section of pipe in mm, using a metric scale. **measurements may vary from answer key with different printed versions**

a: _____

b: _____

c: _____

d: _____

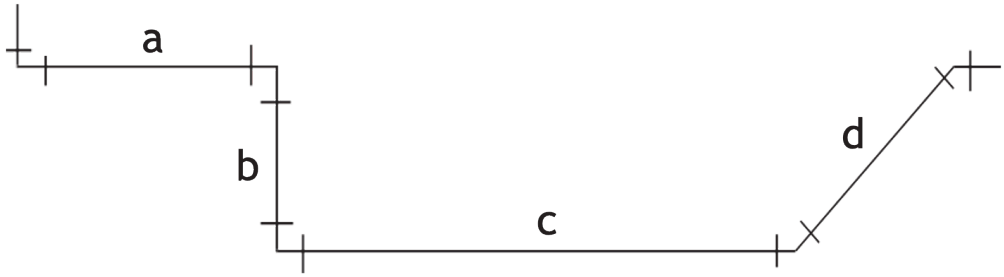


Figure 3 *Scale 1-20 illustration for Questions 4 and 5*

5. What would the lengths be in Figure 3 if the scale was 1:50?

a: _____

b: _____

c: _____

d: _____

6. Find the millimetre lengths of the sections of pipe, centre-to-centre, in each of the four scales in Figure 4, using a metric rule. **measurements may vary from answer key with different printed versions**

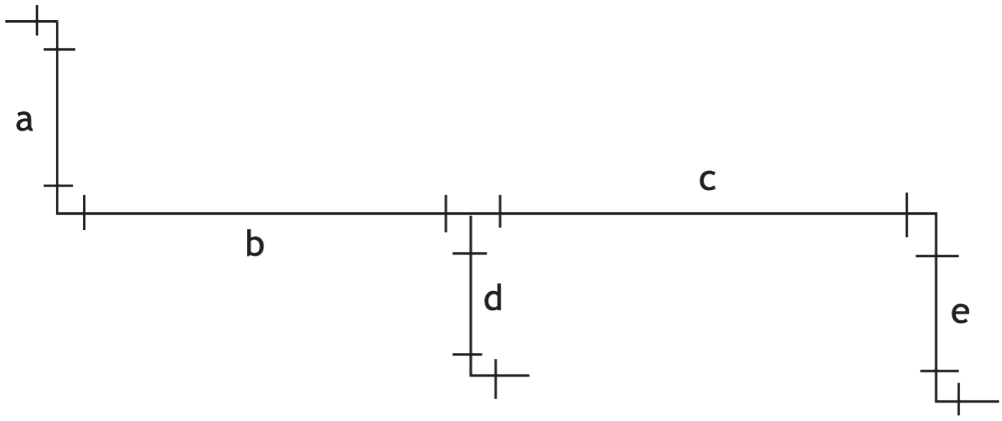


Figure 4 *Illustration for Question 6*

Table 1: Scale's Table

Scale	1:5	1:50	1:20	1:100
a.				
b.				
c.				
d.				
e.				

7. State the two reasons why it is poor practice to obtain dimensions by measuring drawings.

a: _____

b: _____

8. State reasons why it is not usually necessary to measure drawings for dimensions.

Answer: _____

9. State the procedure required to obtain dimensions that appear to be missing.

Answer: _____

10. State why arithmetic is necessary occasionally for finding dimensions.

Answer: _____

11. Using a metric tape, calculate the lettered dimensions in Figure 5. The scale is 1:20.

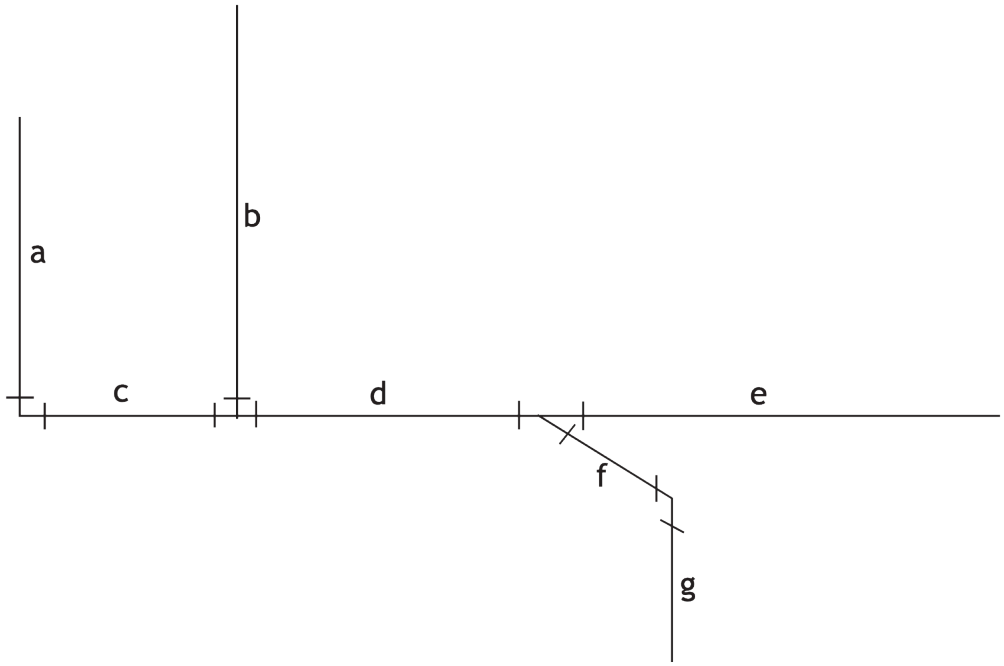


Figure 5 *Illustration for Question 11 and 12*

a: _____

b: _____

c: _____

d: _____

e: _____

f: _____

g: _____

12. If the scale in Figure 5 were 1:50, what would the dimensions be?

a: _____

b: _____

c: _____

d: _____

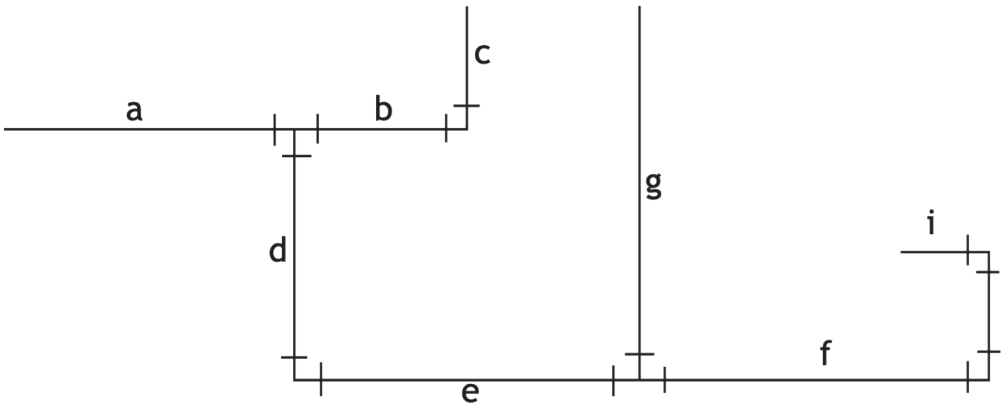
e: _____

f: _____

g: _____

13. Using an imperial tape measure, calculate the lettered dimensions in Figure 6 at a scale of $\frac{1}{8}$ inch = 1 foot.

measurements may vary from answer key with different printed versions



a: _____ f: _____

b: _____ g: _____

c: _____ h: _____

d: _____ i: _____

e: _____

14. Find the exact length of the lettered dimensions in Figure 7, according to the scale. **measurements may vary from answer key with different printed versions**

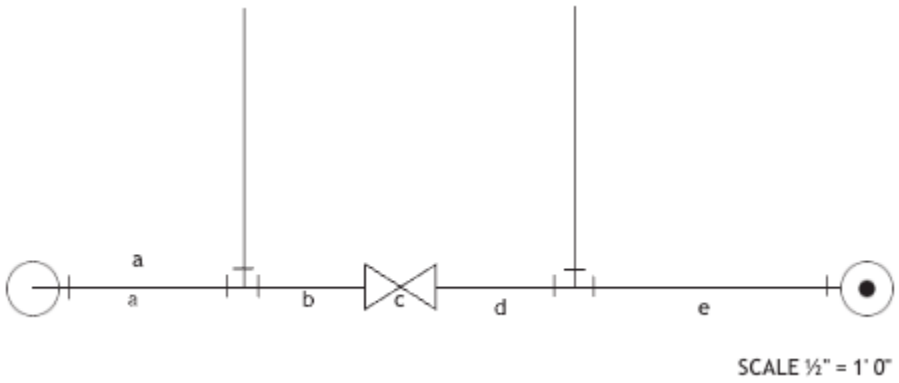


Figure 7 *Illustration for Question 14*

a: _____

b: _____

c: _____

d: _____

e: _____

Answer Key: Self-Test C-3.2 is on the other page.

Answer Key: Self-Test C-3.2

1. List the correct measurements for the lettered dimensions in Figure 1.
    a. 6′-5″
    b. 12′-10″
    c. 1′-6″
    d. 4′-9″
    e. 0′-6″
    f. 0′-11″
    g. 2′-0″
    h. 0′-3″
    i. 1′-9″
    j. 2′-11″
2. Find the lengths of the sections of pipe (Figure 2), centre to centre, using an architect's rule. Scale

    $\frac{3}{4}" = 1' - 0"$.

    a. 1′- $\frac{1}{2}$„
    b. 2′- $4\frac{1}{2}$„
    c. 1′-10″
    d. 0′-10″
    e. 1′-1″
3. Write the correct measurement of the dimensions shown below in the box at the right:
    a. 9.65 m
    b. 6.05 m
    c. 0.58 m
    d. 1.13 m
    e. 2.36 m
    f. 2.8 m
    g. 3.4 m
    h. 8.6 m
    i. 1.02 m
    j. 1.66 m
    k. 1.8 m
4. Using Figure 3 give the C—C (centre to centre) lengths of each section of pipe in mm, using a metric scale.
    a. 560 mm
    b. 400 mm
    c. 1,140 mm
    d. 540 mm
5. What would the lengths be in Figure 3 if the scale was 1:50?
    a. 1,400 mm
    b. 1,000 mm

c. 2,850 mm
d. 1,350 mm

6. Find the millimetre lengths of the sections of pipe, centre-to-centre, in each of the four scales in Figure 4, using a metric rule.

Scale	1:5	1:50	1:20	1:100
a.	100 mm	1 m	0.4 m	2 m
b.	225 mm	2.25 m	0.89 m	4.5 m
c.	175 mm	1.75 m	0.7 m	3.5 m
d.	80 mm	0.8 m	0.32 m	1.6 m
e.	105 mm	1.05 m	0.42 m	2.1 m

7. State the two reasons why it is poor practice to obtain dimensions by measuring drawings.
   a. Shrinkage may occur in the reproduction process.
   b. Drawing is not necessarily to scale.
8. State reasons why it is not usually necessary to measure drawings for dimensions.
   a. All necessary dimensions are generally included on the blueprints (drawings).
9. State the procedure required to obtain dimensions that appear to be missing.
   a. Examine several or all prints in the set. Measure only after you are sure that dimensions cannot be found from information given on any of the prints.
10. State why arithmetic is necessary occasionally for finding dimensions.
    a. To obtain dimensional (size) information.
11. Using a metric tape, calculate the lettered dimensions in Figure 5. The scale is 1:20.
    a. 0.7 m
    b. 0.94 m
    c. 0.5 m
    d. 0.7 m
    e. 1.06 m
    f. 0.36 m
    g. 0.38 m
12. If the scale in Figure 5 were 1:50, what would the dimensions be?
    a. 1.75 m
    b. 2.35 m
    c. 1.25 m
    d. 1.65 m
    e. 2.45 m
    f. 0.9 m
    g. 0.95 m
13. Using an imperial tape measure, calculate the lettered dimensions in Figure 6 at a scale of $\frac{1}{8}$ inch = 1 foot.
    a. 10′
    b. 6′

c. 4′
d. 8′
e. 12′
f. 12′
g. 12′
h. 4′
i. 3′

14. Find the exact length of the lettered dimensions in Figure 7, according to the scale.

a. $2'-7\frac{1}{2}"$
b. 1′-0″
c. $0'-10\frac{1}{2}"$
d. 4′
e. $10'-\frac{3}{4}"$

Self-Test C-3.3: Describe Piping and Fixture Symbols Used in the Piping Trades

Complete Self-Test C-3.3 and check your answers.

1. Why are piping symbols used?

Answer: _____

2. State the two basic requirements for symbols.

Answer: _____

3. Why are single-line symbols usually used in piping drawings?

Answer: _____

4. Lengths of valves and fittings in single-line drawings are always drawn to scale.
   a. true
   b. false
5. Flanged or welded valves and fittings in double line drawings are always drawn to scale.
   a. true
   b. false
6. The joint in Figure 1 is
   a. screwed
   b. flanged
   c. butt welded
   d. socket welded

