Trades Access Common Core

Line D: Organizational Skills

Competency D-2: Apply Science Concepts to Trades Applications

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Trades Access
COMMON CORE

Line D: Organizational Skills

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The ITA works with employers, employees, industry, labour, training providers, and government to issue credentials, manage apprenticeships, set program standards, and increase opportunities in approximately 100 BC trades. Among its many functions are oversight of the development of training resources that align with program standards, outlines, and learning objectives, and authorizing permission to utilize these resources (text and images).

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Foreword

The BC Open Textbook Project began in 2012 with the goal of making post-secondary education in British Columbia more accessible by reducing student cost through the use of openly licensed textbooks. The BC Open Textbook Project is administered by BCcampus and is funded by the British Columbia Ministry of Advanced Education.

Open textbooks are open educational resources (OER); they are instructional resources created and shared in ways so that more people have access to them. This is a different model than traditionally copyrighted materials. OER are defined as teaching, learning, and research resources that reside in the public domain or have been released under an intellectual property licence that permits their free use and repurposing by others (Hewlett Foundation). Our open textbooks are openly licensed using a Creative Commons licence, and are offered in various e-book formats free of charge, or as printed books that are available at cost. For more information about this project, please contact opentext@bccampus.ca. If you are an instructor who is using this book for a course, please let us know.

Preface

The concept of identifying and creating resources for skills that are common to many trades has a long history in the Province of British Columbia. This collection of Trades Access Common Core (TACC) resources was adapted from the 15 Trades Common Core line modules co-published by the Industry Training and Apprenticeship Commission (ITAC) and the Centre for Curriculum Transfer and Technology (C2T2) in 2000-2002. Those modules were revisions of the original Common Core portion of the TRAC modules prepared by the Province of British Columbia Ministry of Post-Secondary Education in 1986. The TACC resources are still in use by a number of trades programs today and, with the permission from the Industry Training Authority (ITA), have been utilized in this project.

These open resources have been updated and realigned to match many of the line and competency titles found in the Province of BC's trades apprenticeship program outlines. A review was carried out to analyze the provincial program outlines of a number of trades, with the intent of finding common entry-level learning tasks that could be assembled into this package. This analysis provided the template for the outline used to update the existing modules. Many images found in ITA apprentice training modules were also incorporated into these resources to create books that are similar to what students will see when they continue their chosen trades training. The project team has also taken many new photographs for this project, which are available for use in other trades training resources.

The following list of lines and competencies was generated with the goal of creating an entry-level trades training resource, while still offering the flexibility for lines to be used as stand-alone books. This flexibility—in addition to the textbook content being openly licensed—allows these resources to be used within other contexts as well. For example, instructors or institutions may incorporate these resources into foundation-level trades training programming or within an online learning management system (LMS).

Line A – Safe Work Practices

- A-1 Control Workplace Hazards
- A-2 Describe WorkSafeBC Regulations
- A-3 Handle Hazardous Materials Safely
- A-4 Describe Personal Safety Practices
- A-5 Describe Fire Safety

Line B – Employability Skills

- B-1 Apply Study and Learning Skills
- B-2 Describe Expectations and Responsibilities of Employers and Employees
- B-3 Use Interpersonal Communication Skills
- B-4 Describe the Apprenticeship System

Line C – Tools and Equipment

- C-1 Describe Common Hand Tools and Their Uses
- C-2 Describe Common Power Tools and Their Uses
- C-3 Describe Rigging and Hoisting Equipment
- C-4 Describe Ladders and Platforms

Line D – Organizational Skills

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

Line E – Electrical Fundamentals

- E-1 Describe the Basic Principles of Electricity
- E-2 Identify Common Circuit Components and Their Symbols
- E-3 Explain Wiring Connections
- E-4 Use Multimeters

All of these textbooks are available in a variety of formats in addition to print:

- PDF—printable document with TOC and hyperlinks intact
- HTML—basic export of an HTML file and its assets, suitable for use in learning management systems
- Reflowable EPUB—format that is suitable for all screen sizes including phones

All of the self-test questions are also available from BCcampus as separate data, if instructors would like to use the questions for online quizzes or competency testing.

About This Book

In an effort to make this book a flexible resource for trainers and learners, the following features are included:

- An introduction outlining the high-level goal of the Competency, and a list of objectives reflecting the skills and knowledge a person would need to achieve to fulfill this goal.
- Discrete Learning Tasks designed to help a person achieve these objectives
- Self-tests at the end of each Learning Task, designed to informally test for understanding.

- A reminder at the end of each Competency to complete a Competency test. Individual trainers are expected to determine the requirements for this test, as required.
- Throughout the textbook, there may also be links and/or references to other resources that learners will need to access, some of which are only available online.
- Notes, cautions, and warnings are identified by special symbols. A list of those symbols is provided below.

Symbols Legend

 **Important:** This icon highlights important information.

 **Poisonous:** This icon is a reminder for a potentially toxic/poisonous situation.

 **Resources:** The resource icon highlights any required or optional resources.

 **Flammable:** This icon is a reminder for a potentially flammable situation.

 **Self-test:** This icon reminds you to complete a self-test.

 **Explosive:** This icon is a reminder for a possibly explosive situation.

 **Safety gear:** The safety gear icon is an important reminder to use protective equipment.

 **Electric shock:** This icon is a reminder for potential electric shock.

Safety Advisory

Be advised that references to the Workers' Compensation Board of British Columbia safety regulations contained within these materials do not/may not reflect the most recent Occupational Health and Safety Regulation. The current Standards and Regulation in BC can be obtained at the following website: http://www.worksafebc.com.

Please note that it is always the responsibility of any person using these materials to inform him/herself about the Occupational Health and Safety Regulation pertaining to his/her area of work.

BCcampus
January 2015

Disclaimer

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Contents

Introduction

This Competency introduces the basic principles governing the structure and the behaviour of solids, liquids, and gases. You will look at the effects forces have on objects and the basic machines that transmit a force. You will also examine the effects of thermal and electrical energy.

Objectives

When you have completed the Learning Tasks in this Competency, you will be able to:

- identify the various properties of matter
- describe practical applications of mechanics
- describe the basic properties of thermal and electrical energy

Resources

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

LEARNING TASK 1

Identify the properties of matter

This Learning Task introduces the basic principles governing the structure and the behaviour of solids, liquids, and gases—the three forms of matter. "Matter" is the term used to identify things that occupy space and have a mass or weight.

The study of matter is important for trades students because understanding the strengths and weaknesses of different materials is vital when selecting them for appropriate use in a manufacturing or construction situation.

When you have completed this Learning Task, you will be able to:

- describe matter and its properties
- identify types of forces and stresses that act on matter
- recognize units associated with forces, pressure, mass, and weight
- recognize Archimedes' principle, Pascal's principle, and Boyle's law

You may also be required to solve mathematical problems related to the above subjects.

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).

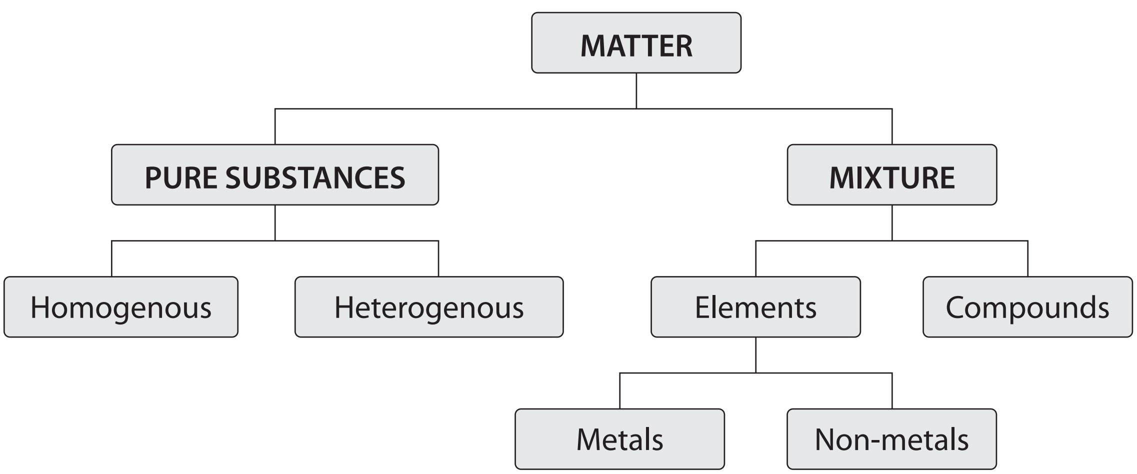


Figure 1 — Categories of matter

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 definite proportions.

Elements

Elements are unique in that they cannot be broken down or decomposed into other materials by ordinary means. For example, pure gold possesses only gold particles. Gold is an example of an element. The smallest particle of an element is called an "atom."

There are at present 118 confirmed elements, including hydrogen, oxygen, carbon, copper, lead, silver, and gold.

Molecules

Atoms of elements can unite to form more complex structures called "molecules." Molecules are made up of atoms configured in definite proportions 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 resulting product is known as 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 and produce ferric hydroxide—common rust.

Aside from some of the elements that can exist in atom form, such as helium, most matter is composed of molecules that contain two or more elemental 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 that material. For example, iron is harder than copper because of differences in the arrangement and structure of their molecules. Similarly, the colour of gold is determined by its molecular structure.

The choice of the tools used to work a material depends on the molecular make-up 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 clog 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 the product of two or more elements that chemically unite to create a pure substance. The elements in a compound are always present in definite proportions. For example, the ratio of sodium to chlorine masses in a sodium chloride molecule (table salt) is always 0.65:1 (Figure 2). If there is extra sodium or chlorine available when table salt is being created, the extra atoms will not unite.

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.

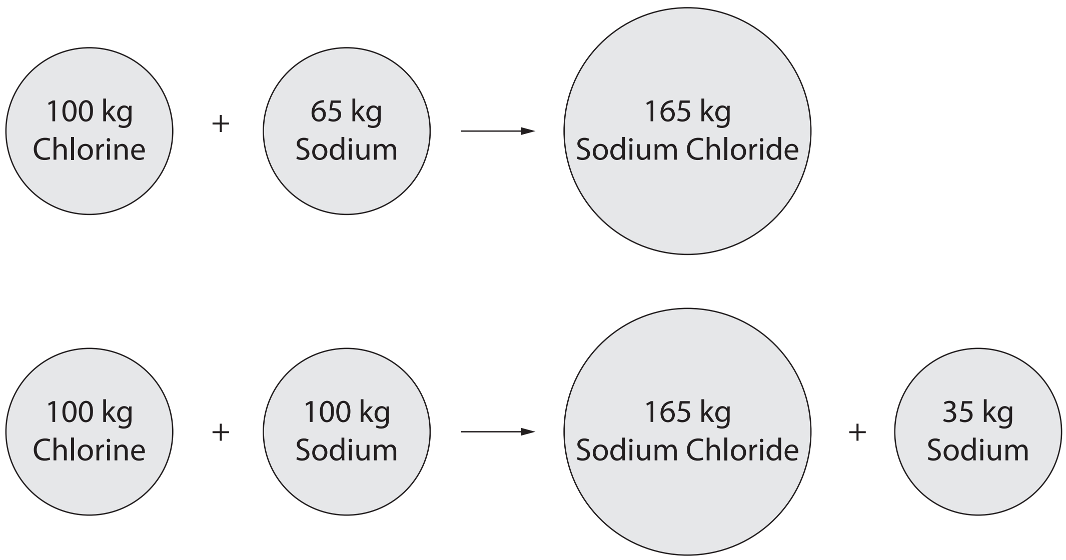


Figure 2 — Ratio of elements in sodium chloride (table salt)

Molecules of compounds have all the properties of the compound and can be considered the smallest unit of the material.

Mixtures

A mixture is the product of two or more elements or compounds combined, with the resulting material having molecules that retain their original properties.

Unlike the components of a compound, a mixture can be formed using varying 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. However, 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. However, the proportion of copper and zinc varies widely. If you wish to produce a bronze-coloured alloy, 90% copper and 10% zinc is used;

to produce silvery-white metal, a mixture of 55% copper and 45% zinc is used. 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.

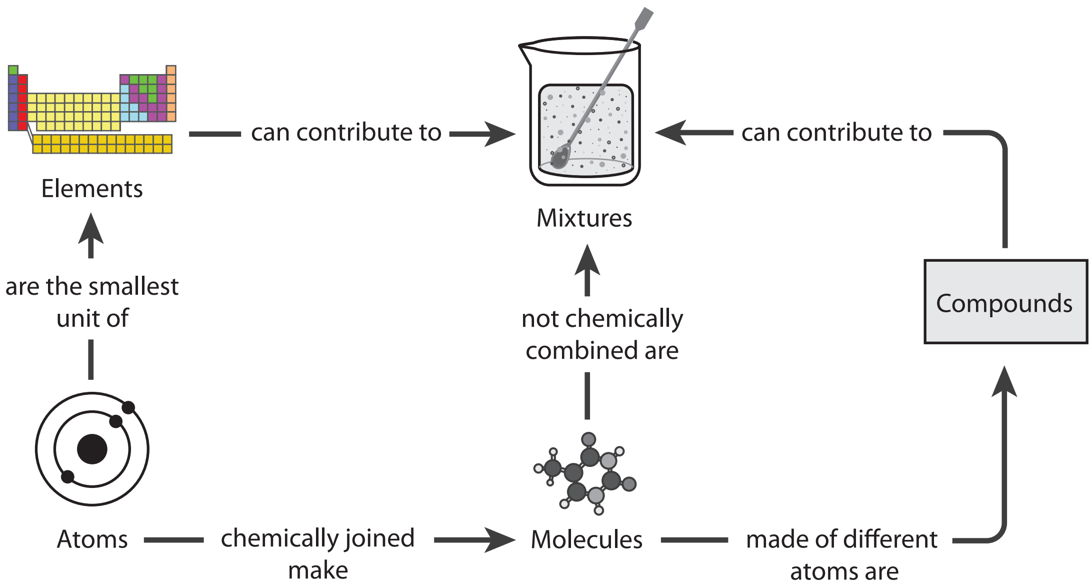


Figure 3 — Composition and relationship of elements, compounds, and mixtures

States of matter

Matter commonly exists in one of three forms or states: solid, liquid, or gas.

Under certain conditions, some substances change states. With the appropriate amount of heat or cold, solids often melt into liquids, and liquids freeze to solids. Similarly, liquids often vaporize into gases and gases condense into liquids.

Water is a common substance that is capable of changing its state while retaining its chemical structure. Whether in the form of ice, water, or water vapour, the chemical structure of water is always H_2O (two hydrogen atoms and one oxygen atom). However, some matter cannot change from one state to another without becoming unrecognizable. For example, a solid oak block cannot be melted into liquid oak. Instead, given enough heat, the oak will become carbon ash. Although heat may produce a liquid (resin or sap) and a solid (ashes) that have some of the characteristics of an oak tree, the removal of the heat certainly will not cause these residues to reassemble themselves into an oak block.

When organic material (such as an oak block) changes states, the molecular structure of the liquids or solids produced only faintly resemble the molecular structure of the original material. However, when inorganic material such as water changes state, the molecular structure of the new state is identical to the original state. Because it has retained its molecular structure, the "new" state can revert to the previous state. In the case of water, the water can be frozen into ice (a solid), then melted back into water (liquid), and heated to form water vapour (gas).

Molecular attractions in matter

The individual motion of molecules in a substance and the space between them determines the state of a substance—solid, liquid, or gas. Several attracting forces determine the spacing between the molecules.

Cohesive forces

Solids have molecules that are strongly attracted to one another. This mutual attraction, called cohesive force if all molecules are identical, 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 hung from a steel rod one centimetre in diameter without causing the molecules in the rod to separate.

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 is what allows liquids to flow.

Gas molecules exhibit little cohesion. Individual molecules are, relatively speaking, widely separated. Indeed, under certain standard conditions, the distance between molecules in a gas can be more than 10 times 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.

Adhesive forces

Dissimilar molecules often exhibit a force of attraction similar to cohesion. The intermolecular force acting between unlike molecules is called the "adhesive force." The adhesive force between unlike molecules allows water to wet rocks, paint to stick to wood, oil to lubricate bearings, and ink to adhere to paper.

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. In the case of gluing, thin is often stronger than thick!

Physical properties of matter

In addition to the intermolecular forces described above, matter also has several other general properties.

Mass and weight

You may recall that the concept of mass is embedded in the definition of matter. Mass is a measurement of the quantity of material in a body. An object's mass does not vary; it is the same everywhere in the universe. For example, a ball having a mass of 0.5 kg on Earth has a mass of 0.5 kg on the moon.

When a quantity of material (a mass) is acted on by the pull of gravity, the resulting force can be determined by the equation:

Force (F) = mass (m) × gravitational pull (g)

In this equation, gravitational pull is quantified by the acceleration caused by it acting on the mass. The acceleration due to gravity has the approximate value of 9.8 m/s^2 or 32 $ft./s^2$.

In the metric system, the unit of force found by the equation $F = m \times g$ is the newton (N), the unit of mass is the kilogram (kg), and the unit of acceleration and gravitational pull is metres per second per second (m/s^2).

In the imperial system, the unit of force found by the equation $F = m \times g$ is the pound (lb.), and the unit of acceleration is feet per second per second ($ft./s^2$). Instead of using a word for mass, force in the imperial system is almost always defined in terms of gravity, and the term "weight" is used when referring to a quantity of matter (a mass) even though weight is actually a force. For example, a pound of copper is really the quantity (mass) of copper that is pulled toward Earth with a force of 1 lb.

The gravitational force equation ($F = m \times g$) can be rewritten as:

weight = mass × gravitational pull
$w = m \times g$

Although we use the terms "kilogram" and "pound" almost interchangeably and even have calculators to quickly convert between the two units of measurement, strictly speaking this practice is not correct. "Kilograms" refers to a quantity of matter that has not been acted on by gravity, while "pounds" refers to a force produced when a quantity of matter has been acted on by gravity.

In most everyday situations, you can think of kilograms and pounds as being units of weight. For example, you can buy 5 kg of oranges or 11 lb. of oranges. However, in some cases (such as in calculating pressure resulting from the depth of a liquid), this difference between the mass quantity kilogram and the force quantity pound must be considered.

In summary:

- Weight is a force measured in pounds (lb.) in the imperial system and newtons (N) in the metric system.
- Mass is a quantity of matter measured in kilograms (kg) in the metric system. Calculations involving mass are seldom made in the imperial system.

Figure 4 — Portrait of Sir Isaac Newton. Dated between 1715–1720

> ***Sir Isaac Newton*** *(1642–1727) was a mathematician, scientist, and philosopher. He is widely recognized as one of the most influential scientists of all time. His theories and accomplishments in the laws of motion and universal gravitation were revolutionary, and their impact continues into present time.*

Volume

Volume is a measurement of the amount of space an object occupies or contains (holds). To find the volume of a rectangular-shaped object, you multiply the length by the width by the height:

Volume (V) = Length (L) × Width (W) × Height (H)

Volume is measured in cubic metres (m^3), cubic centimetres (cm^3), and litres (L) in the metric system. 100 cm^3 = 1 litre

Imperial units of volume include cubic inches ($in.^3$), cubic feet ($ft.^3$), cubic yards ($yd.^3$), as well as quarts and gallons.

Finding the volume of an irregular-shaped solid material is often done indirectly. Because of the impenetrability of matter (a concept discussed later in this Competency), when a solid is immersed in water, the volume of the solid is equal to the volume of water that is displaced. This information can be used to quickly find the volume of an object.