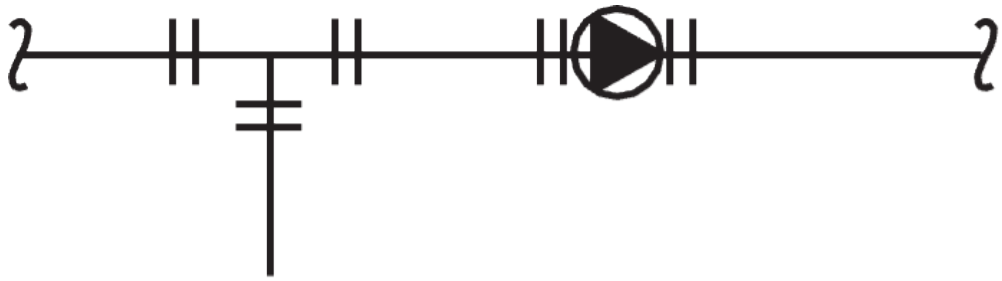


Figure 1 *Illustration for Question 6*

7. The joint in Figure 2 is
   a. screwed

b. flanged
c. butt welded
d. socket welded

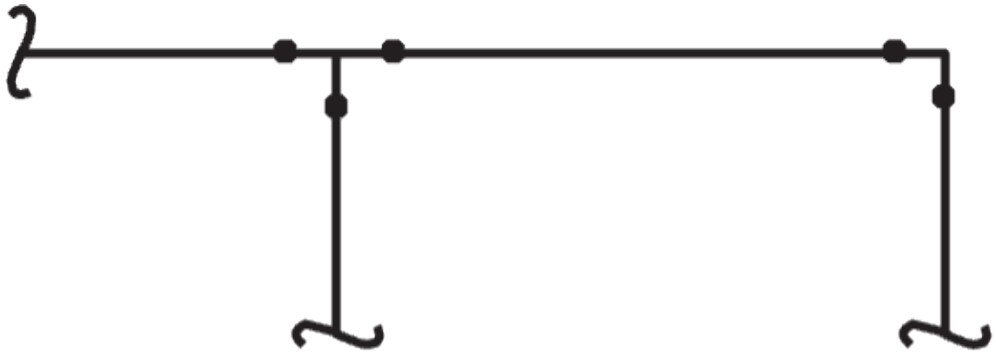


Figure 2 *Illustration for Question 7*

8. The joint in Figure 3 is
    a. screwed
    b. flanged
    c. butt welded
    d. socket welded

Figure 3 *Illustration for Question 8*

9. The joint in Figure 4 is
    a. screwed
    b. flanged
    c. butt welded
    d. socket welded

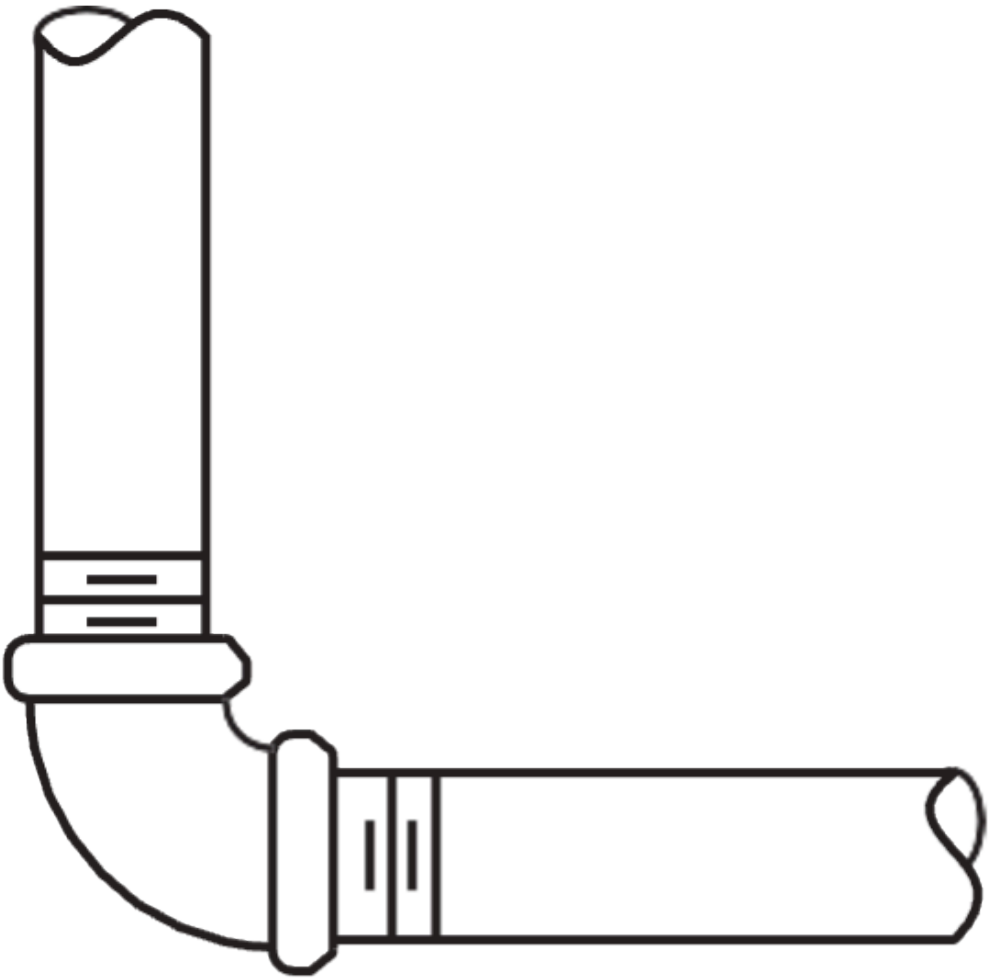


Figure 4 *Illustration for Question 9*

10. The joint in Figure 5 is
    a. screwed
    b. flanged
    c. butt welded
    d. socket welded

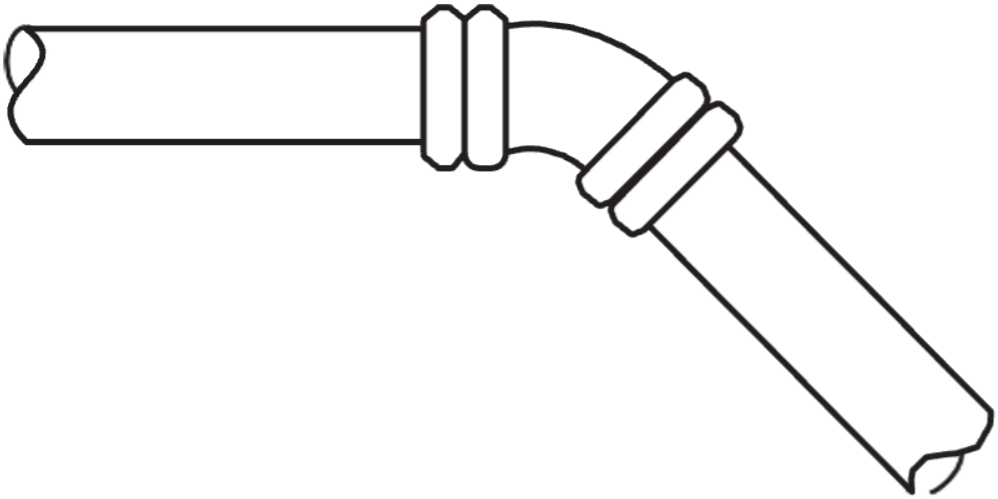


Figure 5 *Illustration for Question 10*

11. The symbol in Figure 6 is a

    a. 90° elbow
    b. tee
    c. 45° elbow
    d. union

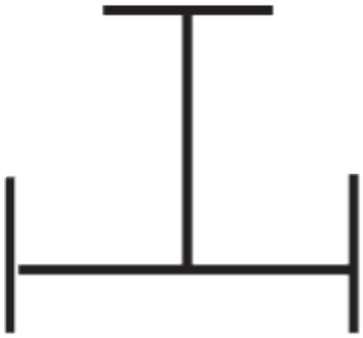


Figure 6 *Illustration for Question 11*

12. The symbol in Figure 7 is a

    a. 90° elbow
    b. tee
    c. 45° elbow
    d. union

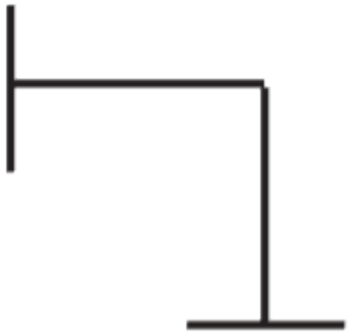


Figure 7 *Illustration for Question 12*

13. The symbol in Figure 8 is a

    a. 90° elbow
    b. tee
    c. 45° elbow
    d. union

Figure 8 *Illustration for Question 13*

14. The symbol in Figure 9 is a

    a. globe valve
    b. gate valve
    c. check valve
    d. relief valve

Figure 9 *Illustration for Question 14*

15. The symbol in Figure 10 is a

    a. globe valve
    b. gate valve
    c. check valve
    d. relief valve

Figure 10 *Illustration for Question 15*

16. The symbol in Figure 11 is a

    a. globe valve
    b. gate valve
    c. check valve
    d. relief valve

Figure 11 *Illustration for Question 16*

17. The symbol in Figure 12 is a

    a. safety valve
    b. pump
    c. control valve
    d. pressure-reducing valve

Figure 12 *Illustration for Question 17*

18. The symbol in Figure 13 is a

    a. safety valve
    b. pump
    c. control valve
    d. pressure-reducing valve

Figure 13 *Illustration for Question 18*

19. The symbol in Figure 14 is a

    a. safety valve
    b. pump
    c. control valve
    d. pressure-reducing valve

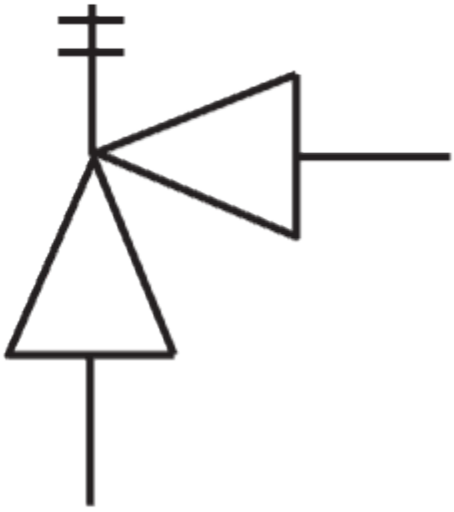


Figure 14 *Illustration for Question 19*

20. The symbol in Figure 15 is a

    a. safety valve
    b. pump
    c. control valve
    d. pressure reducing valve

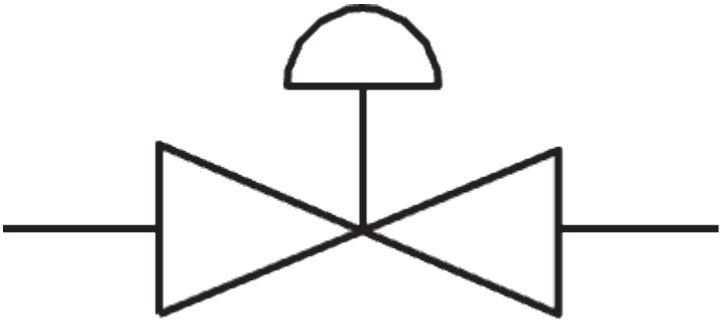
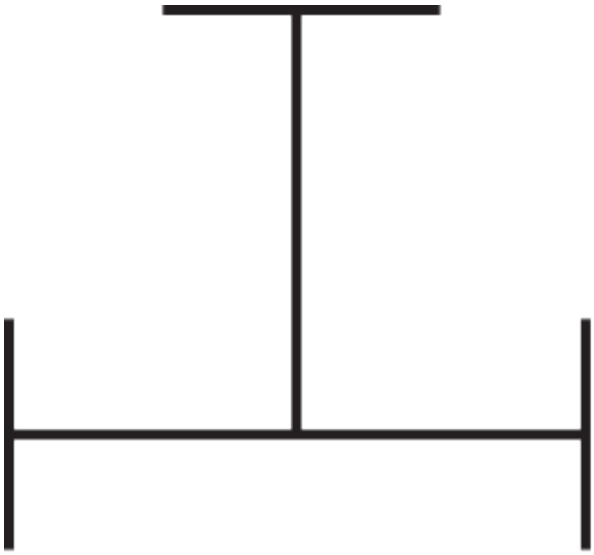
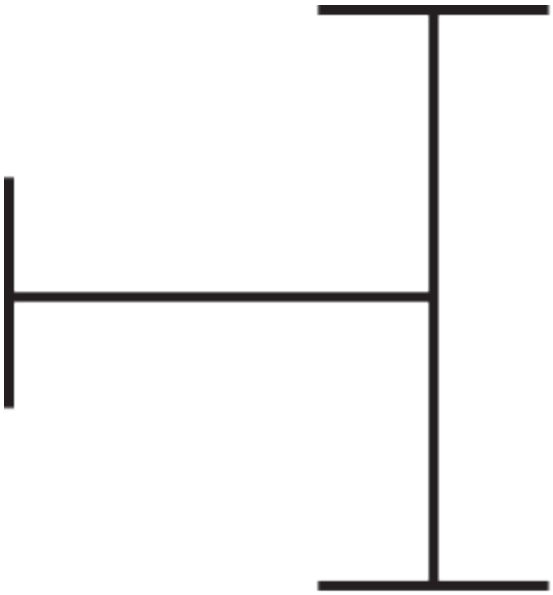
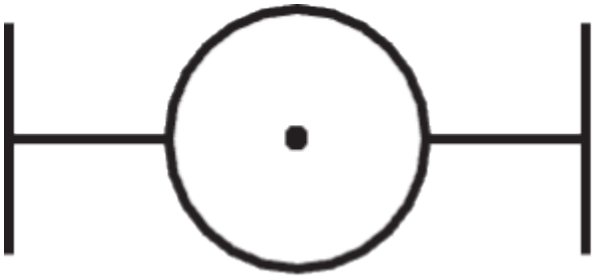
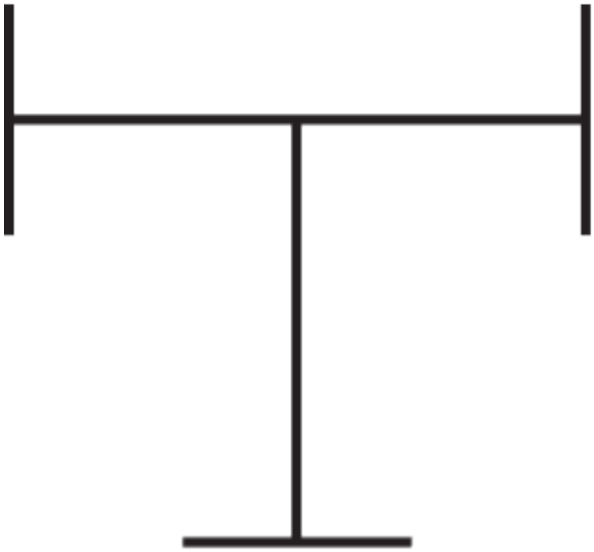
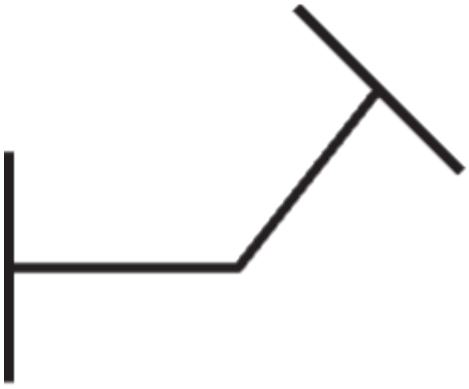
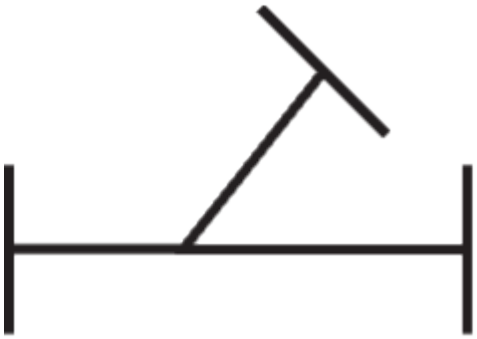
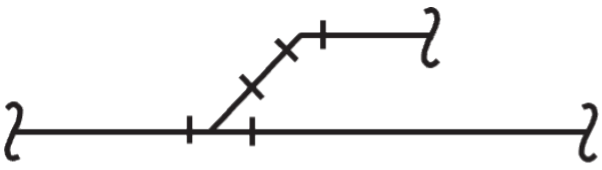


Figure 15 *Illustration for Question 20*

21. Draw the right view of the following front views.

	Front view	Right view
a.		
b.		

c.		
d.		
e.		

f.		
g.		
h.		
i.		

22. Identify the symbols A to G in Figure 16.

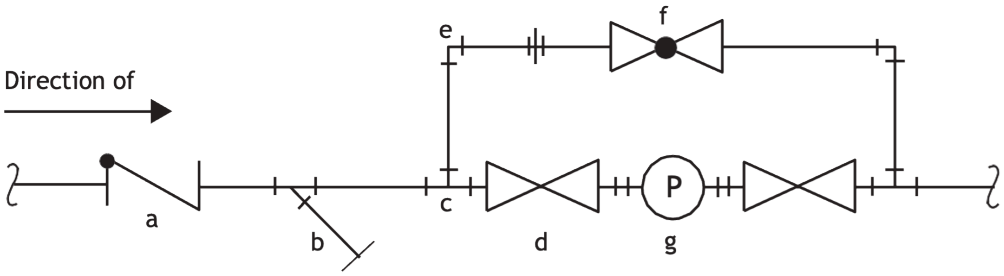


Figure 16 *Illustration for Question 21*

a. _____
b. _____
c. _____
d. _____
e. _____
f. _____
g. _____

Answer Key: Self-Test C-3.3 is on the other page.

Answer Key: Self-Test C-3.3

1. Why are piping symbols used?
    a. to visually represent pipes, fittings, etc.
2. State the two basic requirements for symbols.
    a. must be simple
    b. must be easy to draw
3. Why are single-line symbols usually used in piping drawings?
    a. because they are simplest and easiest to draw
4. Lengths of valves and fittings in single-line drawings are always drawn to scale.
    a. false
5. Flanged or welded valves and fittings in double line drawings are always drawn to scale.
    a. true
6. The joint in Figure 1 is
    a. flanged