For example, in Figure 5 an object has been lowered into a full tank of water and has caused 1.8 L of the water to overflow. The volume of the displaced water is equal to the volume of the immersed object. Figure 4 shows that the irregular-shaped object must have a volume of 1.8 L.

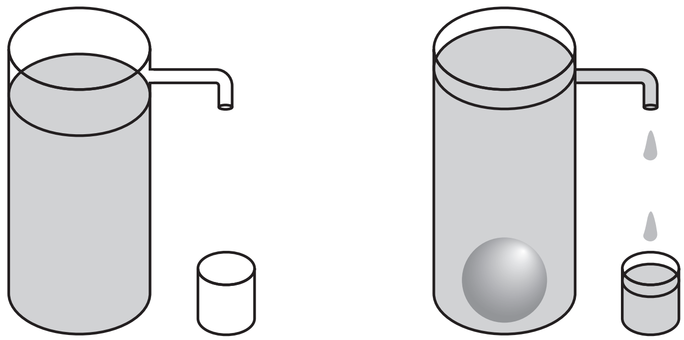


Figure 5 — Volume displacement

Another indirect method is sometimes used to find the volume of odd-shaped containers, such as the head of an automobile engine. In this example, if the head is removed and the valves are held in place, the volume (the displacement) of the combustion chamber can be found by simply filling it with water poured from a graduated measuring cup. By noting the amount of water originally in the cup and the amount left in the cup after filling the chamber, then subtracting one quantity from the other, you can determine the volume of water in the chamber. This volume of water will equal the combustion chamber's displacement—in other words, its volume.

Density and specific gravity

Lead is often described as a heavy metal while aluminum is called a light metal. More precisely, a lead block that is identical in size to an aluminum block will be heavier than the aluminum block. To be even more precise, we can say that the lead has a greater density than does aluminum.

"Density" is the ratio of a mass to a volume or the ratio of a weight to a volume. In the metric system, mass density is found by the equation:

$$\text{density} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$

The most common units of mass density are kilograms per cubic metre (kg/m^3) or grams per cubic centimetre (g/m^3).

In the imperial system of measurement, weight density is found by using the equation:

$$\text{density} = \frac{\text{weight}}{\text{volume}} \quad \text{or} \quad D = \frac{wt}{v}$$

The most common weight density units are pounds per cubic foot (lb./ft.^{3}) and pounds per cubic inch (lb./in.^{3}). The density values for a variety of materials are shown in Figure 6.

Substance	Mass density kg/m^3	Weight density lb./ft.^{3}
Air	1.30	0.08
Aluminum	2700.00	170.00
Brass	8400.00	520.00
Concrete	2300.00	140.00
Ethyl alcohol	790.00	48.00
Fir, Douglas	500.00	31.00
Gasoline	680.00	42.00
Gold	19 000.00	1200.00
Ice	920.00	58.00
Iron and steel	7800.00	480.00
Lead	11 000.00	700.00
Mercury	13 600.00	830.00
Oak, white	720.00	45.00
Pine, lodge pole	450.00	28.00
Silver	10 500.00	660.00
Walnut, black	600.00	37.00
Water, pure	1000.00	62.00
Water, sea	1300.00	64.00

Figure 6 — Densities of some materials

Density often influences the strength and other physical properties of materials. However, when weight is a major factor, as it is in the construction of airplanes and automobiles, material density automatically also becomes a factor.

Specific gravity is closely related to density. The specific gravity of a solid or liquid is defined as the ratio of the object's density to the density of water (which has been assigned a specific gravity of 1.0). The specific gravity of an object tells you how many times as 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. A material with a specific gravity of precisely 1.0 will stay suspended under the surface.

For example, the specific gravity of aluminum is found by either dividing 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.

Metric calculation:

$$\text{specific gravity} = \frac{\text{mass density}}{\text{mass density of water}}$$

$$\text{specific gravity of aluminum} = \frac{2700\ \text{kg}/\text{m}^3}{1000\ \text{kg}/\text{m}^3}$$

$$= 2.7$$

Imperial calculation:

$$\text{specific gravity} = \frac{\text{weight density}}{\text{weight density of water}}$$

$$\text{specific gravity of aluminum} = \frac{170\ \text{lb.}/\text{ft.}^3}{62\ \text{lb.}/\text{ft.}^3}$$

$$= 2.7$$

There are no units associated with specific gravity. When you divide as shown above, the units cancel out.

In addition, the specific gravity of any material that will float in water tells you what percentage of the volume will be submerged if a piece of the material is thrown into the water. For example, a floating pine log (specific gravity of pine = 0.37) will have 37% of its volume submerged.

Impenetrability

Impenetrability means that two objects cannot occupy the same space at one time.

To understand the concept of impenetrability, consider the possibility of two blocks of wood occupying the same space at the same time.

It cannot be done: one block can be on top of the other, or the two can be touching each other, but they cannot occupy the identical space at the same time.

Summary of equations and relationships

You should be able to recall and use the following equations and relationships:

newton	$N = kg \times m/s^2$
gravitational force (or weight)	$F = m \times g$ ($w = m \times g$)
acceleration due to gravity	$g = 9.8\ m/s^2$ ($g = 32\ ft./s^2$)
mass density	$D = \frac{m}{v}$
weight density	$D = \frac{wt}{v}$
specific gravity (metric)	$\text{sp. gr.} = \frac{\text{mass gravity}}{\text{mass density of water}}$
specific gravity (imperial)	$\text{sp. gr.} = \frac{\text{weight density}}{\text{weight density of water}}$
density of water	$D = 1000\ kg/m^3$ ($D = 62\ lb./ft.^3$)

Calculations

The concepts introduced in this Learning Task can be used to solve problems encountered by tradespeople.

Example 1 (Determining adequacy of equipment)

A small hydraulic jack has a rating marked on it that says it should not be used to raise a weight greater than 500 N. Determine if the jack is adequate to safely raise a drum having a mass of 45 kg.

Solution

Weight is the product of a mass and the acceleration of gravity. In metric units, the gravitational acceleration is $9.8\ m/s^2$.

$$w = m \times g$$

$$= 45\ kg \times 9.8\ m/s^2$$

$$= 441\ N$$

The drum weighs 441 N. It is within the rated working load limit capacity of the jack, but should not be left unattended in the raised position.

Example 2 (Determining additional contents in prefabricated materials)
A 3600 kg standard concrete slab is delivered to a work site. It measures 3 m × 2 m × 20 cm. Can you roughly determine if the slab has been made with reinforcement rod?

Solution
Find the density of the concrete slab. If the density is greater than the density for concrete that is given in Figure 5, then you may conclude that it does contain some type of reinforcing material.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$\begin{aligned}\text{volume} &= L \times W \times H \\ &= 2\text{ m} \times 3\text{ m} \times 20\text{ cm} \\ &= 2\text{ m} \times 3\text{ m} \times 0.20\text{ m} \\ &= 1.2\text{ m}^3\end{aligned}$$

$$\begin{aligned}\text{density} &= \frac{3600\text{ kg}}{1.2\text{ m}^3} \\ &= 3000\text{ kg/m}^3\end{aligned}$$

Since the density of concrete is 2300 kg/m^3, you have roughly determined that the slab has been made with reinforcement rod.

Example 3 (Finding weight using density and volume)
You are asked to build a form for a concrete footing. You are told that the length and width are both 3 feet and the height is 2 feet.

Find the weight of the concrete that would fill this form.

Solution
First, find the volume of the form.

$$\begin{aligned}\text{volume} &= L \times W \times H \\ &= 3\text{ ft.} \times 3\text{ ft.} \times 2\text{ ft.} \\ &= 18\text{ ft.}^3\end{aligned}$$

Use the weight density of concrete (from the table in Figure 5) to solve the weight density equation for weight.

$$\text{density} = \frac{\text{weight}}{\text{volume}}$$

$$\text{weight} = \text{density} \times \text{volume}$$

Insert the known values into the newly arranged equation:

$$\begin{aligned}\text{weight} &= \text{density} \times \text{volume} \\ &= 140 \text{ lb./ft.}^3 \times 18 \text{ ft.}^3 \\ &= 2520 \text{ lb.}\end{aligned}$$

The concrete footing will weight 2520 lb.

Example 4 (Identifying materials using mass density)
You have been given two metal castings. Object A has a mass of 160 g and displaces 60 cm^3 of water when placed in a metric measuring cup. Object B has a mass of 112 g and displaces 65 cm^3 of water. Use the table shown in Figure 7 to identify the metal in castings A and B.

Mass density		
	kg/m^3	g/cm^3
Aluminum	2700	2.7
Brass	8400	8.4
Iron	7800	7.8
Magnesium	1700	1.7

Figure 7 — Mass density of some materials

Find the mass densities of the two objects and then find the closest values from the chart in Figure 6. Because you are given density values in g/cm^3, there is no need to change the given values into the usual kg and m^3.

Object A

$$\begin{aligned}\text{density} &= \frac{\text{mass}}{\text{volume}} \\ &= \frac{160 \text{ g}}{60 \text{ cm}^3} \\ &= 2.67 \text{ g/cm}^3\end{aligned}$$

Object A is probably made of aluminum, as their densities are almost identical.

Object B

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{112\text{ g}}{65\text{ cm}^3}$$

$$= 1.72\text{ g/cm}^3$$

The density of magnesium is given as 1.7, which is almost identical to the density of Object B. Casting B is made from magnesium.

Now complete the Learning Task 1 Self-Test 1: Structure of matter.

Self-Test 1: Structure of matter

1. What is the name for most basic building block of all matter?
    a. The atom
    b. The quark
    c. The newton
    d. The molecule

2. What are the three general states of matter?
    a. Cold, cool, and hot
    b. Solid, liquid, and gas
    c. Organic, inorganic, and plasma
    d. Molecule, compound, and mixture

3. What is the term used to describe the force of attraction between dissimilar molecules?
    a. Cohesive forces
    b. Adhesive forces
    c. Attractive forces
    d. Gravitational forces

4. What is the unit of force used in the metric system?
    a. Pascal
    b. Newton
    c. Kilogram
    d. Pounds per square inch

5. What is the unit of mass used in the metric system?
    a. Pound
    b. Pascal
    c. Kilogram
    d. Newton

6. What is the approximate metric value for the acceleration due to gravity?
    a. 32 feet per second^2
    b. 9.8 metres per second
    c. 9.8 metres per second^2
    d. 32 metres per second

7. What is the term "volume" used to describe?
   a. The density of an object
   b. The metric term for force of gravity
   c. The weight of an object compared to water
   d. The amount of space an object occupies or a container holds

8. How is the term "mass density" best described?
   a. The ratio of a mass or weight to a volume
   b. The portion of an object at its most dense
   c. The comparison of an object's mass to that of water
   d. A description of the densest material known to humans

9. In metric, what is the most common unit of mass density?
   a. kg/L
   b. kg/m^3
   c. $lb./m^3$
   d. $lb./ft.^2$

10. If salt water is denser than fresh water, what would the specific gravity of salt water be?
    a. SD=1
    b. SD= <1
    c. SD= >1
    d. Salt water doesn't have a specific gravity, only fresh water does.

11. Given that oak has a specific gravity of 0.72, approximately what portion of a block of oak floating in fresh water would be submerged?
    a. 28%
    b. 72%
    c. 100%
    d. More information is needed

12. What does the term "specific gravity" describe?
    a. The buoyancy of salt water
    b. The specific acceleration due to gravity
    c. A ratio of a substance's weight compared to air
    d. A ratio of a substance's density compared to fresh water

13. Why do objects experience higher buoyancy in salt water than in fresh water?
    a. Salt water has a higher specific gravity than fresh water.
    b. Objects have less buoyancy in salt water than fresh water.
    c. The salinity of salt water creates negative ions to support the object.
    d. An object has the same buoyancy in salt water as it does in fresh water.

14. A 100 cm^3 block of iron dropped into a tank of water will displace 200 cm^3 of water.
    a. True
    b. False

15. When determining a solid's specific gravity, one is comparing the solid's density to the density of iron.
    a. True
    b. False

Describe the basic properties of solids

Solids are used extensively in the fabricating, casting, welding, and construction trades. This Learning Task introduces the basic properties of solids in general, and metals in particular.

The properties of solids can be grouped into two categories: mechanical and physical.

Mechanical properties

Mechanical properties are the front-line resistances that solids offer to the forces that act on them. When we say something is tough, strong, or durable, we are referring to the mechanical properties of the material. These properties are called mechanical because they predict how the material will react when it is used in a mechanical situation such as carrying a load, resisting a rubbing action, or absorbing a shock.

Stress

A very important mechanical property is the material's ability to react to stress. When an external force acts on a solid, the molecular forces of the material try to resist the changes. The interaction of the external and internal forces creates stress on the material.

Engineers and physicists have identified four main types of stress. In order to select an appropriate material for a specific job, the material's ability to resist job-associated stresses must be considered.

The four types of stress that act on a solid are:

- tension
- compression
- shear
- torque

Tension

Tension is a stress caused by an external force trying to stretch a body. For example, a rope is under tension when it has a weight hanging from it.

Tensile strength is one of the most important properties evaluated in a metal. This strength is the resistance a material offers to a force that is gradually and steadily trying to pull it apart. Supporting cables, for example, must be carefully evaluated for tensile strength. 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 1 sq. in. or 1 sq. cm. The tensile strength of mild steel pipe, for example, is 60 000 pounds per square inch (psi). Figure 8 shows tensile strength being tested.

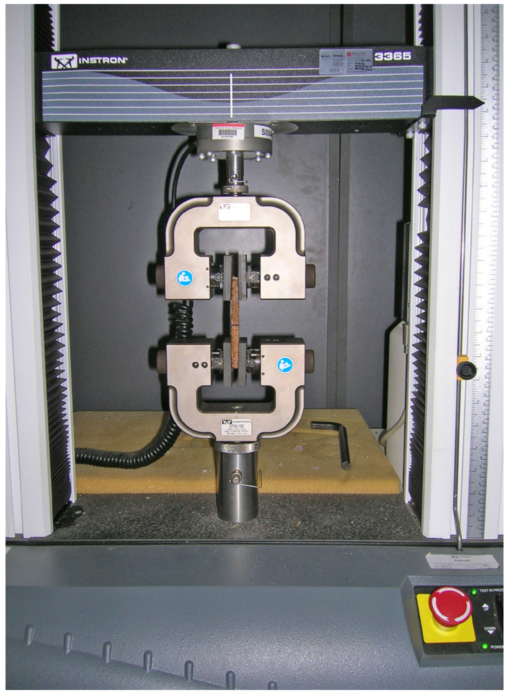


Figure 8 — Tool testing tensile strength

Compression

Compression is a stress caused by an external force trying to push into or against a body. The foundation of a house is subject to a constant compression stress. Support beams, columns, and girders made from metal and wood should be compression rated.

Shear

Shear is a stress caused by two or more external forces trying to force a body to change its shape but not its volume. The shear strength of a material is about 40% of its tensile strength. Rivets and bolts holding together two pieces of material that may slide over one another are subject to shearing stress. Shear often causes cracks or fractures in materials under any type of stress. For example, early feller-buncher machines used in the forestry industry to snip down trees sometimes caused cracks to run great lengths through the tree due to the stress created by the shearing.

Torque

Torque is a stress caused by a turning force. A rotating automobile drive shaft is subject to a twisting stress when under a heavy load.

In short, tension stretches, compression shrinks, shear shifts or cuts, and torque twists. All four stresses are shown in Figure 9.

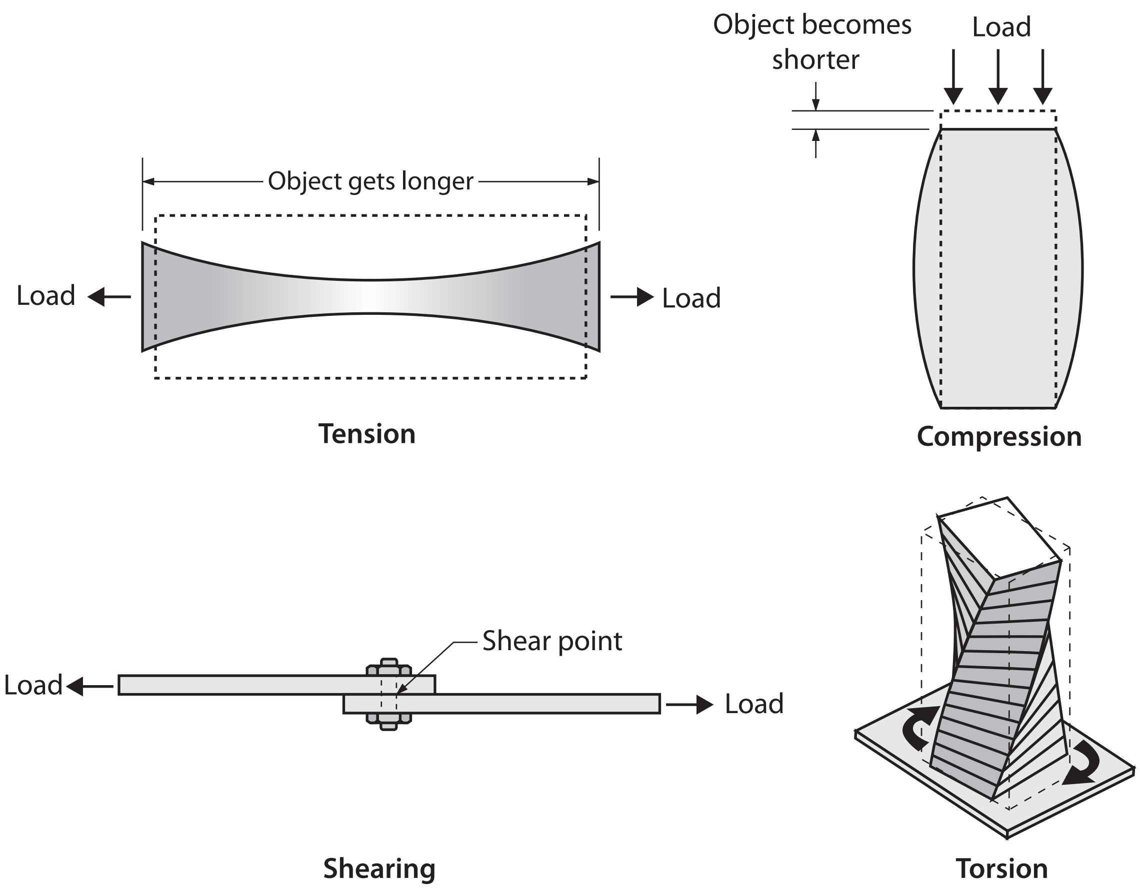


Figure 9 — Stress types

Technically, stress is defined as the ratio of an external force (often called a "load") and the area affected by the force.

Mathematically,

$$\text{stress} = \frac{\text{external force}}{\text{area over which force acts}}$$

$$S = \frac{F}{A}$$

The stress equation is often solved to find the acting force and becomes:

$$F = \text{stress} \times \text{area}$$

$$F = S \times A$$

The most common units of stress are newtons per square metre (N/m^2), pascals (Pa), and pounds per square inch ($lb./in.^2$). Stress and pressure use the same units.

Strain

The physical effect of stress on a material is called "strain." Strain is the relative change in size of the material caused by stress. Although we cannot always see a change caused by stress in a material, material technologists have discovered that even minute forces do change the shape of material. For example, sensitive measuring devices can detect the compression of a train rail caused by a sparrow landing on it!

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.

We think of rubber as being very elastic, but when compared to special steels used in timing springs, rubber barely earns its elastic reputation.

Elastic limit

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 material's "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 flattened or shaped long after the elastic limit is reached particularly if they are heated.