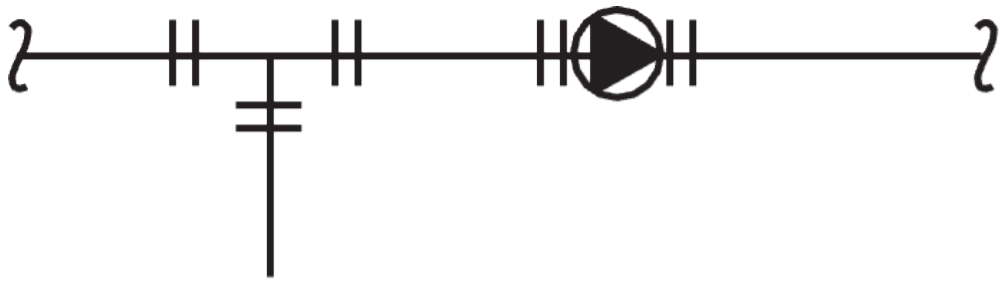


Figure 1 *Illustration for Question 6*

7. The joint in Figure 2 is
    a. butt welded

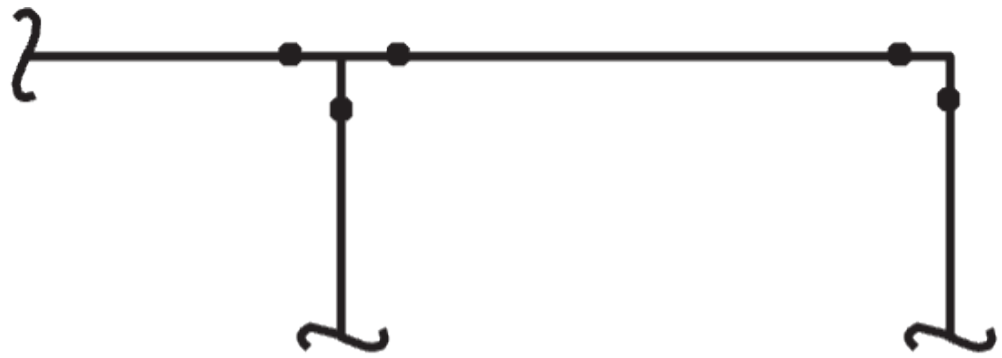


Figure 2 *Illustration for Question 7*

8. The joint in Figure 3 is
    a. butt welded

Figure 3 *Illustration for Question 8*

9. The joint in Figure 4 is
    a. screwed

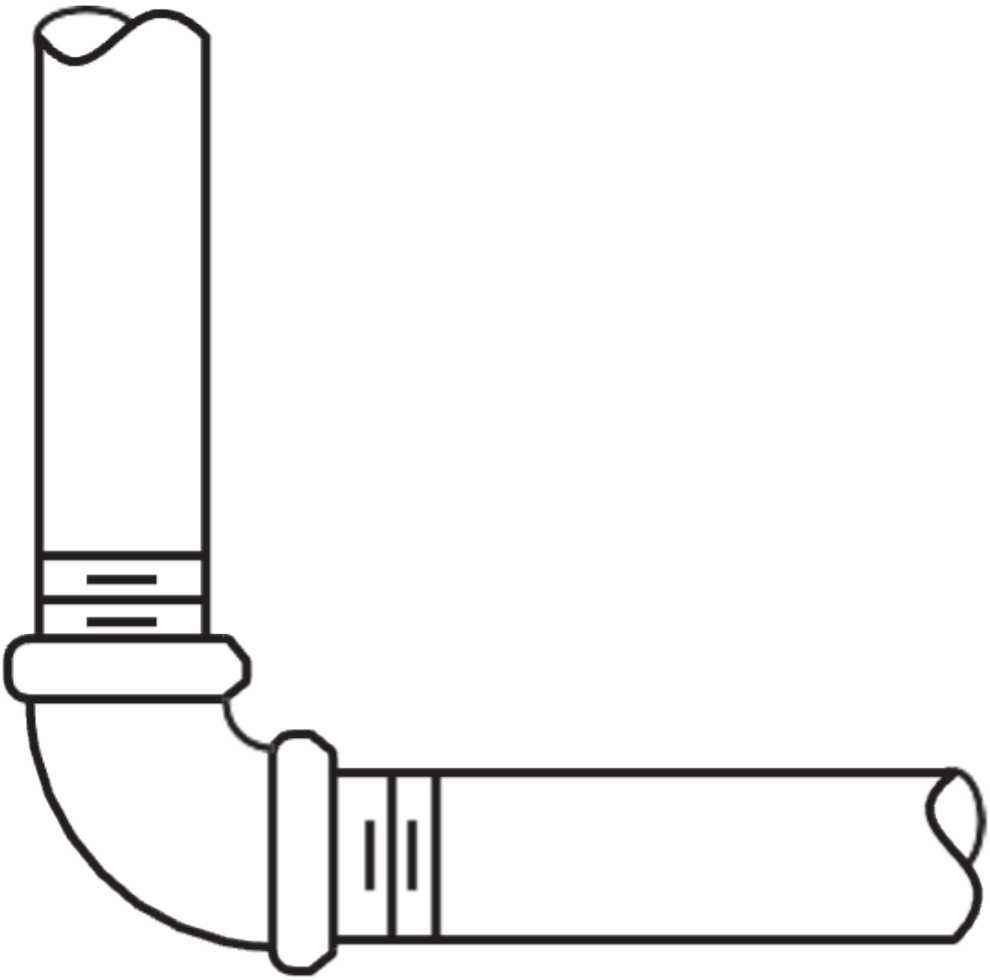


Figure 4 *Illustration for Question 9*

10. The joint in Figure 5 is
    a. flanged

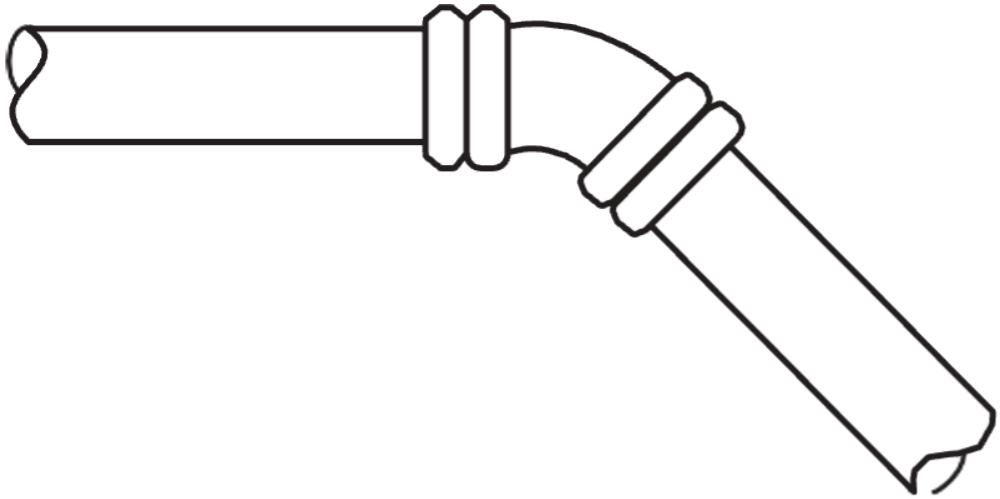


Figure 5 *Illustration for Question 10*

11. The symbol in Figure 6 is a
    a. tee

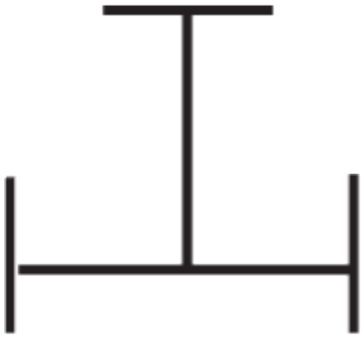


Figure 6 *Illustration for Question 11*

12. The symbol in Figure 7 is a
    a. 90° elbow

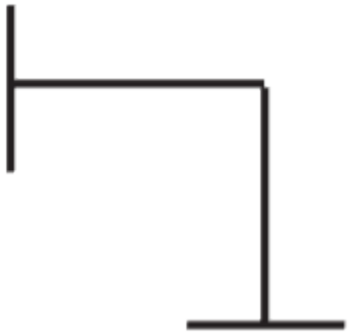


Figure 7 *Illustration for Question 12*

13. The symbol in Figure 8 is a
    a. union

Figure 8 *Illustration for Question 13*

14. The symbol in Figure 9 is a
    a. gate valve

Figure 9 *Illustration for Question 14*

15. The symbol in Figure 10 is a
    a. globe valve

Figure 10 *Illustration for Question 15*

16. The symbol in Figure 11 is a

    a. check valve

Figure 11 *Illustration for Question 16*

17. The symbol in Figure 12 is a

    a. pump

Figure 12 *Illustration for Question 17*

18. The symbol in Figure 13 is a
    a. pressure-reducing valve

Figure 13 *Illustration for Question 18*

19. The symbol in Figure 14 is a
    a. safety valve

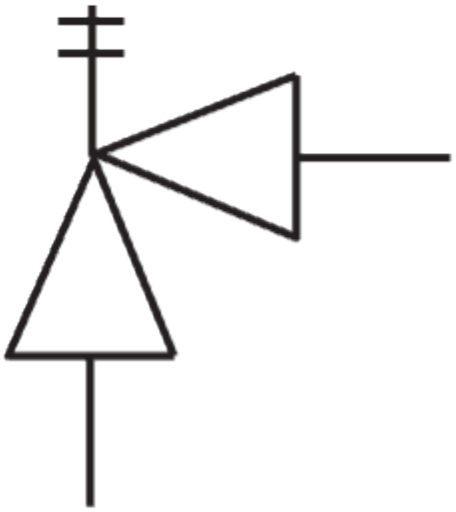


Figure 14 *Illustration for Question 19*

20. The symbol in Figure 15 is a
    a. control valve

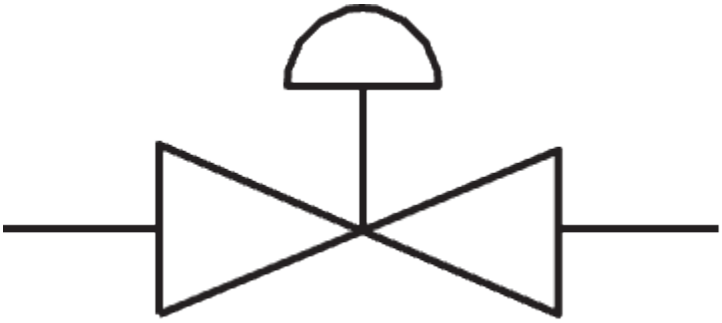
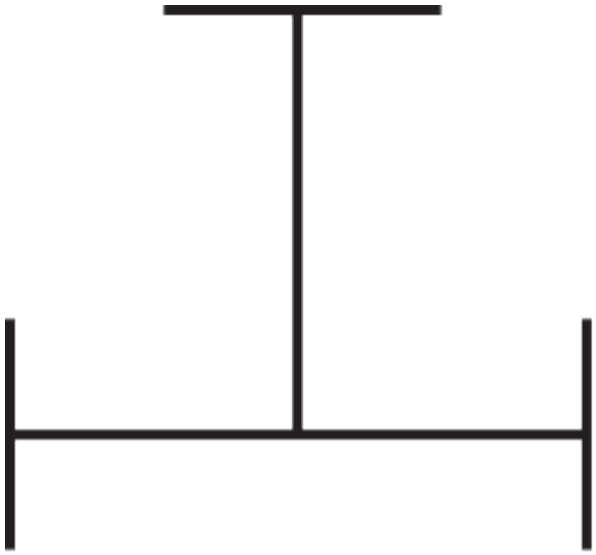
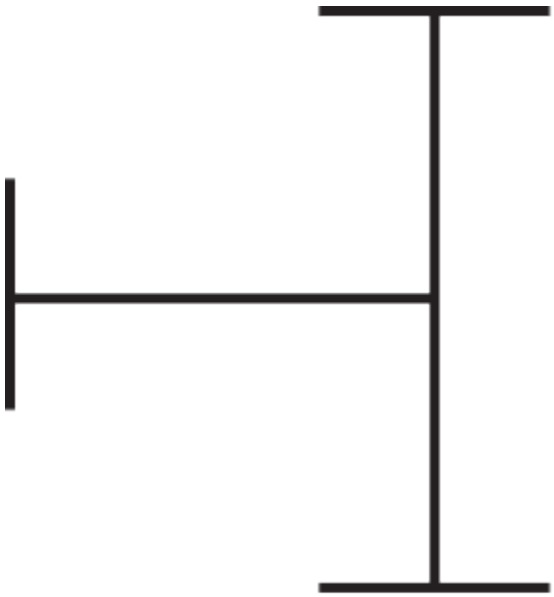
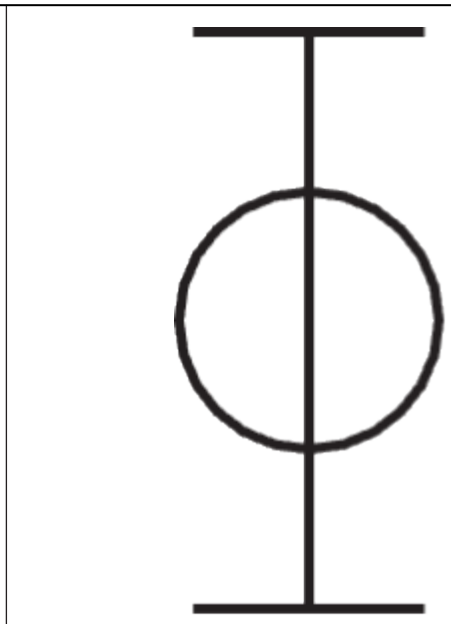
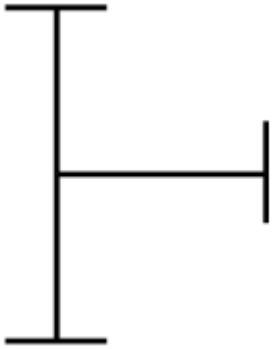
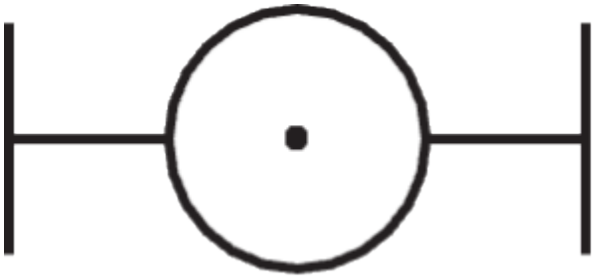
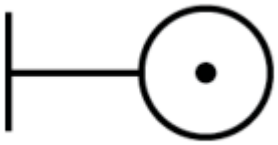
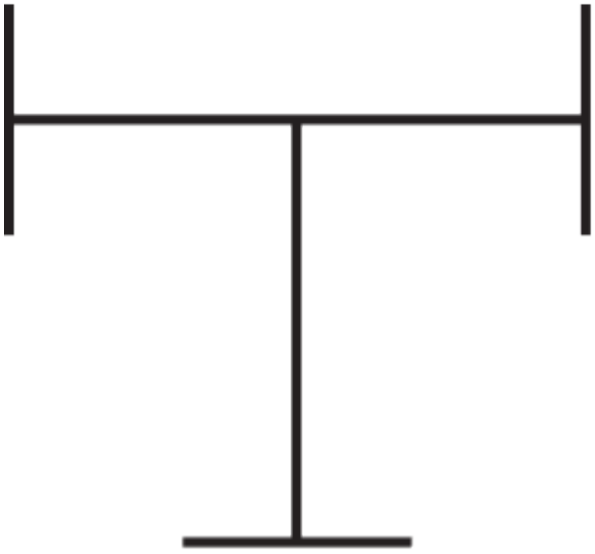
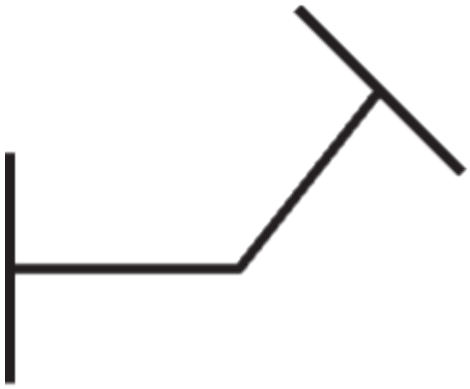
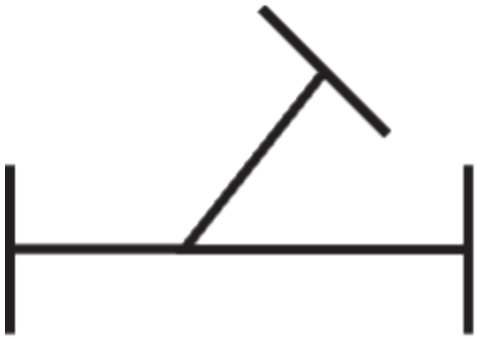


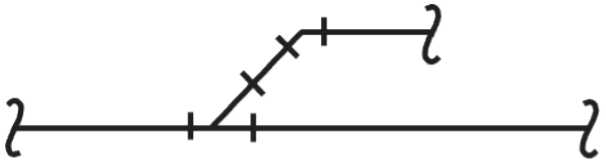
Figure 15 *Illustration for Question 20*

21. Draw the right view of the following front views.

	Front view	Right view
a.		
b.		

c.		
d.		
e.		

f.		
g.		
h.		

i.		

22. Identify the symbols A to G in Figure 16.

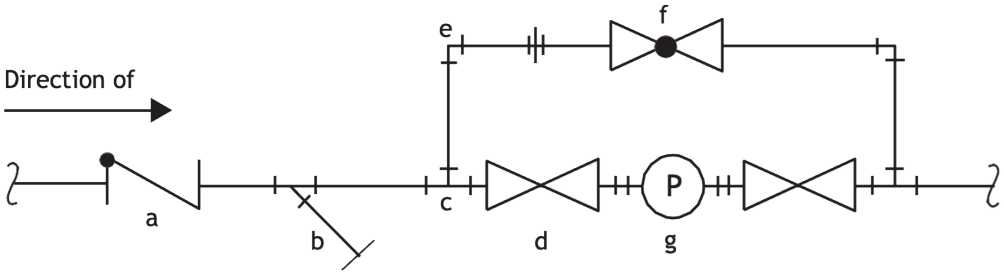


Figure 16 *Illustration for Question 21*

a. check valve
b. strainer
c. tee
d. gate valve
e. 90° elbow
f. globe valve
g. pump

Self-Test C-3.4: Describe Lettering and Dimensioning of Piping Diagrams

Complete Self-Test C-3.4 and check your answers.

Identify each type of line in Figure 1 below by stating:

a. its name (visible line, hidden line, centre line, etc.)
b. its main use (shows object outline, shows centre of hole, shows location of sections, etc.)

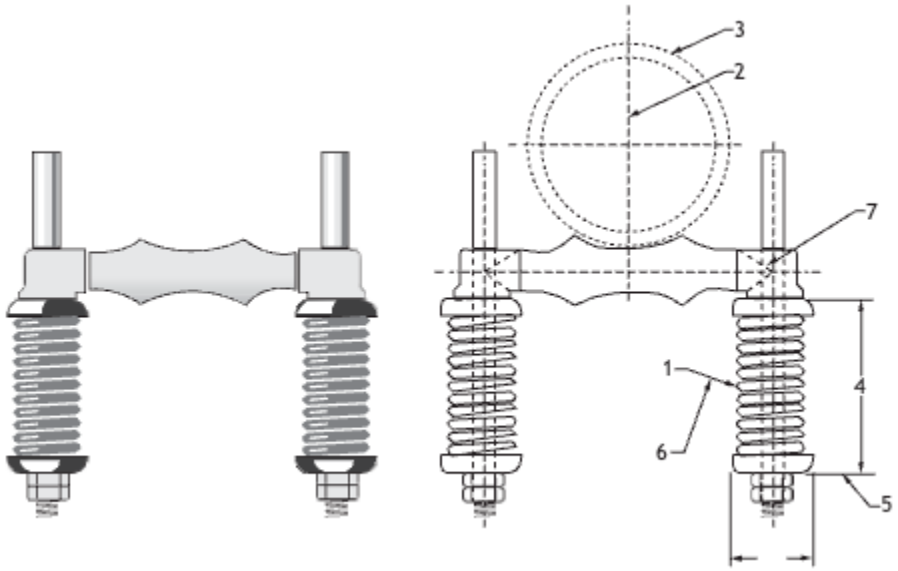


Figure 1 *Illustration for Self-Test 4*

1. Line 1
   a. _____
   b. _____
2. Line 2
   a. _____
   b. _____
3. Line 3
   a. _____
   b. _____
4. Line 4
   a. _____
   b. _____

5. Line 5
    a. _____
    b. _____
6. Line 6
    a. _____
    b. _____
7. Line 7
    a. _____
    b. _____

Answer Key: Self-Test C-3.4 is on the other page.

Answer Key: Self-Test C-3.4

Identify each type of line in Figure 1 below by stating:

a. its name (visible line, hidden line, centre line, etc.)
b. its main use (shows object outline, shows centre of hole, shows location of sections, etc.)

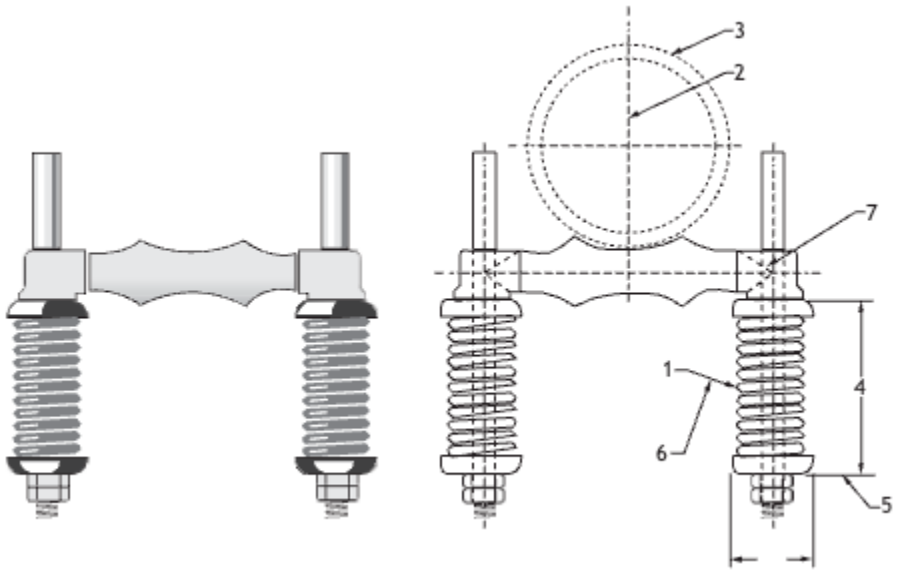


Figure 1 *Illustration for Self-Test 4*

1. Line 1
    a. outline
    b. outline of a part
2. Line 2
    a. centre line
    b. centre of an object
3. Line 3
    a. phantom
    b. shows location of removed parts not detailed
4. Line 4
    a. dimension line
    b. shows dimension of a part
5. Line 5
    a. extension lines
    b. shows where a dimension is taken from
6. Line 6

a. leader line
b. points out a dimension or part

7. Line 7
   a. hidden
   b. shows hidden surfaces

Self-Test C-3.5: Describe Drawing Projections

Complete Self-Test C-3.5 and check your answers.

1. Orthographic drawings accurately represent the length of piping systems from all directions.
    a. true
    b. false
2. Isometric drawings are three-dimensional.
    a. true
    b. false
3. List the three orthographic views that are used in piping drawings.
    a. _____
    b. _____
    c. _____
4. What is the term to describe an orthographic drawing of a building showing the front exteriors?
    a. street view
    b. store front
    c. civic address
    d. front elevation
5. Which of the following information is found on an architectural plan view of a building?
    a. exterior siding material
    b. concrete slab thickness
    c. location of building services
    d. location of plumbing fixtures
6. What is the term used to describe a cross-sectional drawing of a wall?
    a. section
    b. cut away
    c. material list
    d. interior elevation

Answer Key: Self-Test C-3.5 is on the other page.

Answer Key: Self-Test C-3.5

1. Orthographic drawings accurately represent the length of piping systems from all directions.
    a. true
2. Isometric drawings are three-dimensional.
    a. true
3. List the three orthographic views that are used in piping drawings.
    a. front
    b. plan (top)
    c. side
4. What is the term to describe an orthographic drawing of a building showing the front exteriors?
    a. front elevation
5. Which of the following information is found on an architectural plan view of a building?
    a. location of building services
6. What is the term used to describe a cross-sectional drawing of a wall?
    a. section

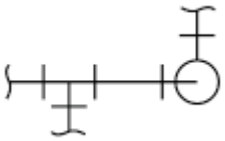
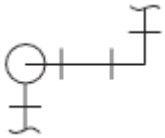
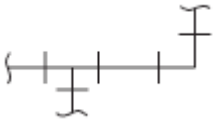
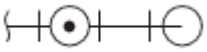
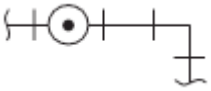
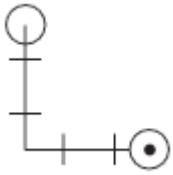
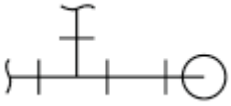
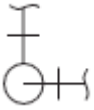
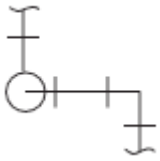
Self-Test C-3.6.1: Use Drawing Projections

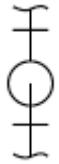
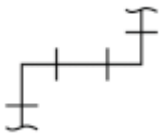
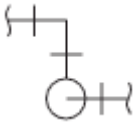
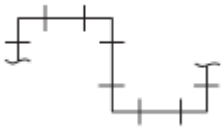
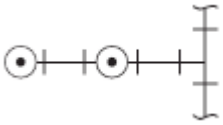
Complete Self-Test C-3.6.1 and check your answers.

1. One advantage of orthographic projections is that
    a. they can be used for complex piping systems
    b. they pinpoint the exact location of equipment
    c. if the drawing is to scale, all the items are to scale
    d. the building appears just as it would look to you
2. Orthographic piping drawings normally include how many views?
    a. 1
    b. 2
    c. 3
    d. 4

In questions 3–18, draw the remaining view in the space provided. Complete your drawings neatly at a scale proportional to the given views.

Table 1 Drawings at a scale

	Plan	Front Elevation	Right Elevation
3.			
4.			
5.			
6.			
7.			
8.			
9.			

10.			
11.			
12.			
13.			
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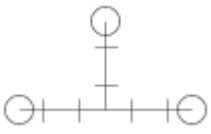
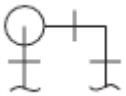
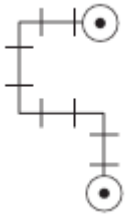
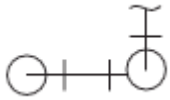
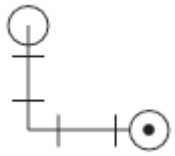
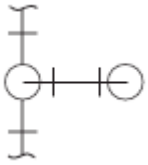
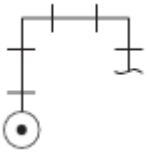
15.			

16.			
17.			
18.			

For questions 19–23, select the correct numbers from the chart on the right below. In questions 19–21 identify:

a. Top view
b. Right elevation for the front views shown. (The same number may be used more than once.)

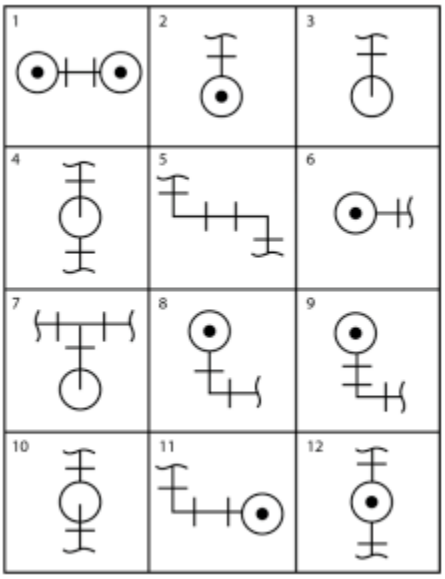
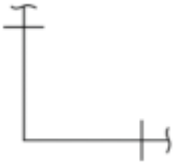


Figure 1 *Perspective's Drawings*

Figure 2 *Image for question 19*



19. a. _____
    b. _____

Figure 3 *Image for question 20*

20. a. _____
    b. _____

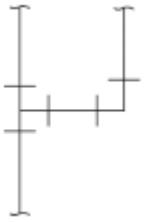


Figure 4 *Image for question 21*

21. a. _____
    b. _____

In Questions 22 and 23 select the correct numbers that identify:

a. Front view
b. Right view for the top views shown.

Figure 5 *Image for question 22*

22. a. _____
    b. _____

Figure 6 *Image for question 23*

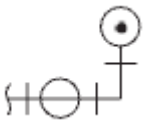
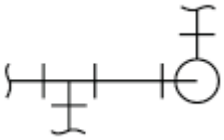
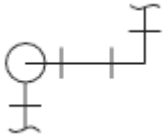
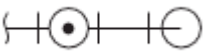
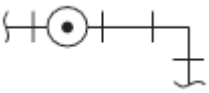
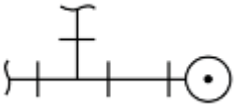
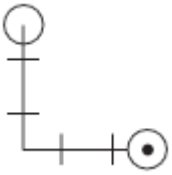
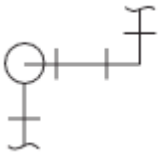
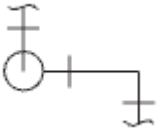
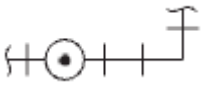
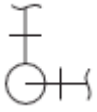
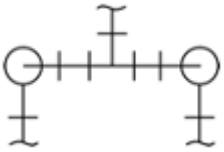
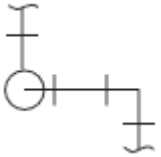
23. a. _____
    b. _____

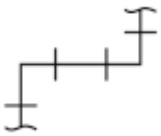
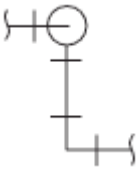
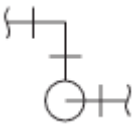
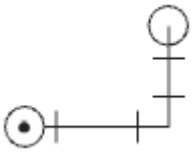
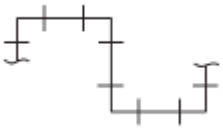
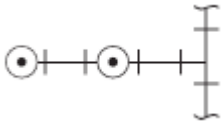
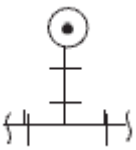
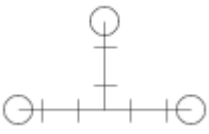
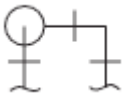
Answer Key: Self-Test C-3.6.1 is on the other page.

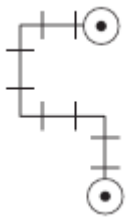
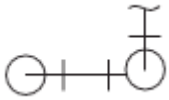
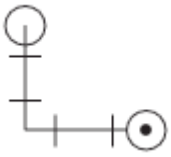
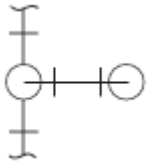
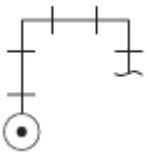
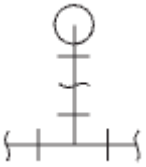
Answer Key: Self-Test C-3.6.1

1. One advantage of orthographic projections is that
    a. they pinpoint the exact location of equipment
2. Orthographic piping drawings normally include how many views?
    a. 3

In questions 3–18, draw the remaining view in the space provided. Complete your drawings neatly at a scale proportional to the given views.

	Plan	Front Elevation	Right Elevation
3.			
4.			
5.			
6.			
7.			
8.			
9.			

10.			
11.			
12.			
13.			
14.			
15.			

16.			
17.			
18.			

For questions 19–23, select the correct numbers from the chart on the right below. In questions 19–21 identify:

a. Top view
b. Right elevation for the front views shown. (The same number may be used more than once.)

19. Question 19
    a. 6
    b. 2
20. Question 20
    a. 6
    b. 12
21. Question 21
    a. 1
    b. 4

In Questions 22 and 23 select the correct numbers that identify:

a. Front view
b. Right view for the top views shown.

22. Question 22
    a. 5
    b. 10
23. Question 23
    a. 7
    b. 9

Self-Test C-3.6.2: Use Drawing Projections

Complete Self-Test C-3.6.2 and check your answers.

1. Which of the following is an isometric diagram?

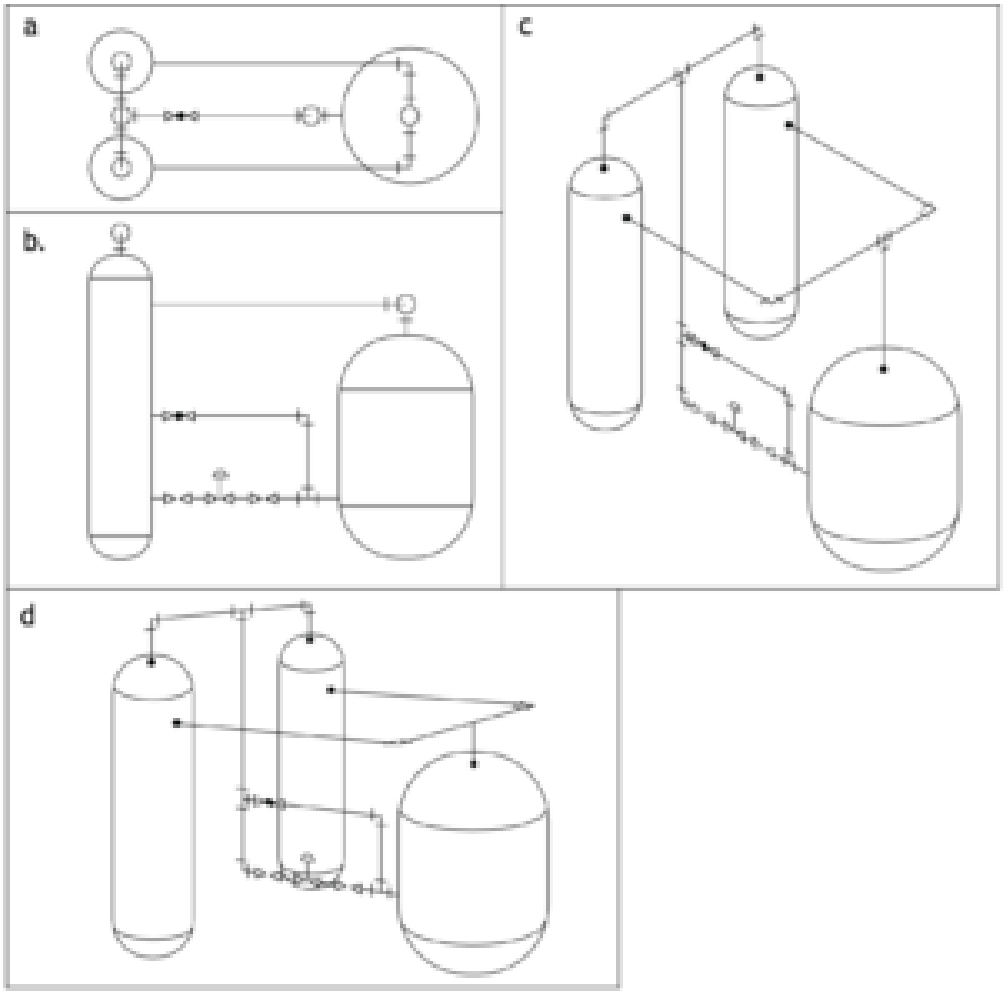


Figure 1 *Image for question 1*

2. The left-right and the back-front axes of isometric drawings are drawn
    a. 30° from the horizontal
    b. 30° from the vertical
    c. 45° from the horizontal
    d. 45° from the vertical
3. An isometric drawing showing 45° fittings and pipes can be drawn to scale.
    a. true
    b. false
4. One advantage of isometric projections is that
    a. they show perspective

b. they pinpoint the exact location of equipment
c. if the drawing is to scale, all the items are to scale
d. the drawing is three dimensional

5. Convert the orthographic projections to an isometric projection.

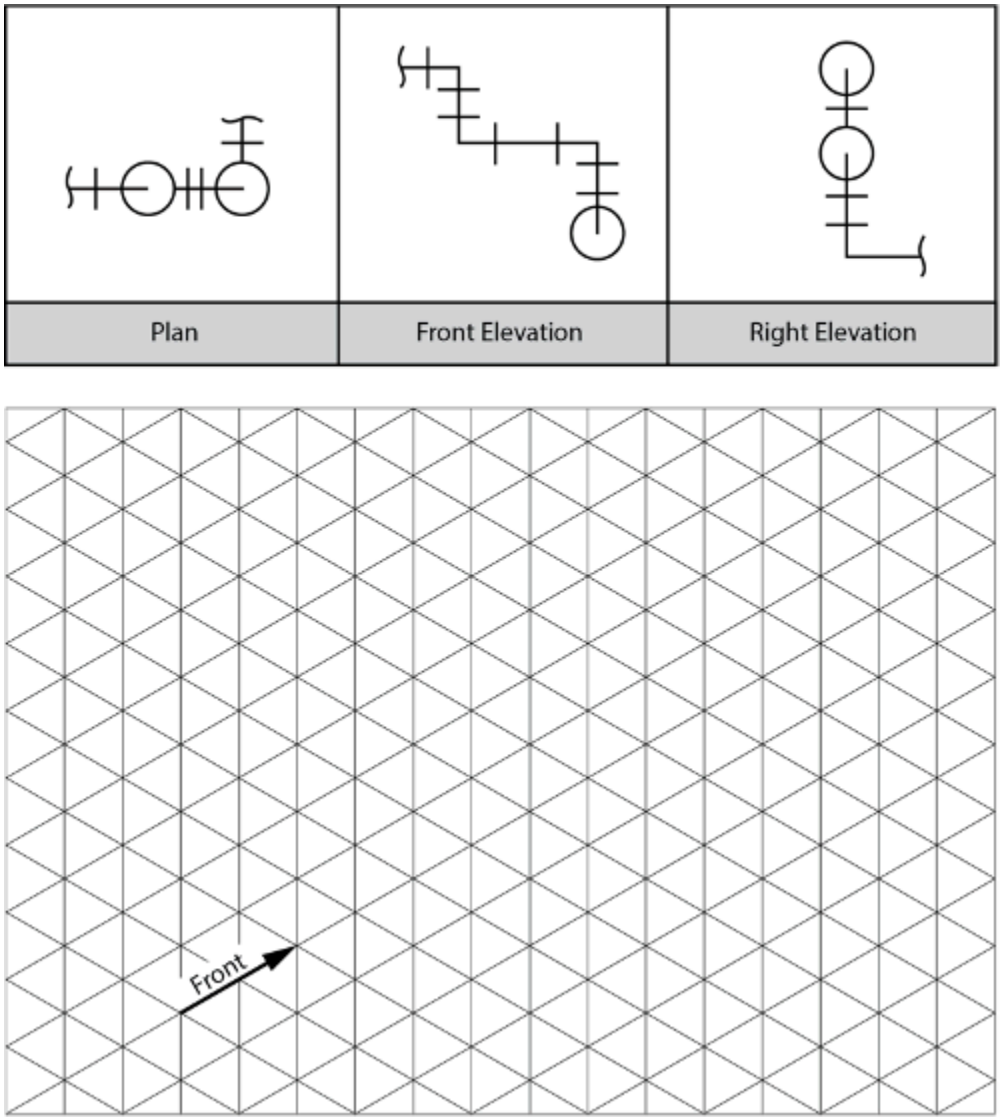


Figure 2 *Image for question 5*

6. Convert the orthographic projections to an isometric projection.

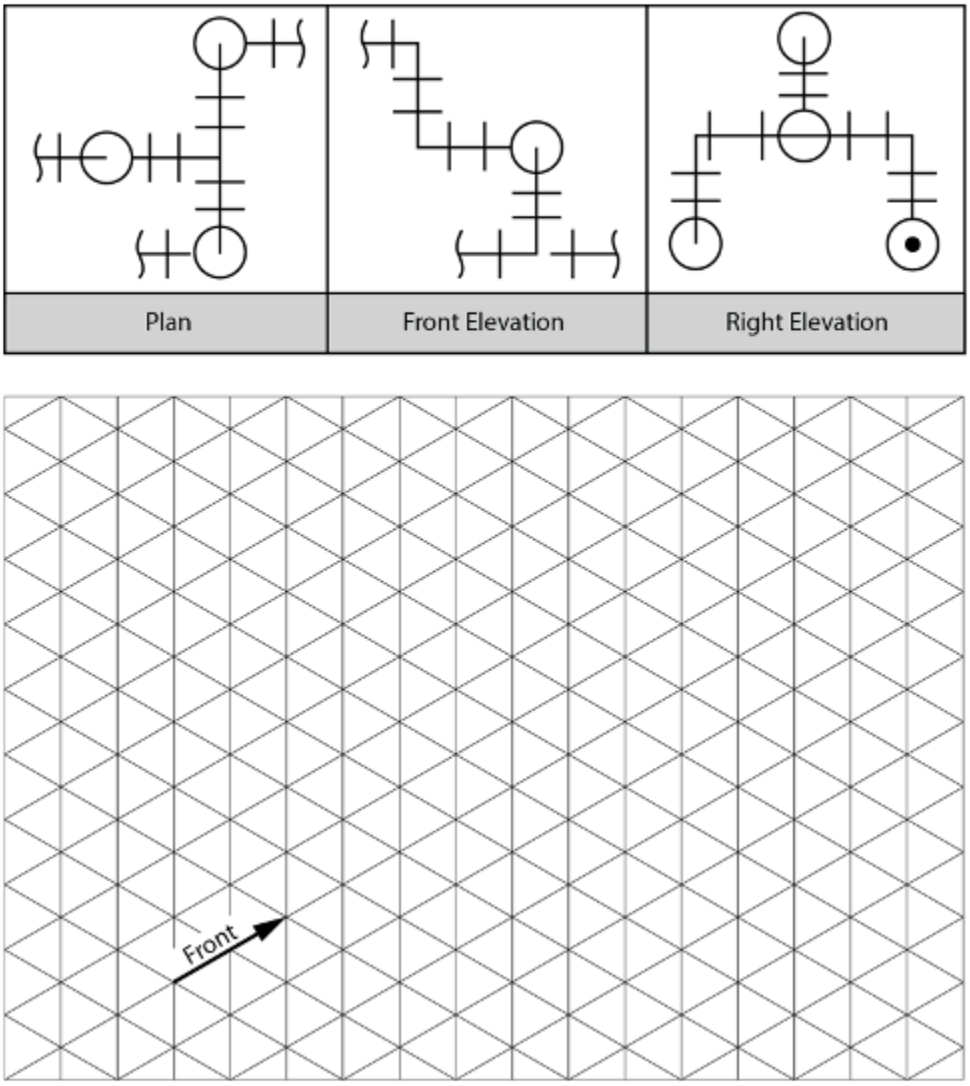
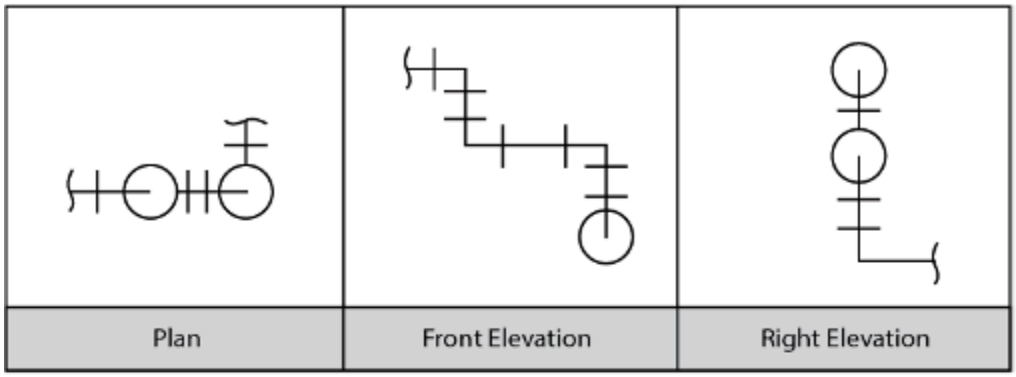


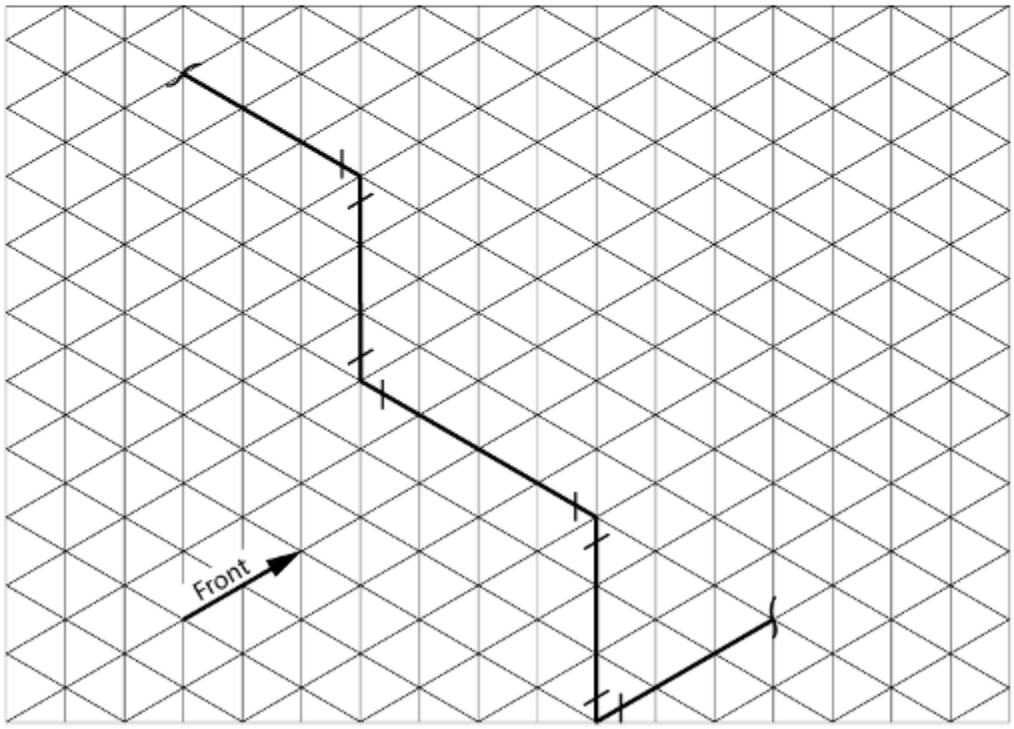
Figure 3 *Image for question 6*

Answer Key: Self-Test C-3.6.2 is on the other page.

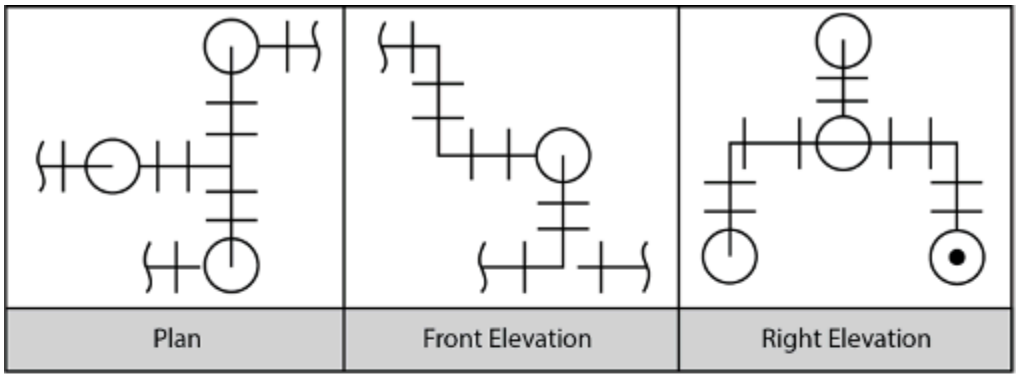
Answer Key: Self-Test C-3.6.2

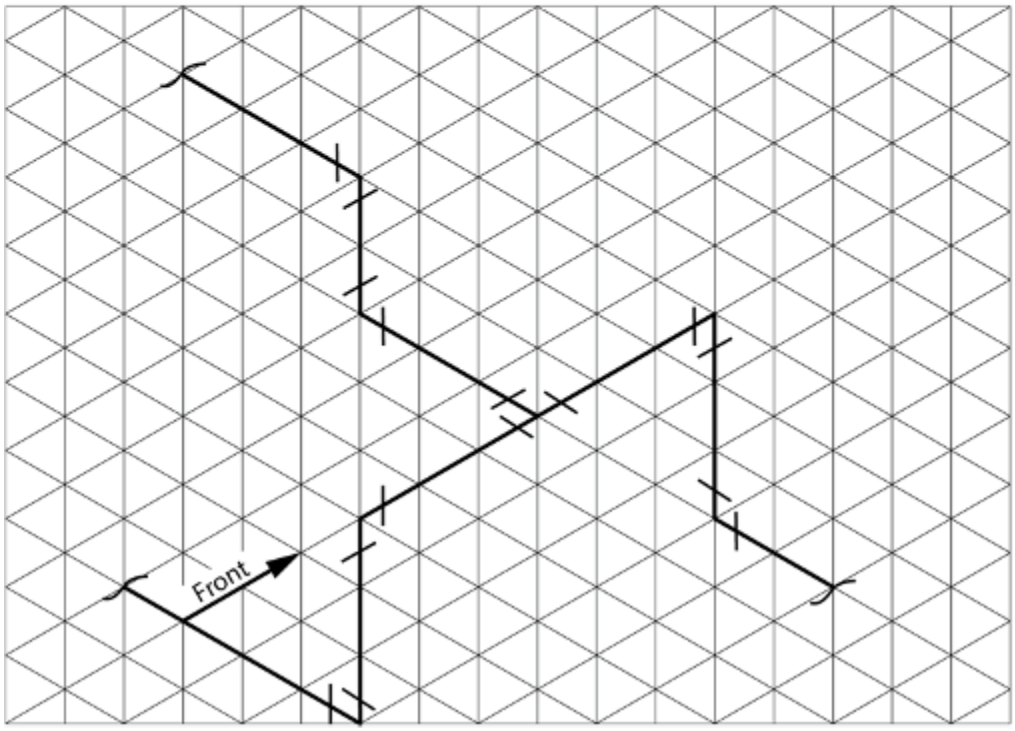
1. Which of the following is an isometric diagram?
    a. C
2. The left-right and the back-front axes of isometric drawings are drawn
    a. 30° from the horizontal
3. An isometric drawing showing 45° fittings and pipes can be drawn to scale.
    a. false
4. One advantage of isometric projections is that
    a. the drawing is three dimensional
5. Convert the orthographic projections to an isometric projection.





6. Convert the orthographic projections to an isometric projection.





C-4 CODES, REGULATIONS AND STANDARDS

Plumber Apprenticeship Program – Level 1

Engineer with safety gear inspecting red industrial piping system indoors (Marianna Zuzanna/Pexels) Pexels License

C-4 Codes, Regulations and Standards Introduction

Codes, regulations, and standards play a critical role in the pipe trades by ensuring that work is safe, reliable, and meets legal and environmental requirements. They guide how systems are designed, installed, and maintained, and help protect both people and the environment.

In this section, you will learn about the organizations that develop these codes and standards, where they are applied in everyday trade work. Environmental agencies and health authorities play a key role in regulating sewage disposal systems to protect public health and water quality. In British Columbia, this includes provincial legislation, regional health authorities, and local permitting bodies. Understanding these requirements is essential for working to code, maintaining public health and safety, and meeting industry expectations.

Learning Objectives

After completing this section, you should be able to:

- Identify organizations, codes, and standards affecting the pipe trades.
- Describe where various codes and standards are encountered within the pipe trades.
- Identify environmental agencies with concerns related to sewage disposal.

Topic areas covered in this publication are in alignment with SkilledTradesBC Harmonized 2018 Program Outlines.

You will be required to reference publications and videos available online at WorkSafeBC.

In practice: The most commonly used documents in everyday plumbing work include the National Building Code of Canada, the CSA Gas Code, local permits, and Technical Safety BC regulations. The tables below summarize key codes, standards, and organizations you may encounter in the pipe trades.