Ultimate strength

The point at which a material finally breaks is called its "ultimate strength." Elastic limit and ultimate tensile strength (which is usually the same as ultimate elastic strength) for several materials are shown in Figure 10. Materials also have ultimate compression and shear strengths. When materials are used at close to their strength limits, they must be reinforced. Steel rods are used in concrete and glass fibres are used in plastics to increase the strength of the material. 1 MPa = 1 000 000 N/m^2.

Material	Elastic limit		Ultimate strength			
			Tensile		Compression	
	MPa	lb./in.^{2}	MPa	lb./in.^{2}	MPa	lb./in.^{2}
Aluminum	180	26 000	200	29 000	200	29 000
Concrete			3	400	140	2000
Copper	150	22 000	340	49 000	340	49 000
Iron, cast	160	23 000	170	24 000	170	80 000
Pine	30	4000	40	6000	40	5000
Steel, hard	250	36 000	500	73 000	500	73 000
Steel, tempered	1170	170 000	1380	200 000	1380	200 000

Figure 10 — Elastic limit and ultimate strength

Elasticity and safety

Elastic limit and ultimate strength values are important to understand to safely use materials. For example, if a crane cable is subjected to a force beyond its elastic limit, the cable will be deformed, creating a weak spot. In fact, not only will the elastic limit of the cable be reduced markedly, the ultimate strength of the now reduced-capacity cable can be reached unexpectedly during a future lift. Cable failure during a lift would have disastrous results.

Materials that are repeatedly required to handle loads close to their elastic limit often experience fatigue. Even a minor stress that is repeatedly administered to the material can cause failure. For example, a diesel engine operating at 3000 rpm undergoes close to 200 000 stress cycles per hour of operation. Any imperfection in the cylinders, crankshaft, valves, or wrist pins can lead to an expensive breakdown.

Ultimate strength values are often used to determine a factor of safety on a job site. A service elevator is an example. In essence, a service elevator should be overbuilt. If the elevator is expected to carry a maximum of 1000 kg but is actually capable of carrying 5000 kg, it has a safety factor of 5. The factor of safety is the ratio of the potential load the elevator is capable of carrying and the actual load it is expected to carry.

$$\text{factor of safety} = \frac{\text{potential load}}{\text{actual load}}$$

The engineer designing the elevator uses the ultimate strength value of the cables to calculate and build in an appropriate factor of safety.

Hardness

Hardness is a material's ability to resist a force that is trying to penetrate it. These penetrating forces attempt to push molecules apart. Hardness is associated with durability and abrasion resistance.

If you are using a material that has a hardness rating, the following will help you understand what the rating means.

There are several methods used to determine hardness. The scratch test is based on the premise that under standard conditions a harder material will always scratch a softer material. A scale has been devised that compares the scratch hardness of most materials to 10 other materials with hardness ranging from the very soft to the hardest substance known (Figure 11).

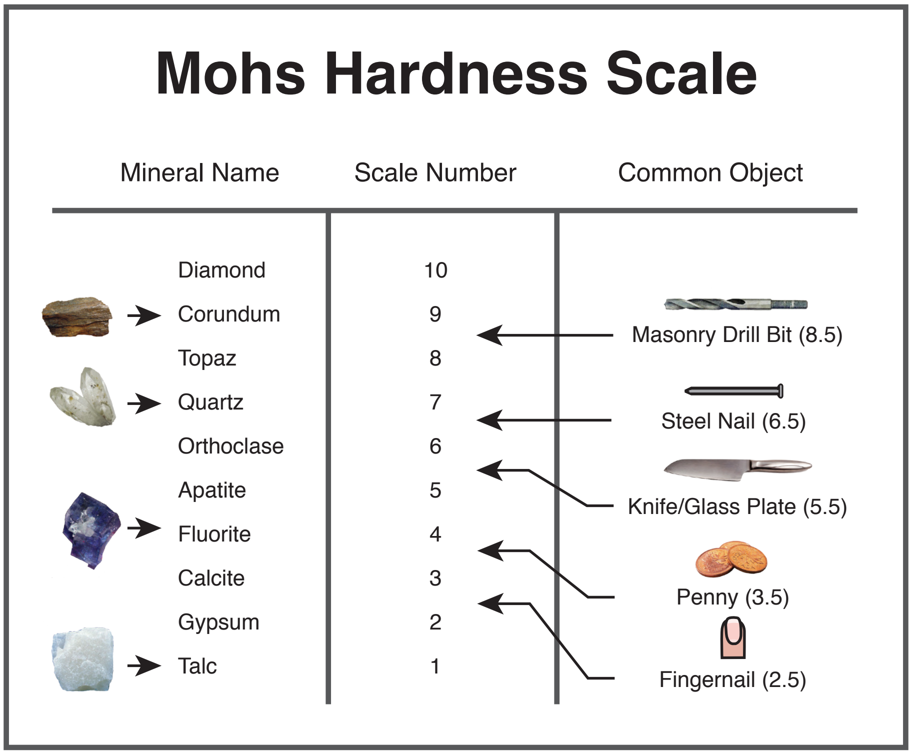


Figure 11 — Scratch test materials

Several other hardness tests are based on how a controlled force and mass affect the tested subject. In the Brinell test, a hard steel ball is forced into the surface of the material. The area of the resulting impression is divided into the load used to make the impression. This number is known as the "Brinell number."

The Rockwell, the Shore, and the Vickers hardness tests are variations of the Brinell test and have similar scales.

Johan Brinell (1849–1925) was a Swedish engineer who proposed the first widely used and standardized hardness test in engineering and metallurgy.

Brittleness

Hardness and brittleness are different properties. Brittleness is the absence of another physical property, malleability (see below).

Steel and glass are both hard, but steel (particularly annealed steel, which is steel that is heated and then cooled slowly) is much less brittle and so considered tougher than glass.

Toughness

Toughness refers to the ability of a material to withstand a permanent change. A combination of strength and ductility is required to have toughness.

For example, laminated wood is used in arched rafters because the laminations allow the wood to retain the desired but unnatural curve. A laminated rafter is tougher than a single piece of wood that has been curved by applying a large stress.

You should also be aware that the terms "hardwood" and "softwood" do not refer to the relative hardness of wood, but simply to the type of tree producing the wood. All the hardwoods come from trees that lose their leaves (deciduous trees), while all the softwoods come from trees that retain their needles (coniferous trees). Unfortunately, this categorization can be confusing, as many types of softwood are relatively hard.

Ductility and malleability

Ductility is the ability of a material to be drawn out through a die and stretched into thin wire without pulling apart or breaking (Figure 12). The finer the wire that can be produced, the more ductile the material. Platinum, gold, silver, and copper are highly ductile; in fact, gold threads can be woven into fabrics. Molten glass can also be formed into fine threads.

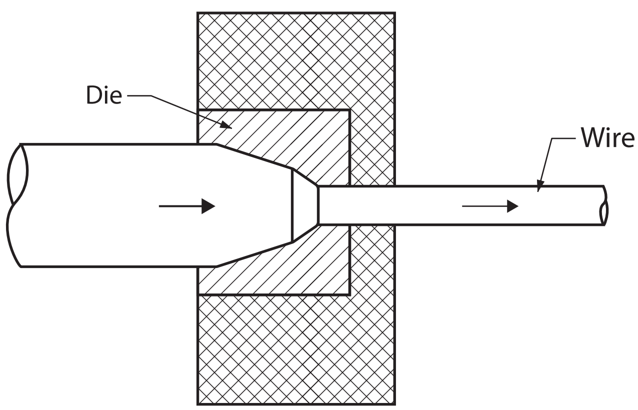


Figure 12 — Ductility

Ductility should not be confused with elasticity. Ductility is the ability to stretch or withstand strain and maintain the new shape. Elasticity is the ability to elongate and then return to the original shape.

Malleability, a property similar to ductility, is the ability of a material to be permanently deformed by compression forces such as hammering or rolling (Figure 13). Materials having high malleability can be hammered or bent into numerous shapes. Highly malleable metals are often produced as very useful thin sheets. Aluminum foil, for example, is extremely thin yet does not allow moisture or light to pass through it.

Malleable steel is used extensively in the automotive, shipbuilding, and other manufacturing industries.

Figure 13 — Malleability allows steel to be hammered into endless shapes.

Both of these mechanical properties are aspects of plasticity, the extent to which a solid material can be plastically deformed without fracture. However, just because a material possesses one property does not always mean it has the other. For example, while gold has high ductility and malleability, lead has low ductility but high malleability.

Physical properties

Physical properties are those properties that are inherent to the material but are not related to the ability to withstand the application of physical stresses. Physical properties include electrical and thermal characteristics.

Electrical conductivity

Electrical conductivity is the ability of a material to conduct an electrical current. Metals that have high conductivity include gold, silver, copper, aluminum, and steel. Copper and aluminum are the most common materials used in electrical wires.

You must be careful when using conductive materials around electrical power sources. For example, a copper pipe or aluminum ladder accidentally making contact with a power line can cause a fatal shock. Substances that are poor in electrical conductivity are also important. Such materials as hard rubber, Bakelite, glass, and oil are used as insulators to contain current.

Thermal conductivity

Thermal conductivity is a measure of the rate at which heat flows through a material. The difference in thermal conductivity between iron and copper is illustrated in Figure 14. The copper conducts heat at a much higher rate and lights the match first. The match at the outer end of the iron bar will burst into flame later.