Core codes and legislation (Canada and British Columbia)

Document or organization	What it is used for	Where you will see it
National Building Code of Canada (NBC)	Sets minimum requirements for building safety, construction, and occupancy	Design, construction, inspections
BC Public Health Act	Protects public health, including water and sewage systems	Onsite sewage, drinking water systems
BC Sewerage System Regulation and Standard Practice Manual	Governs design and installation of onsite sewage systems	Residential and rural plumbing
Safety Standards Act (BC)	Regulates installation and operation of technical systems	Gas, boilers, pressure systems
Gas Safety Regulation (Technical Safety BC)	Rules for installing and maintaining gas systems	Gas fitting work
Power engineers and pressure equipment regulation	Governs boilers, pressure vessels, and refrigeration systems	Industrial and commercial systems

CSA codes (Canada)

Document or organization	What it is used for	Where you will see it
CSA Gas Code (with BC variations)	Installation and safety requirements for gas systems	Daily gas work
CSA B51 and CSA B52	Standards for pressure vessels and refrigeration systems	Mechanical systems

Technical industry codes

Document or organization	What it is used for	Where you will see it
ASME B31 series (piping codes)	Design and construction of piping systems	Industrial piping
ASME Boiler and Pressure Vessel Code	Safety and design of pressure equipment	Boilers and pressure systems
ANSI and National Board codes	Inspection and safety requirements	Equipment inspection
API standards	Inspection and maintenance of piping and vessels	Oil, gas, and industrial work

Fire and safety codes

Document or organization	What it is used for	Where you will see it
NFPA codes (e.g., NFPA 85)	Fire prevention and safety systems	Combustion systems and safety compliance

Material and product standards

Document or organization	What it is used for	Where you will see it
ASTM International	Material testing and specifications	Product selection
ULC (Underwriters Laboratories of Canada)	Product safety testing and certification	Approved equipment
CGSB (Canadian General Standards Board)	National standards for products and systems	Materials, transport, safety
AWWA (American Water Works Association)	Standards for water systems and treatment	Water distribution systems

International standards

Document or organization	What it is used for	Where you will see it
ISO (International Organization for Standardization)	Global standards for products and systems	Manufacturing and international work

Sustainability frameworks

Document or organization	What it is used for	Where you will see it
LEED (Leadership in Energy and Environmental Design)	Green building certification and environmental performance	Design and construction projects

Local requirements and permits

Document or organization	What it is used for	Where you will see it
Municipal bylaws and permits	Legal approval and compliance for construction	All job sites
Building, plumbing, and gas permits	Ensure work meets code requirements	Daily trade practice
Authority having jurisdiction (AHJ)	Reviews and approves permits and inspections	Inspections and approvals

Terminology

The following terms may be used throughout this section. Note that some glossary terms may be in italics throughout the section content but are not included in this list. A complete list of terms for this section can be found in the **Glossary.**

- **authority having jurisdiction (AHJ):** The person or organization responsible for making sure rules, codes, and laws are followed. They have the power to approve work, inspect it, and enforce safety standards. (Section C-4.1)
- **building code:** A set of rules that tells you how buildings must be built to keep people safe. (Section C-4.1)
- **CANDU (Canada Deuterium Uranium):** A type of nuclear power system made in Canada that uses heat to make electricity. (Section C-4.1)

- **certification:** Proof that something meets certain rules or standards. (Section C-4.1)
- **code:** A set of rules that must be followed by law to keep people safe. (Section C-4.2)
- **compliance:** Following rules, laws, or standards. (Section C-4.1)
- **enforcement:** Actions taken to make sure rules are followed, such as fines or license suspension. (Section C-4.1)
- **harmonize:** To make different rules or systems work the same way. (Section C-4.1)
- **inspection:** A check to make sure work is done correctly and safely. (Section C-4.1)
- **Leadership in Energy and Environmental Design (LEED):** A system that rates how environmentally friendly a building is. (Section C-4.1)
- **permit:** Official permission to do work, like building or plumbing. (Section C-4.1)
- **pressure-retaining components:** A part (like a pipe or tank) that holds fluids under pressure safely. (Section C-4.1)
- **public health:** The health and safety of people in a community. (Section C-4.1)
- **regulation:** A rule made by a government that must be followed. (Section C-4.1)
- **standards organization:** A group that creates rules and guidelines for industries; e.g., ANSI, ASME, ASTM, CSA, UL. (Section C-4.1)
- **sustainability:** Using resources in a way that protects the environment for the future. (Section C-4.1)

C-4.1 Identify Organizations, Code and Standards Affecting the Pipe Trades

Building codes are legally adopted ***regulations***, while ***standards*** are technical documents referenced by codes to define acceptable materials, methods, and performance.

A ***standards organization's*** primary activities are developing technical codes and standards that address industry needs. The main purpose of building codes is to protect ***public health***, safety, and general welfare, as they relate to the construction and occupancy of buildings and structures. A ***standard*** is a document that provides requirements, specifications, guidelines, or characteristics that ensure materials, products, processes, and services are fit for their intended purpose. Standards in the construction industry cover a range of topics, but they are usually in one of the following categories:

- **Test or measurement standards**, which provide information on the acceptability (pass/fail) in a performance category, usually under some standard condition (fire separation ratings), or provide data that can be used to determine acceptability or performance.
- **Procedural standards,** which describe how products or systems are to be installed, used, maintained, tested, or operated to be safe, reliable, and fit for the intended use.

As tradespeople, we come into contact with code requirements and standards every day. Due to their importance, a construction industry without them is almost unimaginable.

Organizations

The following are some of the organizations that issue codes and standards for our industry and the areas they oversee.

American National Standards Institute

The American National Standards Institute (ANSI) has served as coordinator of the voluntary standardization system for the US private sector for more than 90 years.

ANSI establishes the procedures that are the basis for the development of American national standards. They then accredit standards-developing organizations that operate in accordance with these procedures and approve their draft standards, provided they are developed via this process.

A recent example of this accreditation process occurred when ANSI-accredited the American Society of Safety Engineers (ASSE). The ANSI/ASSE A10 Construction Package is a comprehensive compilation of the ANSI/ASSE A10 series of construction safety standards, which includes more than 30 construction and demolition standards.

American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) publishes a well-recognized series of standards and guidelines relating to HVAC systems and issues. These standards are often referenced in building codes and are considered useful standards for use by consulting engineers, mechanical contractors, architects and government agencies. These are legally unenforceable, except when referenced as mandatory provisions in building codes, but they are commonly accepted standards for architects and engineers.

American Society of Plumbing Engineers

The American Society of Plumbing Engineers (ASPE) is a non-profit association dedicated to the advancement of the science of plumbing engineering, to the professional growth and advancement of its members and to the health, welfare and safety of the public.

ASPE is a member of and approved by ANSI as an ANSI-accredited standards developer. As such, ASPE may submit standards for approval by ANSI's Board of Standards Review as meeting certain criteria regarding due process in development to be designated American National Standards.

ASPE provides plumbing engineers and designers with ways to enhance their skills and knowledge through research and education.

American Society for Testing and Materials

The American Society for Testing and Materials (ASTM) is a group of voluntary members who test and certify standards of materials and procedures. It is now international in range and is currently known as ASTM International. ASTM standards apply to a large area of products and technology in over 130 industries. ASTM standards have made product selection easier for a wide variety of products and techniques, such as steel classifications.

The standards produced by ASTM International fall into six categories:

- The Standard Specification, which defines the requirements to be satisfied by the subject of the standard.
- The Standard Test Method, which defines the way a test is performed and the precision of the result. The result of the test may be used to assess ***compliance*** with a Standard Specification.
- The Standard Practice, which defines a sequence of operations that, unlike a Standard Test Method, does not produce a result.
- The Standard Guide, which provides an organized collection of information or series of options that does not recommend a specific course of action.
- The Standard Classification, which provides an arrangement or division of materials, products, systems or services into groups based on similar characteristics such as origin, composition, properties or use.
- The Terminology Standard, which provides agreed definitions of terms used in the other standards.

ASTM has a dominant role among standards developers in the USA and claims to be the world's largest developer of

standards. The quality of the standard test methods is such that they are frequently used worldwide, even in places where ASTM specifications are not required.

American Water Works Association

The American Water Works Association (AWWA) is the largest non-profit scientific and educational association dedicated to managing and treating water. AWWA is the only organization dedicated strictly to the interest of people in the waterworks field. Its publications, committee studies, reports and standard specifications are all of great value, as is the opportunity to interact and exchange ideas with others in the profession.

Currently, there are over 150 AWWA standards covering filtration materials, treatment chemicals, disinfection practices, meters, valves, utility management practices, storage tanks, pumps, ductile iron, steel, concrete, asbestos-cement, and plastic pipe and fittings. Standing committees periodically review and update the standards as required.

The International Organization for Standardization (ISO)

The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from more than 145 countries. ISO is a non-governmental organization established in 1947 and based in Geneva, Switzerland. Its mission is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological and economic activity. ISO's work results in international agreements that are published as International Standards and other types of ISO documents.

Out of 19,400 standards from almost all sectors of business and technology, more than a hundred come from ISO technical committee ISO/TC 59, Buildings and Civil Engineering Works. In addition, many other ISO technical committees have developed standards and related technical documents on construction products.

Standards Council of Canada

The Standards Council of Canada (SCC) is a federal Crown corporation. Its mandate is to promote efficient and effective standardization in Canada. *Standardization* is the development and application of standards publications that establish accepted practices, technical requirements and terminologies for products, services and systems. Standards help to ensure better, safer and more efficient methods and products, and are an essential element of technology, innovation and trade. SCC carries out a variety of functions intended to ensure the effective and coordinated operation of standardization in Canada. It also represents Canada's interests on standards-related matters in foreign and international forums.

The designation *National Standard of Canada* indicates that a standard is recognized as the official

Canadian standard in a particular subject area or topic. Before a standard can become a national standard, it must be approved by the SCC. Inclusion of the abbreviation CAN in the prefix of the standard's reference number indicates that a particular standard has been designated a National Standard of Canada.

Canadian Construction Code Development

Canada's model construction and fire codes are developed through a national process supported by the National Research Council (NRC). Historically, the **Canadian Commission on Building and Fire Codes (CCBFC)** oversaw code development, working with technical committees and receiving policy input from provinces and territories.

In 2022, the Canadian Board for Harmonized Construction Codes (CBHCC) was established to replace the CCBFC. The CBHCC works with federal, provincial, and territorial governments to improve coordination and ***harmonize*** construction codes across Canada, while continuing to support stakeholder input from industry and the public.

Table 1: Old vs. New Code Development Structure

Aspect	Previous Model (CCBFC)	Current Model (CBHCC)
Governance	Canadian Commission on Building and Fire Codes (CCBFC)	Canadian Board for Harmonized Construction Codes (CBHCC)
Policy Input	Provincial/Territorial Policy Advisory Committee on Codes (PTPACC)	Integrated federal–provincial–territorial governance
Technical Development	Standing committees and task groups	Committees and working groups under CBHCC
Focus	National model codes with provincial input	**Harmonization across jurisdictions**
Role of NRC	Supported development and published codes	Continues to support development and publication
Stakeholder Participation	Industry and public input through committees and public review	Continued stakeholder input through consultations and review processes

Canadian Gas Association

Founded in 1907, the Canadian Gas Association (CGA) is the voice of Canada's natural gas distribution industry. Members include distribution companies, transmission companies, equipment manufacturers and other service providers.

CGA produces and maintains a range of publications, background information, presentations and statistics on natural gas and the natural gas distribution industry. As well, CGA develops educational information and organizes training schools, workshops, seminars and conferences.

They sponsor and participate in a number of forums, partnerships and coalitions to foster dialogue on energy policy and achieve a better understanding of natural gas.

Canadian General Standards Board (CGSB)

The Canadian General Standards Board (CGSB) has historically been one of Canada's largest standards development and conformity assessment organizations. It provided services such as standards development, product and service ***certification***, and the registration of quality and environmental management systems. These activities supported economic, regulatory, procurement, health, safety, and environmental interests across government, industry, and the public.

CGSB developed and maintained more than 900 standards through committees of volunteer experts, covering a wide range of areas, including building construction and the transportation of dangerous goods.

Recent Update (2026)

As of April 1, 2026, CGSB has ceased offering standards development and conformity assessment services. However, its existing standards remain available and can be accessed free of charge through the CGSB catalogue. While CGSB no longer develops new standards, its existing standards continue to be used as reference documents in industry and regulatory contexts.

Canadian Standards Association

Figure 1 CSA *certification mark.*

The Canadian Standards Association (CSA) is the largest standards development organization (SDO) in Canada, with the widest subject area recognition. They have published more than 3000 standards and codes addressing subjects that affect the interests of industry, consumers, regulators and the public at large.

The Canadian Standards Association is a not-for-profit standards organization that develops standards in over 50 areas, including:

- Safety and performance standards for electrical and electronic equipment
- Industrial equipment
- Boilers and pressure vessels
- Compressed gas handling appliances
- Environmental protection
- Construction materials
- Selection and installation of backflow preventers

Most standards are voluntary, meaning there are no laws requiring their application. Despite that, adherence to standards is beneficial to companies because it shows products have been independently tested to meet certain standards. Some standards are referenced in codes and regulations, which then makes them law. The CSA mark (Figure 1), like many certification marks, is a registered certification logo and can only be applied by someone who is licensed or otherwise authorized to do so by the CSA.

Laws and regulations in most municipalities, provinces and states in North America require certain products to be tested to a specific standard or group of standards by a Nationally Recognized Testing Laboratory. Currently 40 percent of all the standards issued by CSA are referenced in Canadian legislation. CSA's sister company, CSA International, is a Nationally Recognized Testing Laboratory (NRTL) that manufacturers can choose, usually because the law of the jurisdiction requires it or the customer specifies it.

National Fire Protection Association

The National Fire Protection Association (NFPA) is an international non-profit organization with the mission of reducing the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training and education.

The world's leading advocate of fire prevention and an authoritative source on public safety, NFPA develops, publishes and circulates more than 300 consensus codes and standards intended to minimize the possibility and effects of fire and

other risks. As part of its commitment to eliminate fire deaths and injuries through effective public education programs and information, NFPA strives to be the definitive source for fire and life safety information.

UL Solutions (formerly Underwriters Laboratories of Canada – ULC)

UL Solutions is an independent product safety testing, ***inspection***, and certification organization operating in Canada and globally. In Canada, this work was historically carried out by Underwriters Laboratories of Canada (ULC), which has been testing products for public safety for over 100 years. UL Solutions in Canada is accredited by the Standards Council of Canada (SCC) and plays a key role in the Canadian National Safety System. It evaluates a wide range of products, components, materials, and systems to ensure they meet established safety and performance requirements.

Standards development is now carried out through UL Standards & Engagement (ULSE Inc.), an independent, not-for-profit organization that develops consensus-based safety and performance standards using input from industry, government, and the public. Today, UL Solutions supports manufacturers in bringing safer products to Canadian and global markets through testing, certification, and standards development. Its certification marks (such as the ULC mark) are widely recognized as indicators of product safety and compliance.

Municipal Bylaws

Depending on the scope of work, you may need a building permit, a development permit, or both.

Building Permits

You need a building permit if you plan to:

- Construct a new building
- Make additions or structural changes to an existing building
- Renovate, repair, or demolish a building
- Change a building's use
- Build a garage, balcony, or deck
- Excavate a basement or construct a foundation

Plumbing and Gas Permits

Plumbing and gas permits are required for the construction of all associated systems and must be obtained *before* construction begins.

A plumbing permit is required if you:

- Install, change, or upgrade any part of a plumbing system
- Open walls

- Change other plumbing or move pipes
- perform major repairs

If your company is a licensed gas contractor, you require a gas permit to install or replace a gas-fired appliance like a fireplace, hot water tank, boiler, furnace or kitchen stove. A permit is also required if you are installing or altering the associated gas pipes and appliance vents.

If you are constructing a new dwelling, a building permit will be required prior to a gas or plumbing permit being issued. A plumbing permit is NOT required for clearing of stoppages or the repairing of leaks in pipes, valves or fixtures.

Plumbing permits are issued by your local municipal building department. Gas permits are typically issued by Technical Safety BC (previously known as the British Columbia Safety Authority [BCSA]). In some instances, gas installation permits might also be offered by municipal departments.

The permit process is generally the same for all types of projects, but more specific requirements may be required for some commercial construction and industrial projects.

Permit Process

Permit Application

A completed permit application must be submitted before work begins. Permit applications are available through the ***authority having jurisdiction (AHJ)***. Typical information required includes who will perform the work, and what, where, and how the work will be completed. Drawings, plans, or other documentation of the proposed work may be required. Permit fees are usually due at the time of application.

Review Process

During the review process, staff officials will determine if the project is in compliance with the applicable codes and other local ordinances and statutes. The length of the review process will depend on the type and complexity of the project. Many small residential applications can be processed in one day.

Permit Approval

If the project meets all requirements, the permit application is approved. Once all final permit fees are paid, the permit is issued.

However, if the permit application is not approved or a review has determined that a project fails to meet the requirements, the permit application, as submitted, will be denied. When a permit application is denied, corrections to the application shall be made and the application is resubmitted for final approval.

Permit Execution

Construction

During the entire construction phase, the permits must be placed in a prominent place at the project site. A copy of the approved building plan and other related documents must also be maintained at the site.

Inspections

Each major phase of construction must typically be inspected by an inspector or similar authority to make certain the work conforms to the code, the permit and the approved plans. Inspection requests may be made via internet, by phone or in person. Normally, the response is one business day after the request is made.

If an inspector finds that work does not conform to the approved plans, the inspector will fail the inspection and provide comments. Another inspection will be necessary before work is resumed. Reinspections can cause project delays and unnecessary expense.

Field Changes

Most changes will require a review and approval in the same manner as the original application. Proposed revisions or alterations must be brought to the attention of the permit staff before making changes in the field.

Project Completion

When the project is completed and code compliance is determined, the inspector issues a final inspection. The final inspection marks the completion of the project and grants permission to occupy a building with the knowledge that it has met the minimum safety standards as required by code.

Codes, Standards, Acts, and Regulations

National Building Code of Canada

The National Building Code (NBC) is the model building code that forms the basis for all of the provincial building codes. Some jurisdictions create their own code based on the NBC, while other jurisdictions have adopted the NBC, often adding supplementary laws or regulations.

The intent of the NBC is to detail the minimum provisions acceptable to maintain the safety of buildings, with specific regard to public health, fire protection, accessibility and structural sufficiency. It is not a textbook for building design. The building code concerns construction, renovation and demolition. It also covers change-of-use projects where the

change would result in increased hazard and/or maintenance and operation in the existing building. The code sets out technical requirements for the aforementioned project types and does not pertain to existing buildings.

British Columbia *Public Health Act* (Ministry of Health)

The Ministry of Health is a provincial organization that provides guidance to health authorities and develops legislation, policy and guidelines in all areas that concern public health. In the piping trades we follow the guidelines from the *Public Health Act* when installing and servicing onsite sewage and private drinking water systems, for example.

BC Sewerage System Regulation

- The Sewerage System Regulation replaces the old Sewage Disposal Regulation (2005). This regulation, along with the companion document, the Sewerage System Standard Practice Manual (SPM), Version 3(PDF, 7.6MB), shifts the focus of managing onsite sewerage systems by using an outcome-based approach to wastewater management. This is intended to allow for greater flexibility in how the systems are regulated.
- An onsite sewerage system is usually located on the land from which sewage originates. This type of system locally treats effluent that is not serviced by a larger municipal or regional sewerage system.
- The Sewerage System Regulation, under the *Public Health Act*, covers holding tanks for sewage effluent or onsite sewerage systems that:
- process a sewage flow of less than 22,700 litres per day
- serve single-family systems or duplexes
- serve different buildings on a single parcel of land
- serve one or more parcels on strata lots or on a shared interest of land
- The regional health authorities are responsible for accepting applications and fees for onsite sewerage systems submitted by homeowners or, on their behalf, by industry professionals. Onsite sewerage systems are installed, repaired and maintained by authorized persons.
- Site investigations of sewerage systems may be initiated in cases where systems are suspected to be negatively affecting a drinking water supply (e.g., as a result of system failure) or causing a health hazard, as per the *Public Health Act*.

Safety Standards Act

The *Safety Standards Act* sets out the general requirements for regulated work performed by contractors involved in the operation and installation of technical systems and equipment. It also includes information on the legal requirements for permits and qualifications. The *Safety Standards Act* authorizes the British Columbia Safety Authority to take ***enforcement*** actions if they discover a non-compliance with the act or regulations.

Products and work regulated under the act include:

- Boilers and boiler systems
- Electrical systems and equipment
- Elevating devices and passenger conveyors
- Gas systems and equipment

- Pressure vessels, pressure piping, refrigeration systems and equipment
- Amusement rides
- Ski lifts

Gas Safety Regulation—Technical Safety BC

The Gas Safety Regulation applies to everyone who installs, alters, maintains, or operates gas technologies.

Technical Safety BC administers and enforces the Gas Safety Regulation in British Columbia. This includes issuing permits, licensing contractors and gas fitters, conducting inspections, and ensuring that gas systems and equipment are installed and operated safely in accordance with applicable codes and regulations.

All licensed contractors and gas fitters are required to keep up to date with changes in the act and regulations. Contractors and gas fitters must have access to a current edition of the Canadian CSA Gas Code and BC Variations to the National Code.

Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation

The Power Engineers, Boilers, Pressure Vessel and Refrigeration Safety Regulation applies in respect of every boiler and boiler plant, every pressure plant, every pressure vessel, every pressure piping system, every fitting, every plant and all refrigeration equipment and refrigeration plants. This regulation has many other agency-adopted national codes and standards listed below:

American Society of Mechanical Engineers (ASME)

a. ASME B31.1 Power Piping
b. ASME B31.3 Process Piping
c. ASME B31.5 Refrigeration Piping and Heat Transfer Component
d. ASME B31.9 Building Services Piping
e. ASME B31.11 Slurry Transportation Piping Systems
f. ASME PTC 25 Pressure Relief Devices

American National Standards Institute and National Board of Boiler and Pressure Vessel Inspectors (ANSI/NB)

a. ANSI/NB-23 National Board Inspection Code
b. ANSI K61.1-1999/CGA G-2.1-1999 Safety Requirements for the Storage and Handling of Anhydrous Ammonia

American Petroleum Institute (API)

The following are adopted:

a. API STD 530 Calculation of Heater-Tube Thickness in Petroleum Refineries
b. API 510 Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration
c. API 570 Piping Inspection Code: Inspection, Repair, Alteration and Rerating of In-Service Piping Systems.

American Society of Mechanical Engineers and American National Standards Institute (ASME/ ANSI)

a. ASME Section I—Rules for Construction of Power Boilers
b. ASME Section IV—Rules for Construction of Heating Boilers
c. ASME Section VIII—Rules for Construction of Pressure Vessels
d. ASME Section X—Fibre-Reinforced Plastic Pressure Vessels 2013 Edition
e. ASME Section XII—Rules for Construction and Continued Service of Transport Tanks
f. ASME CSD-l- Controls and Safety Devices for Automatically Fired Boilers
g. ASME/ANSI PVHO-1 Safety Standard for Pressure Vessels for Human Occupancy
h. ASME QAI-1-2010 Qualifications for Authorized Inspection

Canadian Standards Association (CSA)

a. CSA B51-09 Boiler, Pressure Vessel, and Pressure Piping Code
b. CSA B52-05 (R2009) Mechanical Refrigeration Code
c. CSA N285.0-08/N285.6 Series-08

General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants and Material Standards for Reactor Components for CANDU Nuclear Power Plants.

CANDU (*Canada Deuterium Uranium*) reactors are a type of nuclear power system used to generate electricity by producing steam to drive turbines. Like other large-scale industrial systems, they rely on complex networks of pipes, valves, and ***pressure-retaining components*** to safely transport water and steam under high pressure and temperature.

To ensure safety and performance, these systems must comply with strict codes and standards.

The following codes and standards are adopted:

- NFPA 85, Boiler and Combustion Systems Hazards Code
- Tubular Exchanger Manufacturers Association (TEMA) standards

Safety Orders, Directives and Information Bulletins

- ***Safety orders*** are instruments that are issued to prevent or reduce the risk of personal injury or damage to property. Compliance is mandatory and enforceable by the Safety Authority.
- ***Directives*** are instruments that clarify or provide new interpretation of a regulation or code. Compliance is mandatory.
- ***Information bulletins*** provide helpful information and clarification on existing regulations or code that affect your particular technology.

Non-Compliance Enforcement Process

- An enforcement action typically begins with the safety officer. The safety officer is an employee/ inspector working for TSBC in British Columbia, who may address a non-compliance by suspending a ***permit***, issuing a compliance order, or recommending that a safety manager impose a monetary penalty.
- The next step involves the provincial safety manager, also within Technical Safety BC, who may impose more significant sanctions such as monetary penalties or suspending contractors' licences or certificates of qualification. Enforcement decisions by safety officers and safety managers are generally subject to review or appeal.
- The Safety Standards Appeal Board is created under the *Safety Standards Act*. It is this appeal board that can review certain TSBC decisions when clients request a review.

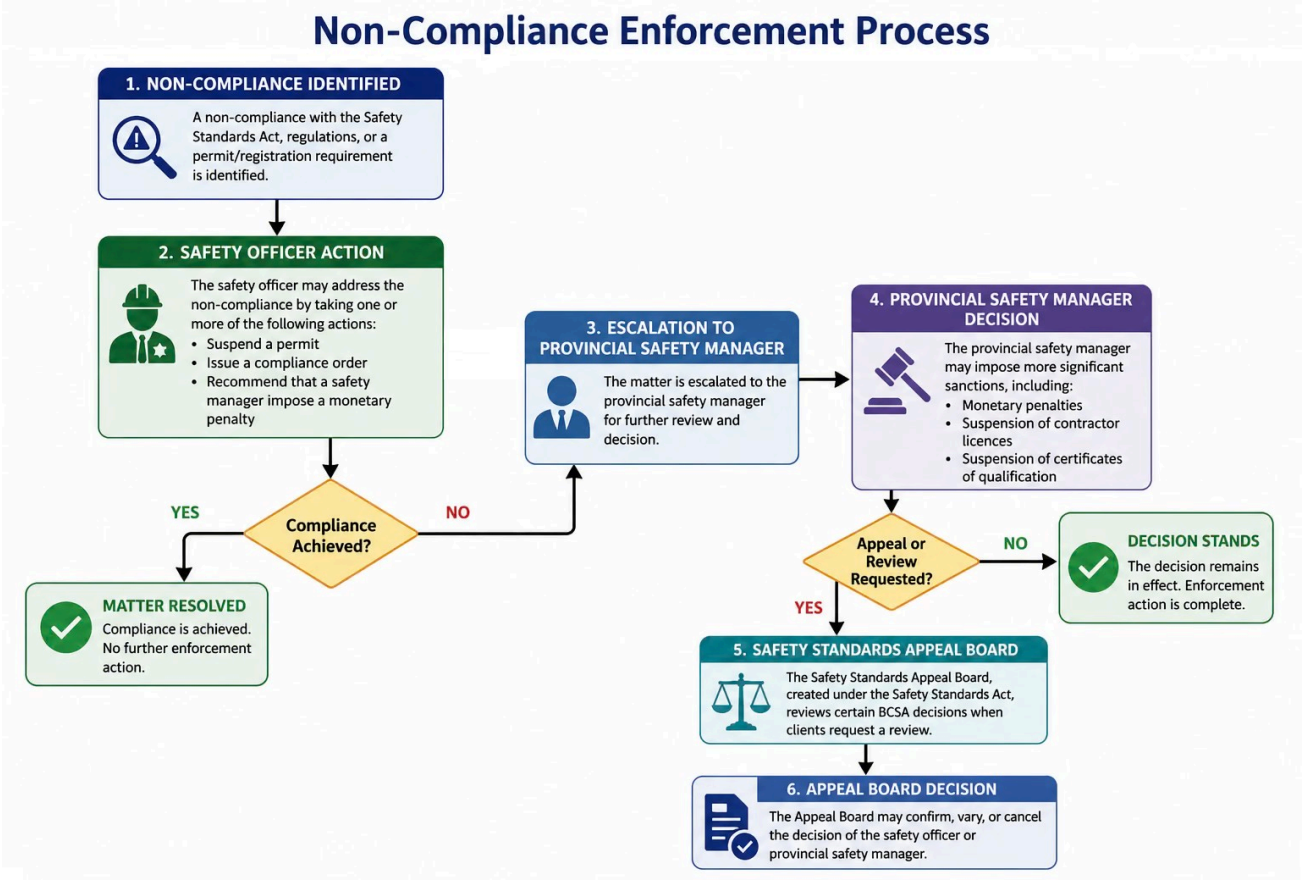


Figure 2 *Non-compliance enforcement process (TRU Open Press/OpenAI) CC BY-NC-SA*

Leadership in Energy and Environmental Design

- ***Leadership in Energy and Environmental Design (LEED)*** is a program developed by the US Green Building Council to certify environmentally responsible and sustainable buildings. It comprises a suite of rating systems for recognizing best-in-class sustainable design, construction, and operation of high-performance green buildings, homes, and neighbourhoods.
- It provides third-party verification of green building projects that satisfy prerequisites and earn points to achieve different levels of certification. Prerequisites and credits differ for each rating system, and teams choose the best fit for the project.
- The program addresses the following types and scopes of projects:
    - New construction and major renovation
    - Core and shell
    - Schools
    - Hospitality
    - Data centres
    - **Retail:** new construction and major renovations / **retail:** commercial interiors
    - Health care
    - Commercial interiors
    - Existing buildings: operations and maintenance

    - Homes and multi-family dwellings
    - Neighbourhood development
- LEED rating systems generally have 100 base points plus six "Innovation in Design" points and four "Regional Priority" points, for a total of 110 points (LEED for Homes is based on a 125-point scale, plus 11 Innovation in Design points). Each credit is allocated points based on the environmental impacts, ***sustainability*** outcomes, and human benefits that the building addresses. Projects achieve certification if they earn points according to the following levels:
    - **Certified:** 40–49 points
    - **Silver:** 50–59 points
    - **Gold:** 60–79 points
    - **Platinum:** 80+ points
- LEED also offers professional credentials for those in the industry who wish to document their knowledge of current sustainability and green building principles. LEED Green Associate and LEED AP accreditations are sought after when developing design teams for LEED projects.

Why This Matters for Plumbing Students

Plumbing systems directly impact:

- **Water efficiency** (low-flow fixtures, reuse systems)
- **Environmental impact** (less waste, energy use)

Many job sites (especially commercial) require LEED standards
You may install:

- High-efficiency fixtures
- Greywater or rainwater systems
- Energy-efficient hot water systems

Self-Test C-4.1: Identify Organizations, Code, and Standards Affecting the Pipe Trades

Complete Self-Test C-4.1 and check your answers.

If you are using a printed copy, please find Self-Test C-4.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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- **Figure 1** CSA *certification mark* is used with permission from CSA.
- **Figure 2** Non-compliance enforcement process was created by TRU Open Press using OpenAI (2026) as is subject to the CC BY-NC-SA license.

C-4.2 Describe Where the Various Codes and Standards are Encountered Within the Pipe Trades

Codes and Standards

There is a unique difference between ***codes*** and ***standards*** used in the plumbing and pipe trades industry. Unlike standards, which typically define best practices for products, services, and processes, codes are often adopted by government regulatory bodies to address safety concerns for consumers and businesses.

Codes are developed as ***regulations*** that can be adopted by regulatory authorities. In general, they are much broader in scope than a standard and cover a wider range of issues. They are also designed to be given the force of law by the various provinces, territories, and jurisdictions in which they are adopted.

Standards are normally narrower in scope, cover a limited range of issues, and are given the force of law when referenced in an adopted code or jurisdictional regulation. Codes often reference other standards, giving them additional visibility and importance within the industries in which they are used.

In the pipe trades, there are many codes and standards that we must reference. Working with some of these documents will be an everyday occurrence, while others will be project-specific. It is important to know that these documents exist and what types of mechanical systems they address.

Canadian Standards Association—Construction Program

The Canadian Standards Association is Canada's leading developer of codes, standards, and related publications in the field of construction. Many of these standards are referenced in various regulations and codes. Documents can be accessed from the CSA website under the following categories and subcategories:

- Concrete
- National construction codes
- Offshore structures
- Structures (design)
- Welding
- Building products and systems
- Plumbing products and materials
- Forest products
- Masonry

British Columbia Building Code

The BC Building Code (BCBC) contains specific requirements in the following categories:

- Fire safety based on construction type, separation distances and occupancy(ies)
- Life safety for occupants based on construction type and occupancy(s)
- Structural integrity based on expected loads
- Approved materials
- Accessibility features
- Energy efficiency features

There are several mechanical issues to be addressed for new buildings, additions, and major renovations to be BCBC-compliant. These include:

- Energy calculations
- Exhaust systems
- Ventilation requirements
- Makeup air
- Roof-mounted equipment anchorage design
- Minimum plumbing facilities
- Fixture requirements

British Columbia Plumbing Code

The BC Plumbing Code (BCPC) applies the core concepts of the National Plumbing Code, combined with elements specific to BC's unique needs, and sets out technical provisions for the design and installation of new plumbing systems. It also applies to the extension, alteration, renewal, and repair of existing plumbing systems.

The BCPC provides the minimum requirements for systems, including:

- Water supply piping location, size, and material
- Sanitary drainage location and sizing
- Specifications for water heater(s) and associated features
- Vent sizing and location
- Roof drainage calculations, and roof primary and secondary drain locations
- Backflow prevention specification, and location of backflow devices
- Irrigation
- Location of water supply line relative to sanitary drain lines
- Grease traps

BC Fire Code

The BC Fire Code contains technical requirements designed to provide an acceptable level of fire safety within a community. It applies the core concepts of the National Fire Code of Canada, combined with elements specific to BC's unique needs. It sets out the technical provisions regulating:

- Activities related to the construction, use, or demolition of buildings and facilities
- The condition of specific elements of buildings and facilities
- The design or construction of specific elements of facilities related to certain hazards

- Protection measures for the current or intended use of buildings.

CSA B51—Boiler, Pressure Vessel, and Pressure Piping Code

Boilers, pressure vessels, pressure piping, and fittings pose potential health and safety risks if they are not designed, installed, operated, and/or maintained. CSA B51 covers the safe design, construction, installation, operation, inspection, testing, and repair practices for these systems.

CAN/CSA B214-21—Installation Code for Hydronic Heating Systems

The purpose of this code is to establish uniformity in the installation of hydronic heating systems. CAN/ CSA B214:21 (R2025) also provides a reference point showing that proper installation of hydronic heating systems will lead to good performance, serviceability, and longevity.

CSA B149.1—Natural Gas and Propane Installation Code

CSA B149.1 targets Canadian gas and propane industry workers. It is intended to protect public health and safety for all building systems that use fuel gas. It addresses system design, installation, and inspection of such systems by providing minimum safeguards and corresponding safety requirements. It has been reviewed by regulatory authorities across Canada and has been adopted into law in every Canadian province and territory. CSA B149.1 applies to the installation of:

- Appliances, equipment, components, and accessories where gas is to be used for fuel purposes
- Piping and tubing systems
- Vehicle-refuelling appliances and associated equipment
- Stationary gas engines and turbines

Canadian Electrical Code

The BC Gas Safety Regulation (Section 8) states that:

> 8 (1) *The holder of a class A or class B gas fitter's certificate of qualification may, while employed by a licensed gas contractor or working under an operating permit, perform electrical work that is restricted to the installation, repair and maintenance of electrical wiring for solid, liquid and gaseous-fuel-fired heating equipment . . .*

Because of this endorsement, gas fitters must be familiar with the electrical code (CSA C22.1:24) as it applies to branch circuit wiring serving gas-fired appliances.

CSA B64.10—Selection and Installation of Backflow Preventers/ Maintenance and Field Testing of Backflow Preventers

Improperly installed wastewater drainage systems can create bacterial or chemical contamination of the public water supply due to accidental backflow and exposure to discharge. The CSA B64.10 standard helps protect consumers from water contamination by specifying requirements and information on:

- The selection, installation, and field testing of backflow preventers
- How backflow occurs, including when caused by back siphonage and back pressure
- Selecting and applying specific devices

Western Canada Section—AWWA—Cross Connection Control Manual

This Cross Connection Control (CCC) Manual was developed by the Western Canada Section CCC Committee and contains information identifying:

- Legal, health, and plumbing aspects of cross connection control (CCC) in Canada
- Aspects of setting up a CCC program
- Causes of backflow
- Hazard classification, including methods of protection
- Typical hazards found on premises
- Maintenance and testing procedures for backflow assemblies
- Test equipment requirements

National Fire Protection Association (NFPA)®

The industry benchmark for design and installation of automatic fire sprinkler systems, NFPA addresses sprinkler system design approaches, system installation, and component options to prevent fire deaths and property loss. There are a number of codes that are based on the type of occupancy served by automatic sprinkler systems:

NFPA 13—Standard for the Installation of Sprinkler Systems

The NFPA 13 standard covers sprinkler system design, installation, and acceptance testing; hanging and bracing systems; underground piping; and seismic protection.

NFPA 13D—Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes

The NFPA 13D standard is the recognized residential sprinkler design standard focussed on one- and two- family

dwellings and manufactured homes. The intent is to provide an affordable sprinkler system in homes while maintaining a high level of life safety.

NFPA 13R—Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies

NFPA 13R is a residential sprinkler design standard focussed on low-rise residential occupancies. The standard's intent is to provide a sprinkler system that aids in the control of residential fires and provides improved protection against injury and loss of life in multi-family dwellings. This document addresses automatic sprinkler system design, installation, and maintenance, including component listing, hydrostatic tests, sprinkler temperature ratings, design documentation, above-ground pipe and equipment, underground pipe, pre-engineered systems, water supply sources, multipurpose piping systems, and hydraulic calculations.

NFPA 14

NFPA 14 provides requirements for the installation of standpipes and hose systems to ensure that systems will work as intended to deliver adequate and reliable water supplies in a fire emergency. The document covers all system components and hardware, including piping, fittings, valves, and pressure-regulation devices, as well as system requirements, installation requirements, design, plans and calculations, water supply, and system acceptance.

NFPA 96

NFPA 96 provides preventive and operative fire safety requirements intended to reduce the potential fire hazard of both public and private commercial cooking operations. The document covers the design, installation, operation, inspection, testing, and maintenance of the full spectrum of cooking equipment, hoods, grease removal devices, exhaust duct systems, fans, fire suppression systems, and clearance to combustibles.

Self-Test C-4.2: Describe Where the Various Codes and Standards are Encountered Within the Pipe Trades

Complete Self-Test C-4.2 and check your answers.

If you are using a printed copy, please find Self-Test C-4.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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C-4.3 Identify Various Environmental Agencies with Concerns to Sewage Disposal

Onsite Sewage Systems

Onsite sewage systems are effective at treating household sewage when properly designed and installed in appropriate soil and maintained regularly. In typical onsite sewage systems, the wastewater from toilets and other drains flows from your house into a tank that separates solids and scum from the liquid. Bacteria help break down the solids into sludge. The liquid flows out of the tank into a network of pipes buried in a disposal field of gravel and soil. Holes in the pipes allow the wastewater to be released into the disposal field. These systems can be efficient and cost-effective and can protect public health and the environment. However, they must be properly planned, installed, and, above all, properly maintained.

Enacted in 2005, the Sewerage System Regulation (SSR) applies to all smaller systems, including those for houses, small businesses, and even small community systems. Compared to the previous Sewage Disposal Regulation, the SSR includes a significant change in approach. The new approach is performance-based, and responsibility for the proper design and installation of onsite systems has been transferred for the most part from health authorities to "authorized persons," as defined by the SSR.

Organizations Concerned with Sewage Disposal

- **The Ministry of Health (Health Protection Branch):** Still plays a role in onsite systems by holding records of sewage systems and enforcing the regulations to protect public health.
- **BC Onsite Sewage Association (BCOSSA) and Western Canada Onsite Wastewater Management Association (WCOWMA)**: Develop educational programs for onsite wastewater practitioners and provide technical information to industry stakeholders and practitioners.
- **Applied Science Technologists and Technicians of BC (ASTTBC)**: The association for technology professionals in British Columbia. The ASTTBC also registers practitioners once they have obtained the required training.
    - **Onsite Wastewater Registration Program (ASTTBC)**: Provides information for onsite wastewater service providers.
- **Engineers and Geoscientists of British Columbia (EGBC)**: The licensing body for professional engineers and geoscientists. Only professional engineers and geoscientists are permitted to construct and/or maintain a Type 3 sewerage system.
- **BC Water and Waste Association (BCWWA)**: This organization supports over 3700 water and wastewater professionals in BC and the Yukon with training, educational opportunities, technology transfer and networking opportunities.
- **Local Governments (Municipal and Regional Governments in BC):** Provides links to regional and municipal governments in the province to help locate any pertinent bylaws under respective jurisdictions.

Self-Test C-4.3: Identify Various Environmental Agencies with Concerns to Sewage Disposal

Complete Self-Test C-4.3 and check your answers.

If you are using a printed copy, please find Self-Test C-4.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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Self-Test C-4.1: Identify Organizations, Code and Standards Affecting the Pipe Trades

Complete Self-Test C-4.1 and check your answers.

1. How many categories do the standards produced by ASTM International fall into?

Answer: _____

2. In Canada, before a standard can become a national standard, it must be approved by whom?

Answer: _____

3. What commission develops and maintains Canada's six model construction and fire codes?

Answer: _____

4. How many standards and codes has CSA published?

Answer: _____

5. What name is given to published standards when there are no laws requiring their application?

Answer: _____

6. In Canada, which building code forms the basis for all of the provincial building codes?

Answer: _____

7. At what point in time during a construction project must all associated permits be obtained?

Answer: _____

8. Who is allowed to install, repair and maintain onsite sewerage systems?

Answer: _____

Answer Key: Self-Test C-4.1 is on the other page.