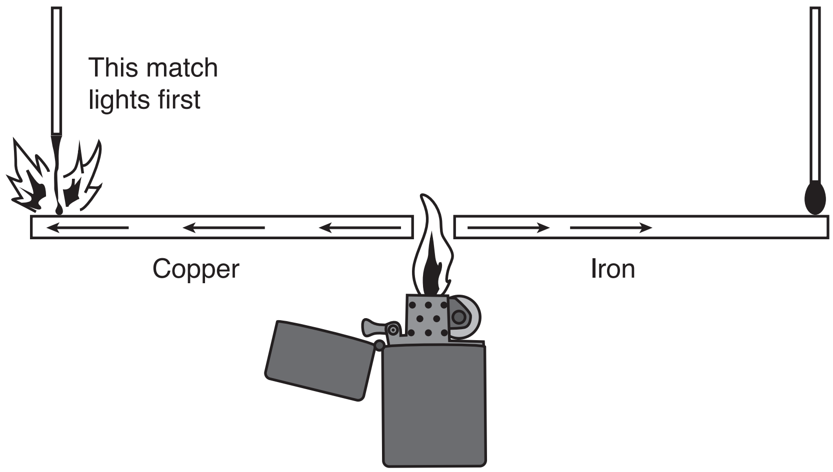


Figure 14 — Thermal conductivity

Thermal conductivity has important industrial implications. For example, when welding you must be constantly aware of thermal conductivity or you run the risk of overheating the metal and possibly destroying some of its desirable properties.

Thermal expansion

Thermal expansion is the increase in the dimensions of a material as a result of a change in temperature. Most materials expand when heated and contract when cooled. This expanding and contracting must be taken into account when a large mass of material is being used. For example, the length of a long steel-decked bridge can vary by more than a metre between cold and hot seasons. Expansion joints are built into the bridge deck to compensate for this variation in length. In a similar fashion, in an automobile engine, using the proper gaskets compensates for the difference in the thermal expansion rates of an aluminum head attached to an iron block.

Corrosion resistance

Corrosion resistance is the ability of materials to resist combining with undesirable elements and chemical compounds. Corrosion is basically a material's reaction to its environment.

The most familiar type of corrosion is the rusting that occurs on ferrous metals. The iron in ferrous metals combines with oxygen to form iron oxide (that is, rust). If the interaction between iron and oxygen is not checked, all the iron in the ferrous metal will eventually rust away.

Other metals also oxidize, but the effects of oxidation vary. Aluminum, for example, oxidizes very rapidly, but the aluminum oxide actually forms a film of metal that effectively protects the aluminum from further reaction. Unfortunately, this oxide acts as an electrical insulator and can create heat problems at the connecting points of aluminum wires. Oxidation also makes fabrication difficult.

Although the actual electrochemical reactions and metallurgical factors affecting corrosion are beyond the scope of this Learning Task, you should be aware of the reactions a metal or metal alloy may have with another metal or alloy. In general, when two dissimilar metals are in contact with one another and there is water present, an electrical current will be produced. This process is called "electrolysis." The electron flow will corrode or even disintegrate the metals. The table shown in Figure 15 contains the names of metals listed in such a way that each metal is corroded by all those metals that are listed after it. This list is sometimes referred to as the "galvanic series."

Most reactive	
1	Magnesium
2	Zinc
3	Cadmium
4	Aluminum
5	Steel
6	Iron
7	Stainless steel
8	Solder
9	Lead
10	Tin
11	Nickel
12	Brass
13	Copper
14	Bronze
15	Silver-solder
16	Silver
17	Titanium
18	Graphite
19	Gold
20	Platinum
Least reactive	

Figure 15 — Galvanic series

The galvanic series implies that if you are working on metallic materials or with metal tools, you must take care to prevent corrosion. Carpenters must store metal tools and materials properly. Fabricators must be sure that highly interactive metals are not stored together.

The potential for corrosion is also a factor that mechanics, welders, fabricators, and piping tradespeople must keep in mind when selecting and storing materials. For example, brake fluid, battery acid, and the paint finish of a car do not mix well. If either fluid were to come in contact with the paint, it would be ruined.

One major point that is often overlooked is that corrosion and rusting are often the result of poor industrial engineering design. For example, if water is able to sit in a crevice of an automobile door, the door panel at the recess will eventually rust even if the door is made from steel. Other potential high-corrosion areas exist around poorly sealed bolts, screws, and welds, particularly if the bolt screw or weld is composed of a metal different from the metal being fastened.

Summary of equations and relationships—solids

You should be able to recall and use the following formulae and relationships.

stress equation:

$$\text{stress (S)} = \frac{\text{force (F)}}{\text{area (A)}}$$

factor of safety:

$$\text{factor of safety} = \frac{\text{potential load}}{\text{actual load}}$$

Note:

$$1\ \text{Pa} = 1\ \text{N/m}^2$$

$$1\ \text{kPa} = 1000\ \text{N/m}^2$$

$$1\ \text{MPa} = 1\,000\,000\ \text{N/m}^2$$

☑ Now complete the Learning Task 1 Self-Test 2: Describe the basic properties of solids.

Self-Test 2: Describe the basic properties of solids

1. What is referred to when a solid is said to have mechanical properties?
   a. The location of a solid in a combustion engine
   b. The usefulness of a solid in a mechanical system
   c. The ratio of the solid's density compared to water
   d. The solid's resistance to physical forces acting upon it

2. Which term best describes an external force trying to stretch a body of material?
   a. Shear
   b. Torque
   c. Tension
   d. Compression

3. Which term best describes an external force trying to push into a body of material?
   a. Shear
   b. Torque
   c. Tension
   d. Compression

4. Which term best describes an external force trying to change the shape of a body of material?
   a. Shear
   b. Torque
   c. Tension
   d. Compression

5. Which term best describes an external force trying to twist a body of material?
   a. Shear
   b. Torque
   c. Tension
   d. Compression

6. Which term best describes a physical change in a material as a result of stress?
   a. Strain
   b. Elasticity
   c. Hardness
   d. Durability

7. Which term best describes a material's ability to return to its original dimensions after a stress has been applied?
   a. Strain
   b. Elasticity
   c. Hardness
   d. Durability

8. Which term best describes the point at which a material under stress finally breaks?
   a. Elastic limit
   b. Tensile strength
   c. Ultimate strength
   d. Compression strength

9. Which statement best describes a safety factor of five?
   a. A piece of equipment can carry a load up to five tons.
   b. A piece of equipment has an ultimate strength of five tons.
   c. A piece of equipment will fail if a load carried is five kilograms over the rating.
   d. A piece of equipment can carry a load five times heavier than its rating.

10. Which term best describes a material's ability to resist a penetrating force?
    a. Ductility
    b. Hardness
    c. Brittleness
    d. Malleability

11. Which term best describes a material's lack of malleability?
    a. Ductility
    b. Elasticity
    c. Hardness
    d. Brittleness

12. Which term best describes a material's ability to be drawn into a wire without breaking?
    a. Ductility
    b. Elasticity
    c. Brittleness
    d. Malleability

13. Which term best describes a material's ability to be permanently deformed by compression forces?
    a. Ductility
    b. Elasticity
    c. Brittleness
    d. Malleability

14. Which term best describes a material's ability to conduct heat?
    a. Galvanic series
    b. Corrosion resistance
    c. Thermal conductivity
    d. Electrical conductivity

15. Which term best describes a material's ability to conduct an electrical current?
    a. Galvanic series
    b. Electrical resistance
    c. Thermal conductivity
    d. Electrical conductivity

16. What physical change occurs when a material's temperature rises?
    a. Thermal current
    b. Thermal expansion
    c. Thermal contraction
    d. Thermal conductivity

17. Which statement best describes the relationship between metals in the galvanic series?
    a. The closer the metals are in the series, the more corrosive they are.
    b. The greater the difference in the series, the quicker corrosion will occur.
    c. The greater the difference in the series, the stronger the magnetic attraction is.
    d. The closer the metals are in the series, the better electrical conductors they are.

18. If a length of wire rope is rated to carry a maximum of 1000 kg, with a safety factor rating of five, its ultimate strength value is 5000 kg.
    a. True
    b. False

Describe the basic properties of liquids

Liquids have many applications in all of the trades. Commonly used liquids include water, paints, lubricants, coolants, hydraulic fluids, and fuels. In addition, many presses, jacks, and other lifting systems depend on liquids and their special properties for their operation. It is important, therefore, for you to understand the general properties of liquids.

Hydrostatics is the study of fluids under pressure and at rest. Some scientists and technicians consider gases and liquids to be a single category of matter identified by the term "fluids." However, here we will be treating gases and liquids separately.

Cohesion and adhesion

Like solids, liquid molecules are held together by cohesive force, although this force is not as strong in liquids as it is in solids. This limited cohesive force gives liquids their familiar ability to pour and to adopt the shape of their storage containers.

Just as important as their weak cohesive forces are the strong adhesive forces of liquids, which allow many liquids to attach themselves to the surfaces of materials. Water wets because of the presence of adhesive forces that surpass the intensity of water's cohesive forces. For the same reason, certain oils adhere to the surfaces of some metals. Indeed, the adhesive quality of oils is an important consideration in the manufacture of lubricants.

Adhesive force also allows liquids to act as coolants. The wet coolant sticks to the solid being worked and removes heat from the material. Some coolants are a mixture of water, oil, and a special soap that allows the two principal ingredients to mix (an emulsifier). This type of emulsion is often used to cool metals being machined on a lathe or drill press.

Specific gravity

Remembering that specific gravity tells you how many times heavier a substance is compared to the weight of the same volume of water, the general equations that can be used to find specific gravity are:

specific gravity (metric):

$$\text{sp. gr.} = \frac{\text{mass density}}{\text{mass density of water}}$$

specific gravity (imperial):

$$\text{sp. gr.} = \frac{\text{weight density}}{\text{weight density of water}}$$

These equations apply equally to liquids. The concept of specific gravity when coupled with buoyancy has very important applications in liquids.

Buoyancy

An object placed in water seems to lose weight. In fact, if you attach a scale to an object, weigh it and then, with the scale attached, lower the object into water, the scale will indicate that the object weighs less than it did out of the water (Figure 16). This is because there is a force supporting the object.