Answer Key: Self-Test C-4.1

1. How many categories do the standards produced by ASTM International fall into?
    a. 6
2. In Canada, before a standard can become a national standard, it must be approved by whom?
    a. Standards Council of Canada
3. What commission develops and maintains Canada's six model construction and fire codes?
    a. Canadian Commission on Building and Fire Codes
4. How many standards and codes has CSA published?
    a. 3,000
5. What name is given to published standards when there are no laws requiring their application?
    a. Voluntary
6. In Canada, which building code forms the basis for all of the provincial building codes?
    a. National Building Code
7. At what point in time during a construction project must all associated permits be obtained?
    a. Before construction begins
8. Who is allowed to install, repair and maintain onsite sewerage systems?
    a. Authorized persons

Self-Test C-4.2: Describe Where the Various Codes and Standards are Encountered Within the Pipe Trades

Complete Self-Test C-4.2 and check your answers.

1. When comparing a code and a standard, which document covers a wider range of issues?

Answer: _____

2. In BC, is a gas fitter allowed to do limited electrical work on the gas appliance that is being installed?

Answer: _____

3. Which document is known as the industry benchmark for design and installation of standpipe and hose fire protection systems?

Answer: _____

4. Which document is known as the industry benchmark for design and installation of automatic fire sprinkler systems?

Answer: _____

Answer Key: Self-Test C-4.2 is on the other page.

Answer Key: Self-Test C-4.2

1. When comparing a code and a standard, which document covers a wider range of issues?
    a. A code
2. In BC, is a gas fitter allowed to do limited electrical work on the gas appliance that is being installed?
    a. Yes
3. Which document is known as the industry benchmark for design and installation of standpipe and hose fire protection systems?
    a. NFPA 14
4. Which document is known as the industry benchmark for design and installation of automatic fire sprinkler systems?
    a. NFPA 13

Self-Test C-4.3: Identify Various Environmental Agencies with Concerns to Sewage Disposal

Complete Self-Test C-4.3 and check your answers.

1. In typical onsite sewage systems, what separation process occurs in the tank?

Answer: _____

2. In a septic tank, what helps break down the solids into sludge?

Answer: _____

3. In what area of the onsite sewerage system is the wastewater released to the soil?

Answer: _____

Answer Key: Self-Test C-4.3 is on the other page.

Answer Key: Self-Test C-4.3

1. In typical onsite sewage systems, what separation process occurs in the tank?
    a. Solids and scum separate from the liquid.
2. In a septic tank, what helps break down the solids into sludge?
    a. Bacteria
3. In what area of the onsite sewerage system is the wastewater released to the soil?
    a. Disposal field

C-5 MANUFACTURER AND SUPPLIER DOCUMENTATION

Plumber Apprenticeship Program – Level 1

RIDGID K-6200 Drain Cleaning Machine – Operator's Manual and Drum and Sectional Tool guide (Ridgid). Used with permission.

C-5 Manufacturer and Supplier Documentation Introduction

Manufacturer and supplier documentation plays an important role in the piping trades by providing the information needed to install, operate, and maintain equipment safely and correctly. These documents include manuals, specifications, product data sheets, and installation guides that help ensure systems meet required standards and perform as intended. In this section, you will learn about the types of documentation commonly encountered in the piping trades, the key information they contain, and how to effectively use the internet to find reliable manufacturer documentation for the products and systems you work with.

Learning Objectives

After completing this section, you should be able to:

- Describe documentation encountered in the piping trades.
- Describe information contained in manufacturer and supplier documentation.
- Describe how to use the internet to source manufacturers' documentation.

Topic areas covered in this publication are in alignment with SkilledTradesBC Harmonized 2018 Program Outlines.

You will be required to reference publications and videos available online at WorkSafeBC.

Terminology

The following terms may be used throughout this section. Note that some glossary terms may be in italics throughout the section content but are not included in this list. A complete list of terms for this section can be found in the **Glossary.**

- **as-built drawings:** Drawings that show how a system was actually built or installed. (Section C-5.2)
- **certification:** Proof that something meets certain rules or standards. (Section C-4.1; Section C-5.1)
- **certification mark:** A symbol on a product that shows it has been tested and approved. (Section C-5.1)
- **commissioning:** The process of testing a system to make sure it works properly. (Section C-5.2)
- **controlled product:** A product that may be dangerous and needs safety information. (Section C-5.1)
- **extended warranty**: Extra coverage you can buy to protect a product for a longer time. (Section C-5.2)
- **fluid-handling equipment**: Machines or tools that move or control liquids or gases, like pumps, pipes, and valves. (Section C-5.2)
- **hazard:** Something that can cause harm or danger. (Section C-5.1)
- **installation instruction manual**: A booklet that explains how to install and set up a product. (Section C-5.2)
- **maintenance:** Taking care of equipment to keep it working properly. (Section C-5.1)
- **manufacturer:** A company that makes products or equipment. (Section C-5.1)
- **operation and maintenance (o&m) manual**: A document that explains how to use and take care of a system. (Section C-5.2)
- **plant installed**: All the equipment and systems that have been set up and put in place as part of a project, such as pumps, boilers, pipes, and control systems. (Section C-5.2)
- **proprietary:** Something owned by a company that others cannot use freely. (Section C-5.1)
- **rough-in dimensions**: Measurements used to plan where pipes or fixtures will be installed. (Section C-5.3)
- **Safety Data Sheet (SDS):** A document that explains how to safely use a product and what dangers it may have. (Section C-5.1)
- **servicing instructions:** Simple directions that explain how to check, clean, fix, or take care of equipment so it keeps working properly and safely. (Section C-5.1)
- **set points**: Values set on a device to control how it operates, like temperature. (Section C-5.2)
- **spec sheet (datasheet)**: A document that lists important details about a product's performance and features. (Section C-5.2)
- **technical documentation:** Written information that explains how to install, use, or fix a product. (Section C-5.1)
- **training:** Learning how to do a job safely and correctly. (Section C-5.1)
- **troubleshooting**: Steps used to find and fix problems with equipment. (Section C-5.2)
- **uncertified products:** Products that have not been tested or approved by an official organization to show they are safe and meet required standards. (Section C-5.1)
- **warranty**: A promise from a company to repair or replace a product if it has problems. (Section C-5.2)

C-5.1 Describe Documentation Encountered in the Pipe Trades

Manufacturers' Instructions

To perform piping work, it is essential to have the right tools. Piping contractors fully appreciate the complexity of these tools and the importance of ***manufacturers***' documentation for completing a job correctly.

Most appliances and plumbing components are supplied with manufacturers' instructions. These provide information on installation, service, and ***maintenance*** requirements. Once equipment is installed, these instructions should be left with the customer for future reference. Depending on the type of equipment or component, user instructions may also be included.

MATERIAL SAFETY DATA SHEET

ADDRESS: Heat and Light Resources, d/b/a HeatCell, PO Box 1033, Jane Lew, WV 26378, (304) 326-2624

DATE: 01/02/00
PREPARED BY: Dr. Charles Simon
EMERGENCY TELEPHONE NUMBER: CHEMTREC 800-424-9300

NFPA HAZARD CLASSIFICATIONS
H = HEALTH
F = FLAMMABILITY
R = REACTIVITY
NF = NOT FOUND
H = 1
F = 1
R = 1

I. IDENTIFICATION

LABEL NAME: FOOD WARMER
TRADE OR PRODUCT NAME: EcoFuel™ XB/HeatCell
PDA NO.:
CAS NO.: Diethylene Glycol: CAS 00111-46-6

II. FIRE, EXPLOSION AND REACTIVITY DATA

FLASH POINT (METHOD): 246°F (104°C) Cleveland Open Cup
EXTINGUISHING MEDIA: DRY CHEMICAL, FOAM OR CO_2
DOT HAZARD CLASSIFICATION: NOT REQUIRED

0 = LEAST
1 = SLIGHT
2 = MODERATE
3 = HIGH
4 = EXTREME

SPECIAL FIRE FIGHTING PROCEDURES: NONE
UNUSUAL FIRE AND EXPLOSION HAZARDS: UNKNOWN, Believed to be relatively safe.

HAZARDOUS COMBUSTIBLE OR DECOMPOSITION PRODUCTS:
Product consists of hydrocarbon component stabilized by tightly packed fiber wool to give an essentially non-spillable mass. The components are contained in a metal can with a metal lid. The mass is not ignitable at room temperature. To ignite, apply flame directly to glass fiber(s). Can produce carbon monoxide and some irritants under some burning conditions. Glass fibers caused cancer in animals through unnatural routes of exposure (surgical implantation), but it is not associated with cancer by inhalation. Use of glass fibers has not been shown to cause cancer in humans. If ingestion of glass fibers occur, observe individual for several days to ensure that intestinal blockage does not occur. It is not recommended to induce vomiting if ingested.

STABILITY: Stable CONDITIONS TO AVOID: Excessive Heat. MATERIALS TO AVOID: Strong Oxidizers.
HAZARDOUS POLYMERIZATION PRODUCTS: NA Will not occur.

III. PHYSICAL DATA

ODOR, APPEARANCE AND PHYSICAL STATE:
Slightly opaque colorless liquid with subtle petroleum solvent odor.
BOILING POINT: 433°F 223°C
MELTING POINT: NA
SPECIFIC GRAVITY (H_2O = 1.0): 1.117 @ 68°F (20°C)
EVAPORATION RATE: < 1 (Butyl Acetate = 1)
VAPOR PRESSURE (mmHg): < 1@20°C, DEG = 0.01
VAPOR DENSITY (AIR = 1): > 1
SOLUBILITY IN WATER: Partially Miscible

IV. PROTECTION INFORMATION

RESPIRATORY: Use MSHA or NIOXH respirator for handling vapor or mist.
VENTILATION: Always use with Good ventilation.
EYE: Safety glasses for working with vapors or mists.
SKIN: Protective gloves or clothing generally not needed.
OTHER PROTECTIVE DEVICES AND PROCEDURES: Generally not required. Avoid prolonged breathing of mist. Wash hands after handling. Wash soiled work clothing frequently.

V. OCCUPATIONAL EXPOSURE LIMIT

THRESHOLD LIMIT VALUE (TLV): NF
OSHA PERMISSIBLE EXPOSURE LIMIT (PEL): NF
HAS THE SUBSTANCE BEEN LISTED AS A CARCINOGEN OR POTENTIAL CARCINOGEN IN THE ANNUAL REPORT ON CARCINOGENS, PUBLISHED BY NTP, BY THE INTERNATIONAL AGENCY FOR RESEARCH ON CANCER, OR BY OSHA? YES ☐ NO ☒

Figure 1 *MSDS Sheet (sid/Flickr) CC BY-NC-ND*

Safety Data Sheets

A ***Safety Data Sheet* (SDS)** is a technical bulletin that provides specific ***hazard*** information, safe handling information, and emergency procedures for a ***controlled product***. Since the SDS contains detailed health and safety information specific to each controlled product, it should be used as a key source of information for developing ***training*** programs and safe work procedures.

Documentation of Hazards in Piping

A number of hazards are present when working with piping. The SDS may provide cautions and specific information about responding to a range of hazards such as:

- Exposure to asbestos during installation, removal, or repair of pipes in buildings contaminated with asbestos.
- Exposure to lead during installation or removal of lead pipes and while working with lead-based solder.
- Exposure to welding fumes, ultraviolet light, heavy metals, and chlorinated compounds during welding or torch cutting.
- Contact with solvents, adhesives, and epoxies during repair or installation of PVC/ABS pipes.
- Exposure to materials and liquids in old pipes during repair or removal.

- Exposure to exhaust fumes from gas- or diesel-powered equipment.
- Awkward postures, vibration, and hazardous noise while using power tools, grinders, saws, and mobile equipment.
- Dust exposure on construction sites and from grinding activities.
- Contact with biological materials in pipes and drains.
- Exposure to hazardous materials from industrial work sites.

It is the employer's responsibility to ensure workers are adequately educated and trained. If the employer cannot provide the required education, training consultants can be employed to provide it. Education covers information about the product, while training must include how to safely use the product.

System Component Documentation

Technical documentation is the generic term for documentation related to a product. People mainly associate the term with documents and information that are provided to the public by the manufacturer, which typically include:

- User instructions
- Operating instructions
- Servicing instructions
- Installation manuals

Proprietary Component Documentation

A ***proprietary*** technology or product is one for which the technology or the product's inner workings are owned and carefully guarded by a company. Some proprietary products can only function properly, if at all, when used with other products made by the same company.

A primary motivation behind the development of products using proprietary technology is straightforward: buyers are compelled to use other products marketed by the same company. For example, some building automation system (BAS) manufacturers use proprietary communication protocols that will communicate only with their own control equipment. These protocols don't allow easy intercommunication with other brands of BAS. That is one reason why this type of system is rapidly disappearing from the marketplace. Because a proprietary system does not communicate with other systems, the user's options for expanding the BAS are limited. Choices are also reduced for the purchase of new equipment, which limits the user's bargaining power. However, proprietary systems do offer the advantage of a single source of responsibility when problems occur.

Plumbing Product Certification

The Canadian Institute of Plumbing and Heating (CIPH), in conjunction with provincial/territorial plumbing inspectors, recently found it necessary to provide an industry bulletin on the distribution and installation of uncertified plumbing products.

Uncertified products are being inappropriately sold and installed in all jurisdictions of Canada. In many instances, this is creating health and safety issues. There is a myth that all plumbing products sold through the wholesale chain are

suitable for sale and installation. There is no jurisdiction in Canada that allows uncertified products to knowingly be installed. In fact, Alberta and Quebec both have legislation against the sale of such products.

All certified plumbing products are required to bear a ***certification mark***. Figure 2 shows some examples.

Figure 2 *Plumbing product certification marks (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Some fixture manufacturers acknowledge that customers want an aesthetic that is mark-free and choose to mark their product with an adhesive label that is designed to be removed after inspection and to self-destruct so that it cannot be placed on another product. If the permanent adhesive label is accidentally removed prior to inspection, the inspector has no choice but to assume the product is uncertified and request its removal.

Therefore, wholesalers need to educate contractors to keep proof of the product's ***certification*** compliance on the product (in addition to the carton, installation instructions, warranty, homeowner's manual, and specification sheet) until AFTER inspection.

Certified products offer several advantages:

- They are more reliable and have been produced using a demonstrated quality program.
- They have been evaluated to ensure they will perform properly (e.g., ensuring threads are the correct type for proper connection).
- They are regularly checked for compliance by accredited certification organizations to ensure they continue to be manufactured in accordance with national standards.
- Where required, they have been evaluated for toxicological concerns.

Self-Test C-5.1: Describe Documentation Encountered in the Pipe Trades

Complete Self-Test C-5.1 and check your answers.

If you are using a printed copy, please find Self-Test C-5.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2417#h5p-44

References

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Plumber: Level 2 Competency C-4 Use Manufacturer and Supplier Documentation
- Steamfitter: Level 2 Competency C-4 Use Manufacturer and Supplier Documentation
- Sprinkler Fitter: Level 1 Competency C-4 Use Manufacturer and Supplier Documentation

Camosun College. (2019). *Line D: Organizational Skills —Competency D-5: Use Manufacturer and Supplier Documentation* (Rev. ed.) [Learning guide]. BCcampus. https://collection.bccampus.ca/textbook/9MgG7bwy/

Camosun College. (2015). Trades Access Common Core *Competency D-5: Use Manufacturer and Supplier Documentation.* Victoria, B.C.: Crown Publications. Download for free from the B.C. Open Textbook Collection (https://open.bccampus.ca/browse-ourcollection/find-open-textbooks/).

Canadian Institute of Plumbing and Heating. (n.d.). *Canadian Institute of Plumbing and Heating*. https://www.ciph.com/

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- **Figure 1** MSDS Sheet, by sid on Flickr is used under a CC BY-NC-ND license.

C-5.2 Describe Information Contained in Manufacturer and Supplier Documentation

Installation Instructions and Requirements

An ***installation instruction manual*** is an instructional booklet that is supplied with almost all technologically advanced products such as gas-fired appliances, control modules and ***fluid-handling equipment***. Information contained in the instruction manual typically includes:

- Safety instructions: For liability reasons, these can be extensive, often including warnings against doing things that no intelligent person would consider doing.
- Assembly instructions: For products that arrive in pieces for easier shipping.
- Installation instructions: For field installation of the equipment
- Set-up instructions: For devices that keep track of time or temperature and maintain user-accessible state.
- Normal usage instructions.
- Programming instructions: For microprocessor-controlled products such as boiler control, programmable thermostats, and building automation controllers.
- ***Maintenance*** instructions.
- ***Troubleshooting*** instructions: For when the product does not work as expected.
- Service locations: For when the product requires repair by a factory-authorized technician.
- Regulatory code compliance information: For example, with respect to safety or electromagnetic interference.
- Product technical specifications.
- *Warranty* information: Sometimes provided as a separate sheet

With the increasing complexity of modern devices, many installation manuals have become so large that separate multi-language booklets are provided. Many manufacturers offer PDF copies of manuals that can be accessed or downloaded free of charge from their websites.

Operation and Maintenance (O&M) Manuals

An essential part of any mechanical services contract is the provision of a professional operation and maintenance manual and a set of ***as-built drawings*** delivered to the client or end user upon completion of the installation.

O&M manuals should contain references to specific equipment used in the project for which they are compiled. They must be compiled properly as they are important for the client and/or end-user as an instruction manual for the safe operation and maintenance of their systems.

These documents should form part of the effective operation of the systems and, as such, should be carefully prepared to include a comprehensive source of reference for the installed equipment.

Each O&M manual is tailored to a specific project, but the following would be a basic outline:

- **Preface**: Lists the contents of the manual's sections and subsections.

- **Section 1**: **Description of Systems**—Contains a description of each system, how it is controlled, and how it interrelates with other systems.
- **Section 2: Operating Instruction & Control**—Contains a description of how each system or type of system is controlled (listing any relevant ***set points*** or parameters), and the use of any user controls. This supplements the instructions contained in the manufacturer's data.
- **Section 3**: **Equipment Schedule**—Lists the items of ***plant installed*** under this contract, giving basic quick reference for model numbers, manufacture and design flows, etc., to be read in conjunction with the as-built drawings so plant designation can be understood.
- **Section 4: Supplier's/Manufacturer's Details**—To be read in conjunction with Section 3: Equipment Schedule, this section contains copies of the relevant manufacturer's literature/ brochures for the equipment installed under this contract.
- **Section 5**: **Routine Maintenance**—Provides information pertaining to the maintenance that must be carried out to ensure trouble-free operation at the lowest possible cost. This includes sample maintenance schedules and sample service sheets for equipment used in plant operation.
- **Section 6**: **Recommended Spares**—A list of items recommended to be held by the building operator for the purposes of routine maintenance and addressing emergency breakdowns.
- **Section 7: Commissioning Test Results**—A full and comprehensive record of system performance at the time of commissioning is shown, giving a picture of how the system was performing at the time it was commissioned; lists actual airflows and temperature splits, etc.
- **Section 8**: **As-Built Drawings**—Details on how the various systems have been installed. Please note that as with any section of an O&M manual, to retain its effectiveness as a reference document, it is imperative that any changes be noted on these drawings.
- **Section 9**: **Warranties & Certificates**—A record of equipment warranties and compliance certificates.

Product Specifications

A ***datasheet*** or ***spec sheet*** is a document summarizing the performance and other technical characteristics of a product in sufficient detail to enable a tradesperson to integrate the component into a system. Typically, a datasheet is created by the product manufacturer and begins with an introductory page describing the rest of the document, followed by listings of specific characteristics.

Warranty Information

The standard equipment ***warranty*** is a commitment from a manufacturer that a product has no defects and that services such as repairs and partial or complete exchange of defective parts are guaranteed for a particular period of time without the customer being billed.

An ***extended warranty***—sometimes called a service agreement, a service contract or a maintenance agreement—is a prolonged warranty offered to consumers in addition to the standard warranty on a new item. Extended warranties cost extra, usually a percentage of the item's retail price.

Self-Test C-5.2: Describe Information Contained in Manufacturer and Supplier Documentation

Complete Self-Test C-5.2 and check your answers.

If you are using a printed copy, please find Self-Test C-5.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2479#h5p-45

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BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

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C-5.3 Describe How to Use the Internet to Source Manufacturer's Documentation

Websites for Manufacturers

One key feature of this section is that you will be asked to carry out some of your own research. Finding information for yourself is a useful skill for a plumber because you need to keep up to date with changes to regulations and new technology. A majority of professionals use the internet to look for services and products. The internet serves as a tool for finding ***technical information*** or other criteria. Thus, the user saves time that would otherwise be spent using printed material to obtain information or compare products or services.

When a manufacturer has a website, there is no need to print product catalogues and brochures. All the manufacturer needs to do is place the information on the website.

You benefit as well because you will be able to find a product on a website much faster, which allows you to stay current as the product information changes and new products are introduced to the industry.

Product manufacturers' websites hold vast amounts of information, including:

- Online catalogues
- Detailed product pages, including:
    - ***Rough-in dimensions*** (every major manufacturer has specifications on their website, usually in PDF format)
    - Related products
    - Sub-assembly components
    - Component drawings and blueprints (including magnification-on-hover)
    - Product manuals
    - Warranty information
    - Support for multiple languages
- Dealer locators with built-in Google Maps integration

Many modern products also include digital controls or software (for example, boilers, pumps, or programmable thermostats). Manufacturers' websites, such as RIDGID, often provide setup instructions, manuals, and updates for these systems. However, not all products include software—many components, such as pipes, fittings, and basic fixtures, are still fully mechanical. Plumbers must still ensure that any software or digital tools are used in accordance with local codes and regulations. Manufacturer software is helpful, but it should be used as a guide and always verified against approved codes and requirements.