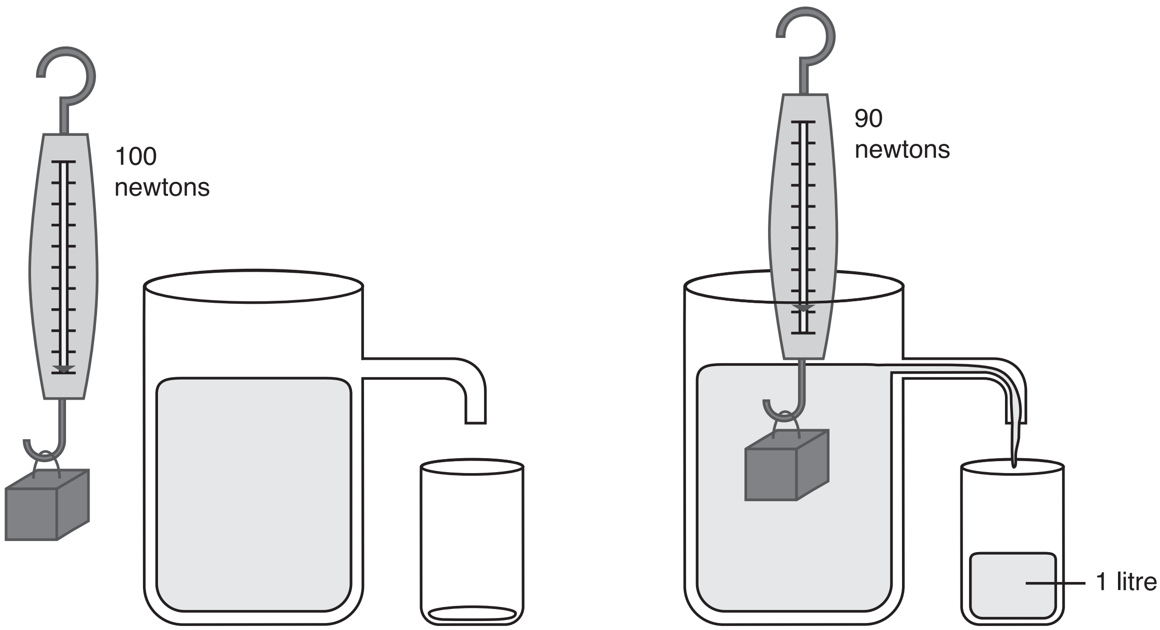


Figure 16 — Buoyant force

The force that is acting on the object in the water is called "buoyancy." You will also notice in Figure 15 that the amount of overflowing displaced water is equal to the volume of the fully submerged object. The Greek philosopher Archimedes analyzed the volume displacement, weight loss, and buoyant force. His conclusion is referred to as "Archimedes' principle":

> *A body wholly or partially immersed in a fluid is buoyed up with a force equal to the weight of the fluid displaced by the body.*

In other words, Archimedes' principle says that the weight of the volume of liquid displaced by an object is equal to the buoyancy force acting on the object—a floating object displaces its own weight of the liquid in which it is floating.

Archimedes' principle explains why human beings float, icebergs are almost entirely submerged, submarines can float or submerge, and why it is easier to float in salt water than fresh water.

Archimedes' principle also explains why objects that sink lose weight when submerged. For example, you can lift a larger stone under water than you can possibly lift in air because the buoyancy force of the water lifts part of the weight.

The buoyant force acting on an object submerged in water can be found by subtracting an object's weight in water from its weight in air:

$$\text{buoyant force} = \text{weight in air} - \text{weight in water}$$

For example, if an object weighs 10 lb. in air and weighs 8.5 lb. in water, the buoyant force is 1.5 lb., which is the weight of the displaced water.

The buoyant force is sometimes used to find the specific gravity of an object. The equation used is:

$$\text{specific gravity} = \frac{\text{weight of object in air}}{\text{buoyant force (in water)}}$$

Thus, the specific gravity of the object that weighs 10 lb. in the air and weighs 8.5 lb. in the water is:

$$\text{specific gravity} = \frac{10\text{ lb.}}{1.5}$$

$$\text{specific gravity} = 6.67$$

Remember that Archimedes' principle applies to all liquids. For example, a log that floats in water will also float in mercury. According to the principle, the volume of water and the volume of mercury displaced by the log will be different, but the weight of the displaced water and the weight of the displaced mercury will be the same. The volumes will differ because water and mercury have different specific gravities.

This difference in displaced volume is used in an instrument that measures the specific gravity of liquids.

Hydrometers

There are several ways to determine the specific gravity of a liquid. The most common way is to use a hydrometer, a special weighted rod that can find a floating level in the fluid being evaluated. The hydrometer is an application of Archimedes' principle: the denser the liquid, the less volume of liquid has to be displaced to equal the weight of the hydrometer.

Figure 17 shows a hydrometer set in containers of gasoline and antifreeze compared to a container of water.

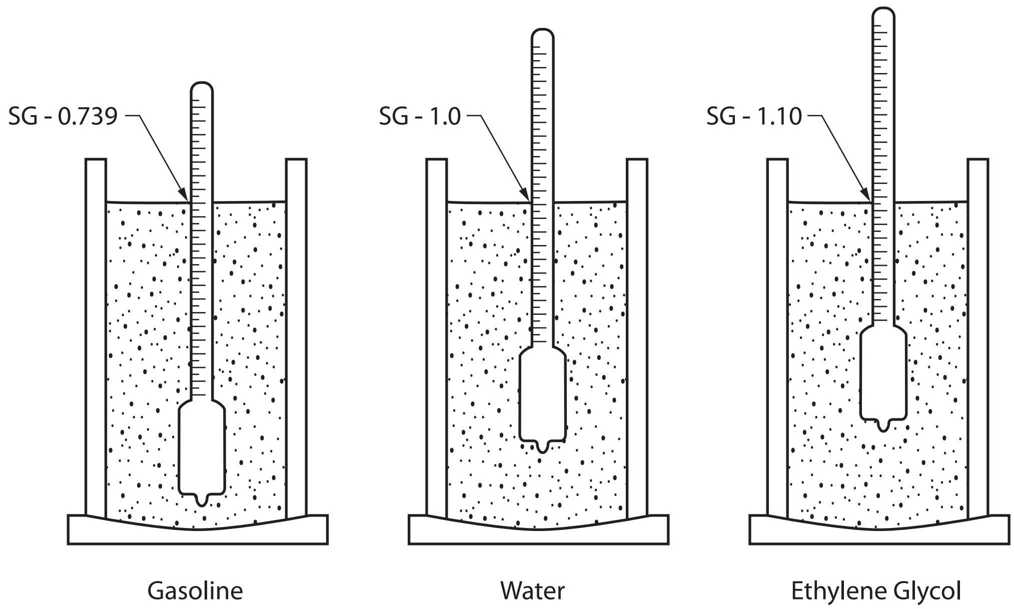


Figure 17 — Hydrometers showing specific gravity of fluids of various densities

The weights of the displaced fluids for each container are the same. However, the volume varies, causing the rod to float at different levels. This means that the gasoline must have a lesser density (and lesser specific gravity) than does water, whereas the ethylene glycol has a greater density than water.

The chart in Figure 18 shows the density of some other liquids. Note that gasoline's density varies by grade and octane levels.

Substance	Mass density kg/m^3	Weight density lb./ft.^{3}
Blood	1060	66
Gasoline	680	42
Ice	920	58
Mercury	13 600	830
Water, pure	1000	62
Water, sea	1300	64

Figure 18 — Density of liquids

Hydrometers are used to determine the specific gravity of alcohols, acids, gasoline, sugar products, and other liquids. A hydrometer is commonly used to determine the freezing point of an antifreeze solution in an automobile's cooling system. The higher the proportion of glycol to water in the antifreeze mixture, the lower the freezing point is.

The two types of hydrometers illustrated in Figure 19 are commonly used for automotive liquids testing during servicing.

Antifreeze hydrometer

Battery fluid hydrometer

Figure 19 — Hydrometers

Surface tension

The surface of a liquid acts as a sort of skin that allows objects with fairly high specific gravities to float. For example, a razor blade can be carefully placed on the surface of a bowl of water it will remain there.

This skin-like effect is called "surface tension"; it is caused by an excess of inward cohesive force applied to the surface molecules. Unlike the other molecules in the liquid, surface molecules do not have other molecules exerting an upward force on them (Figure 20).

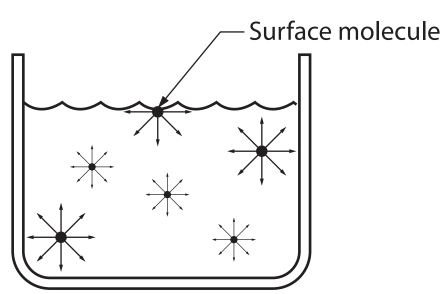


Figure 20 — Surface molecules

The net inward force causes the surface to compress. This compression not only gives the surface a "toughness," but also forces the surface molecules to occupy a minimum of space.

A sphere is the solid form than can enclose a maximum volume within a given surface area. Thus, droplets of water and other liquids are often seen in spherical form. Soap bubbles, raindrops, and hailstones are spherical because of surface tension.

A negative aspect of surface tension is that is can prevent a liquid from wetting a surface efficiently. For example, oil that beads instead of spreading itself evenly across a surface is only lubricating part of the surface. The result will eventually be that of uneven wear on the surface.

The petroleum industry has partially solved the beading problem by adding detergent products to their lubricating oils. These detergents, which are very much like those found in household cleaning products, reduce a liquid's surface tension.

In the soft-soldering process, acid flux reduces the melted filler metal's surface tension, allowing it to flow more easily into the very narrow annular space of the joint.

Detergents and other additives allow appropriate liquids to better penetrate beneath dirt, more effectively coat a surface, more evenly spread an agricultural spray, and even to better shampoo your hair.

Hydrostatic pressure

In addition to surface tension and buoyancy, there are several other important pressure properties. First, let us review the difference between pressure and force.

Pressure is a force per unit area:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

$$P = \frac{F}{A}$$

You will also recall that stress is defined as a force per unit area. Stress is, in fact, a special kind of pressure.