Search Engines

You do not always have to know a website's address to use the internet. It is important to know how to search for information. One of the best search methods is to use a ***search engine***.

A web *search engine* is a type of website that helps a computer user find information on the internet. It does this by

looking through other web pages for the text the user wants to find. You've probably already used one or more search engines. Google is the most popular.

When using a search engine, you must enter at least one ***keyword*** in the search box. Usually an on-screen button must be clicked to submit the search. The search engine looks for matches between the keyword(s) entered and its database of websites and words.

After a search is submitted, the results are quickly returned as a list. The list usually shows web page names, short descriptions and a link for each matching web page. You can click on any of the links to go to one of the websites.

The usefulness of a search engine depends on the ***relevance*** of the ***result set*** it gives back. While there may be millions of web pages that include a particular word or phrase, some pages may be more relevant, popular or authoritative than others. Most search engines rank the results to provide the best results first.

Using AI and Online Search Results

***Artificial intelligence* (AI)** tools and search engines (such as Google Search) can quickly provide summaries and answers, but they are not always reliable for plumbing work.

AI-generated content and search result summaries (often called "AI overviews") may:

- Provide incorrect or outdated information
- Miss important safety details or code requirements
- Oversimplify complex installation or maintenance procedures
- Combine information from multiple sources without verifying accuracy

Plumbing work must follow current codes, manufacturer instructions, and applicable regulations. In British Columbia, these requirements are enforced by authorities such as Technical Safety BC.

Best practice:

- Always verify information using **manufacturer documentation**, **approved codes**, and **trusted industry sources** (e.g., regulatory authorities, certified training materials).
- Use AI and search engines as a **starting point only**, not as your final source.
- When in doubt, consult a **qualified professional, instructor, or inspector.**

Self-Test C-5.3: Describe How to Use the Internet to Source Manufacturer's Documentation

Complete Self-Test C-5.3 and check your answers.

If you are using a printed copy, please find Self-Test C-5.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

Use the internet to access manufacturers' websites to find the following information:

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2481#h5p-46

References

BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

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- Sprinkler Fitter: Level 1 Competency C-4 Use Manufacturer and Supplier Documentation

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Self-Test C-5.1: Describe Documentation Encountered in the Pipe Trades

Complete Self-Test C-5.1 and check your answers.

1. What available documentation contains detailed health and safety information specific to controlled products?

Answer: _____

2. Who has the responsibility to ensure workers are adequately educated and trained on how to safely use controlled products?

Answer: _____

3. What term describes a product that is owned exclusively by a single company that carefully guards knowledge about the technology or the product's inner workings?

Answer: _____

4. At what point in a plumbing fixture installation can a certification sticker be removed for aesthetic purposes?

Answer: _____

Answer Key: Self-Test C-5.1 is on the other page.

Answer Key: Self-Test C-5.1

1. What available documentation contains detailed health and safety information specific to controlled products?
    a. MSDS
2. Who has the responsibility to ensure workers are adequately educated and trained on how to safely use controlled products?
    a. Employers
3. What term describes a product that is owned exclusively by a single company that carefully guards knowledge about the technology or the product's inner workings?
    a. Proprietary
4. At what point in a plumbing fixture installation can a certification sticker be removed for aesthetic purposes?
    a. After inspection

Self-Test C-5.2: Describe Information Contained in Manufacturer and Supplier Documentation

Complete Self-Test C-5.2 and check your answers.

1. What type of documentation is supplied with almost all technologically advanced products?

Answer: _____

2. What type of documentation is delivered to the client or end-user upon completion of a mechanical system installation?

Answer: _____

3. What is the name given to the drawing set that forms part of the documentation listed above?

Answer: _____

4. There is an added cost associated with an extended warranty. How is this cost calculated?

Answer: _____

Answer Key: Self-Test C-5.2 is on the other page.

Answer Key: Self-Test C-5.2

1. What type of documentation is supplied with almost all technologically advanced products?
    a. Instruction manual
2. What type of documentation is delivered to the client or end-user upon completion of a mechanical system installation?
    a. O&M manual
3. What is the name given to the drawing set that forms part of the documentation listed above?
    a. As-built
4. There is an added cost associated with an extended warranty. How is this cost calculated?
    a. % of item retail price

Self-Test C-5.3: Describe How to Use the Internet to Source Manufacturer's Documentation

Complete Self-Test C-5.3 and check your answers.

1. Access the Crane (plumbing fixtures) website to find the following information: What is the width of the toilet tank used with a Hymont toilet?

Answer: _____ in.

2. Access the Burnham (commercial boiler) website to find the following information: What is the maximum allowable working pressure (MAWP) for an Apex boiler?

Answer: _____ psi

3. Access the Grundfos Pumps (heating circulator) website to find the following information: What is the maximum flow rate (gpm) that can be delivered by a UP26F-64 circulator?

Answer: _____ gpm

4. Access the Zurn (roof drain) website to find the following information: What pipe size connections are available on a Z131 Siphonic overflow roof drain?

Answer: _____

5. Access the American Standard (commercial plumbing fixtures) website to find the following information: What is the height of the rim on a Florwell service sink above rough floor?

Answer: _____ in.

6. Access the Bryant (Legacy gas furnace) website to find the following information: What is the length of the standard warranty for the heat exchanger in a Legacy gas furnace?

Answer: _____ years

7. Access the Rigid (plumbing tools) website to find the following information: How many feet of $\frac{5}{8}$" cable can be stored in the drum of a K-6200 drain cleaning machine?

Answer: _____ feet

8. Access the Viking Fire Sprinkler website and find the following information about the ordinary hazard pendant sprinkler head model VK572: What is the distance down from the ceiling to the deflector when installed with a standard $\frac{1}{8}$ surface-mounted escutcheon?

Answer: _____ in.

9. Access the Spirax/Sarco (ball float steam traps) website and find the following information: What is the maximum pipe size available for the flanged FT43 Ball Float steam trap?

Answer: _____

Answer Key: Self-Test C-5.3 is on the other page.

Answer Key: Self-Test C-5.3

1. Access the Crane (plumbing fixtures) website to find the following information: What is the width of the toilet tank used with a Hymont toilet?

   a. $19\frac{7}{8}$"

2. Access the Burnham (commercial boiler) website to find the following information: What is the maximum allowable working pressure (MAWP) for an Apex boiler?

   a. 80 psi

3. Access the Grundfos Pumps (heating circulator) website to find the following information: What is the maximum flow rate (gpm) that can be delivered by a UP26F-64 circulator?

   a. 32 gpm

4. Access the Zurn (roof drain) website to find the following information: What pipe size connections are available on a Z131 Siphonic overflow roof drain?

   a. 2″, 3″, and 4″

5. Access the American Standard (commercial plumbing fixtures) website to find the following information: What is the height of the rim on a Florwell service sink above rough floor?

   a. 13″

6. Access the Bryant (Legacy gas furnace) website to find the following information: What is the length of the standard warranty for the heat exchanger in a Legacy gas furnace?

   a. 20 years

7. Access the Ridgid (plumb

8. ing tools) website to find the following information: How many feet of $\frac{5}{8}$" cable can be stored in the drum of a K-6200 drain cleaning machine?

   a. 100 feet

9. Access the Viking Fire Sprinkler website and find the following information about the ordinary hazard pendant sprinkler head model VK572: What is the distance down from the ceiling to the deflector when installed with a standard $\frac{1}{8}$ surface-mounted escutcheon?

   a. $1\frac{3}{4}$"

10. Access the Spirax/Sarco (ball float steam traps) website and find the following information: What is the maximum pipe size available for the flanged FT43 Ball Float steam trap?

    a. 100 mm (4″)

APPENDICES - ADDITIONAL LEARNING RESOURCES

These appendices include additional learning resources originally developed for *Line D: Organizational skills: Competency D-1: Solve trades mathematical problems* by Camosun College (2015) for the Plumbing Trades series available through BCcampus. We gratefully acknowledge the quality and care reflected in this work and felt it was important to ensure these valuable resources continue to be accessible and used. They have been included here to support student learning and provide convenient access to supplementary materials that reinforce key concepts and skills presented throughout this text.

Camosun College. (2015). *Line D: Organizational skills: Competency D-1: Solve trades mathematical problems*. BCcampus. https://collection.bccampus.ca/textbook/qFKGAJ78/

Appendix A: Math Web Links

Open University (OpenLearn) Resources

- ***Numbers, Units and Arithmetic***
  This free course reviews whole numbers, decimals, and fractions, including positive and negative values.
- ***Ratio, Proportion and Percentages***
  Covers key concepts related to ratios, proportions, and percentages.
- ***Squares, Roots and Powers***
  Reviews powers of numbers (including squares and square roots) and introduces powers of 10 and scientific notation.

Khan Academy Resources

- ***Decimals***
  Learn decimal concepts, operations, rounding, estimating, and conversions.
- ***Fractions***
  Covers fraction concepts, operations, and conversions.
- ***Negative Numbers and Absolute Value***
  Builds understanding of numbers below zero and absolute value.
- ***Arithmetic Properties***
  Explores place value, order of operations, and key arithmetic concepts.
- ***Basic Geometry***
  Introduces the core foundations of geometry.

Appendix B: Metric Unit Symbols and Relationships

Notes for Use

- Metric conversions are based on powers of 10 (move the decimal point).
- Always check units to confirm your answer is reasonable.
- Use this reference sheet during problem solving—memorization is not required.

Table 1: Time Conversions

Unit	Symbol	Conversion
second	s	—
minute	min	1 min = 60 s
hour	h	1 h = 60 min
day	d	1 d = 24 h
year	a	1 a = 365 d

Table 2: Length and Area Conversions

Quantity	Unit	Symbol	Conversion
Length	kilometre	km	1 km = 1000 m
	metre	m	1 m = 100 cm
	centimetre	cm	1 cm = 10 mm
	millimetre	mm	1 m = 1000 mm
Area	hectare	ha	1 ha = 10,000 m^2
	square kilometre	km^2	1 km^2 = 1,000,000 m^2
	hectare	ha	1 km^2 = 100 ha
	square metre	m^2	1 ha = 10,000 m^2
	square centimetre	cm^2	1 m^2 = 10,000 cm^2

Table 3: Volume Conversions

Unit	Symbol	Conversion
kilolitre	kL	1 kL = 1000 L
cubic metre	m^3	1 m^3 = 1 kL
litre	L	1 L = 1000 mL
cubic centimetre	cm^3	1 L = 1000 cm^3
millilitre	mL	1 mL = 1 cm^3

Table 4: Mass Conversions

Unit	Symbol	Conversion
kilolitre	kL	1 kL = 1000 L
cubic metre	m^3	1 m^3 = 1 kL
litre	L	1 L = 1000 mL
cubic centimetre	cm^3	1 L = 1000 cm^3
millilitre	mL	1 mL = 1 cm^3

Table 5: Water Equivalencies

Quantity	Equivalent Mass
1 kL of water	1 tonne (t)
1 L of water	1 kilogram (kg)
1 mL of water	1 gram (g)

Table 6: Metric Prefixes

Prefix	Symbol	Value
mega	M	1,000,000
kilo	k	1,000
hecto	h	100
deca	da	10
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	µ	0.000001

Printable sheets:

- Trades Math Reference SheetC_Lev1 [docx]
- Trades Math Reference SheetC_Lev1 [PDF]

Appendix C: Imperial (U.S.) units

U.S. customary units differ from imperial (Canadian/UK) units, especially for liquid measure. Always confirm which system is being used.

Imperial (U.S.) Units

Table 1: Length – Imperial (U.S.) Units

Unit	Conversion
foot (ft.)	1 ft = 12 inches (in.)
yard (yd.)	1 yd = 3 ft
mile (mi.)	1 mi = 5,280 ft

Table 2: Liquid Measure

Unit	Conversion
pint (pt.)	1 pt = 2 cups
quart (qt.)	1 qt = 2 pt
gallon (gal.)	1 gal = 4 qt

Table 3: Weight

Unit	Conversion
pound (lb.)	1 lb = 16 ounces (oz.)
ton	1 ton = 2000 lb

Metric to Imperial (U.S.) Conversions

Table 4: Length

Metric Unit	Imperial Equivalent
1 cm	0.394 in.
1 m	39.4 in.
1 km	0.621 mi

Table 5: Area

Metric Unit	Imperial Equivalent
1 hectare	2.47 acres
1 km^2	0.386 sq. mi.

Table 6: Liquid Measure

Metric Unit	Imperial Equivalent
1 L	0.26 gal
1 L	4.23 cups

Table 7: Mass/Weight

Metric Unit	Imperial Equivalent
1 g	0.0353 oz
1 kg	2.20 lb

Imperial (U.S.) to Metric Conversions

Table 8: Length

Imperial Unit	Metric Equivalent
1 in.	2.54 cm
1 yd	0.914 m
1 mi	1.61 km

Table 9: Area

Imperial Unit	Metric Equivalent
1 acre	0.405 ha
1 sq. mi.	2.59 km^2

Table 10: Liquid Measure

Imperial Unit	Metric Equivalent
1 gal	3.79 L
1 cup	0.24 L

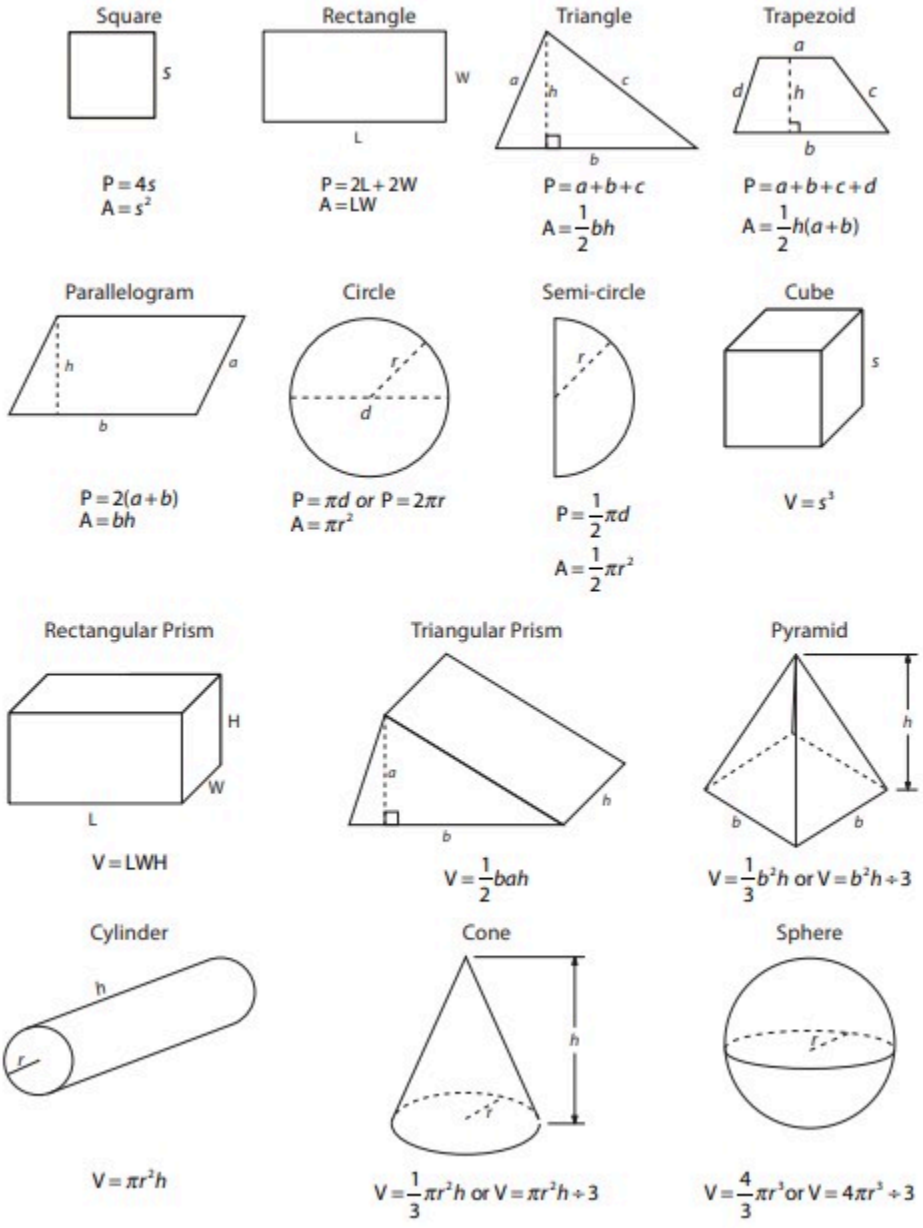
Table 11: Mass/Weight

Imperial Unit	Metric Equivalent
1 gal	3.79 L
1 cup	0.24 L

Printable sheets:

- Trades Math Reference SheetB_Lev1 [PDF]
- Trades Math Reference SheetB_Lev1 [docx]

Appendix D: Perimeter, Area, and Volume Formulas for Shapes



Printable:

- Trades Math Reference SheetD_Lev1 [docx]
- Trades Math Reference SheetD_Lev1 [PDF]

Plumbing Apprenticeship & Trade Resources in BC

A successful career in plumbing requires a strong foundation of skills, knowledge, and workplace safety awareness. Below are key resources to support plumbing apprentices in BC, including educational pathways, trade certifications, workplace safety guidelines, and mental health and wellness support.

Plumbing Apprenticeship & Certification Resources

- **SkilledTradesBC – Plumbing Apprenticeship** — Overview of plumbing training, certification requirements, and apprenticeship pathways in British Columbia.
- **Red Seal Program – Plumber** — National certification program with exam prep guides and trade mobility information.
- **BC Building Codes & Standards** — Official building and plumbing codes for British Columbia.

Workplace Safety & Regulations

- **WorkSafeBC** — Essential safety resources for plumbers, including:
  - Health & Safety – WorkSafeBC
  - Report Unsafe Working Conditions
  - Report a Workplace Injury or Disease
  - Submit a Notice of Project Form
  - Get Health and Safety Resources (Videos, Posters, Publications, and More)
  - Search the OHS Regulations (and Related Materials)
  - Conduct an Incident Investigation
- **CCOHS: OHS Answers Fact Sheets – Plumber** — Safety guidelines and best practices for plumbers in various work environments.

Financial Supports

- **Financial Support (SkilledTradesBC)** — Information about grants, tax credits, Canada apprentice loans, employment insurance, and the Indigenous Skills and Employment Training (ISET) program.
- **StudentAidBC** — Complete post-secondary education through student loans, grants, and scholarships. There is also programs that help with loan repayment.
- **WorkBC (Government of BC)** — Services for apprentices and employers.

Mental Health & Wellness Support

- **HealthLink BC – Mental Health and Substance Use** — HealthLink BC resources for mental health and wellness support.
- **Here2Talk** — Free and confidential counseling services available to all post-secondary students registered at a BC school.
- **Help Starts Here** — A database with over 2,500 listings of services related to mental health and substance use supports.
- **Hope for Wellness Helpline** — 24/7 online chat and phone line with experienced and culturally competent counselors available to all Indigenous people in Canada.
    - First Nations Health Authority Mental Health Supports Info Sheet [PDF] by First Nations health Authority — List of culturally safe services for Indigenous people.
- **HeretoHelp – BC** — Mental health resources, including videos, articles, and support services in BC.
- **BC Construction Industry Rehabilitation Plan** — Mental health and substance use services for CLRA and BCBT members and their families.
- **Virtual Mental Health Supports (Government of BC)** — Virtual services are available for British Columbians who are experiencing anxiety, depression, or other mental health challenges.

Crisis Support

- **Interior Crisis Line Network** — Call 1-888-353-2273 for 24/7 emotional support, crisis intervention, and community resource information.
- **Talk Suicide Chat Service** — An alternative if calling is difficult; available for crisis intervention.
- **310Mental Health Support** — Call 250-310-6789 for emotional support, information, and resources specific to mental health.
- **1-800-SUICIDE** — Call 1-800-784-2433 if you are experiencing feelings of distress or despair, including thoughts of suicide.
- **Opioid Treatment Access Line** — Call 1-833-804-8111 between 9 am and 4 pm to connect with a doctor, nurse, or healthcare worker who can prescribe opioid treatment medication that same day.
- **KUU-US Crisis Response Service** — Call 1-800-588-8717 for culturally-aware crisis support for Indigenous peoples in BC.
- **Alcohol and Drug Information and Referral Service** — Call 1-800-663-1441 to find resources and support.

Emergency Services — For life-threatening situations, call 911 or visit your nearest emergency department.

Version History

This page provides a record of changes made to this learning resource, Plumbing Apprenticeship Level 1, Block C. Each update increases the version number by 0.1. The most recent version is reflected in the exported files for this resource.

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Version	Date	Change	Details