Pressure has the same units as stress. The most common units are newtons per square metre (N/m^2), pascal (Pa, where 1 Pa = 1 N/m^2) and pounds per square inch (psi or lb./in.^{2}).

Hydrostatic pressure increases with depth. You can sense this increase in pressure when you swim underwater. You will also notice that the pressure the liquid exerts on you comes from all directions.

Fluid pressure is the result of the weight of all the fluid above pushing down on the fluid below. Mathematically, pressure and depth are related:

$$\text{pressure of liquid} = \text{height (depth) of liquid} \times \text{weight (mass) density of liquid}$$

As you go deeper, there is a greater weight pushing down (Figure 21). This is the reason water pressure increases with depth. The pressure depends only on the depth and is the same anywhere at a given depth and in every direction.

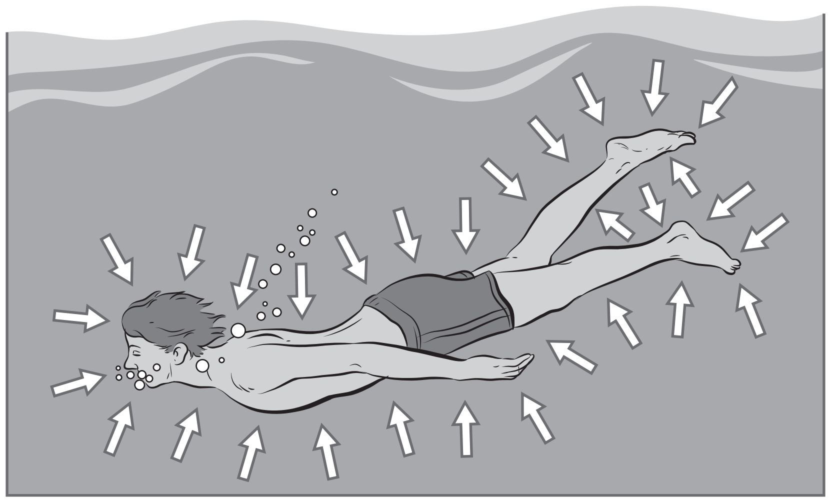


Figure 21 — Swimmer subject to increasing water pressure

Because of the difference between the concepts of mass and weight, the imperial and metric systems each have their own equation for finding pressure in a liquid.

Pressure = height of fluid × weight density (imperial)

= height of fluid × mass × force of gravity (metric)

$P = h \times D$ (in imperial where D is weight density)

$P = h \times D \times g$ (in metric where D is mass density and $g = 9.8\ m/s^2$)

Let's break these two equations down and look more closely at water, as this is the liquid that most measurements are based on.

Imperial

Water has a weight density of 62.4 lb./ft.^{3}; this means that one cubic foot of water (assumed at its most dense temperature of –4°C) exerts a force of 62.4 lb. Because the base of a cubic foot is equal to one square foot, the force of 62.4 lb. is exerted over an area of one square foot (Figure 21). Therefore, the pressure can be expressed as 62.4 lb./ft.^{2} or 62.4 psf. But as mentioned earlier, the most common unit of pressure in the imperial system is actually psi or lb./in.^{2}. So let's express our lb./ft.^{2} water pressure as pounds per square inch (psi) by dividing the pressure by 144 in.^{2} to find the pressure exerted over one square inch.

This equals:

$$62.4 \text{ lb./ft.}^2 \div 144 \text{ in.}^2/\text{ft.}^2 = 0.433 \text{ psi}$$

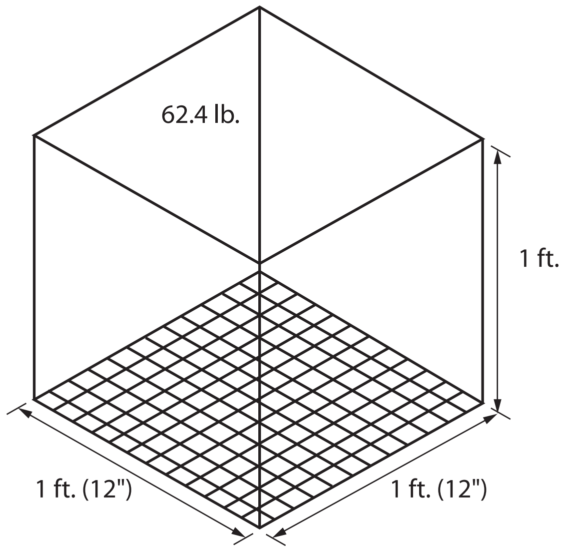


Figure 22 — Pressure equals force ÷ area

Therefore for every 12 in. (1 ft.) of water depth, the pressure exerted is 0.433 psi (Figure 23).

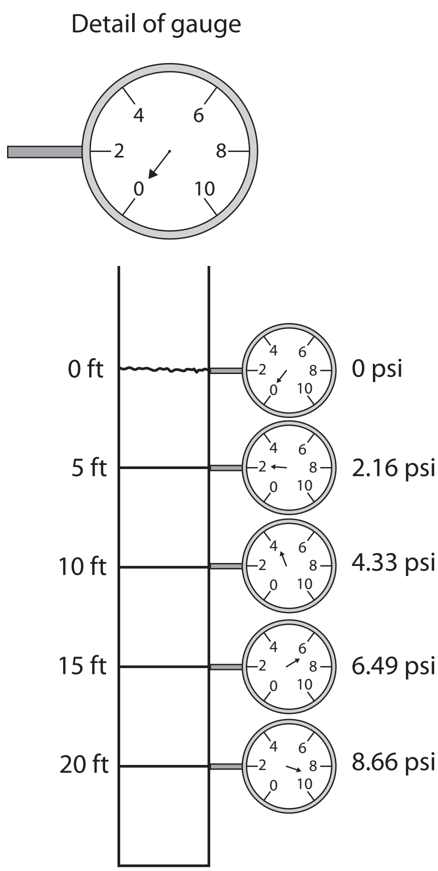


Figure 23 — Fluid pressure increases in proportion to depth

Metric

In the metric system, the basis for all pressures is the pascal, which represents the force in newtons exerted on each square metre.

Figure 24 — Portrait of Blaise Pascal. Anonymous portrait, 17th century.

> *Blaise Pascal (1623–1662) was a French mathematician and philosopher. He discovered the effect of pressure in liquids. The units used to measure pressure are called "pascals" in honour of his discovery.*

Water has a mass density of 1000 kg/m^3, which means that one cubic metre of water (assumed at its most dense temperature of –4°C) exerts a force of 9810 newtons (1000 kg × 9.8 m/s^2) of force on its square metre base.

$9810\ N/m^2 = 9810$ pascals $= 9.81$ kPa

A pascal is a very small unit of pressure, and therefore the kilopascal is more commonly used (Figure 25). Therefore for every one metre of water depth, the pressure exerted is equal to 9.81 kPa.

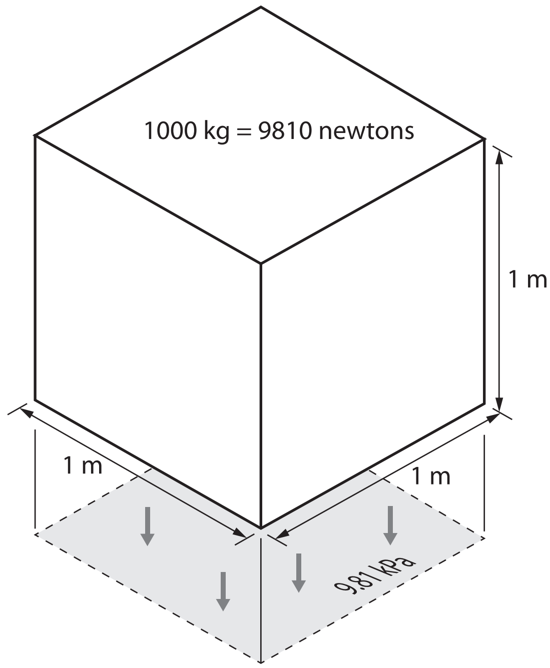


Figure 25 — Pressure under 1 m^3 of water = 9.81 kPa

The relationship between pressure and height is reflected in the design of liquid containment structures.

The pressure equation can be manipulated to solve for a total force over a given area, when the pressure is known:

force = pressure × area

$$F = P \times A$$

Force, then, is the product of pressure acting over an area.

Pascal's law

The pressures of liquids discussed so far are caused by the weight of the liquid. But what happens if an external pressure is applied to an enclosed liquid?

Consider the glass container shown in Figure 26. The body of the container has a number of fine, nipple-like holes inserted along its walls. The flask is filled with water and a tight-fitting plunger is inserted in the neck of the container. When the plunger is pushed, water will not only squirt from every hole, but the pressure of the spray will be the same from each hole. This observation led French mathematician Blaise Pascal to formulate his pressure law.

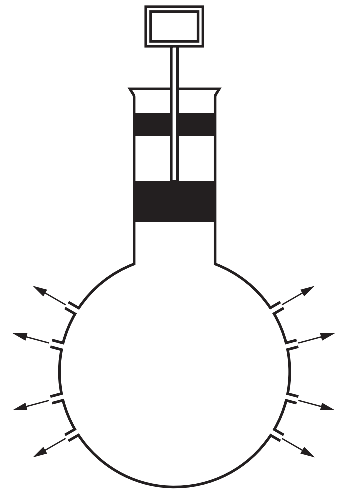


Figure 26 — Nipple flask

In general, Pascal's law states that an external pressure applied to an enclosed liquid is transmitted uniformly throughout the liquid.

This seemingly innocuous principle led to the development of the hydraulic press and the science of modern hydraulics. In honour of his discovery, the units of pressure measurement used in the metric system are called "pascals."

Hydraulic press

The hydraulic press (Figure 27) is used to transfer energy and multiply a force; it consists of a large piston and a small piston. When the small piston is moved downwards, a pressure is created that is transferred to the larger piston. The larger piston will move upwards.

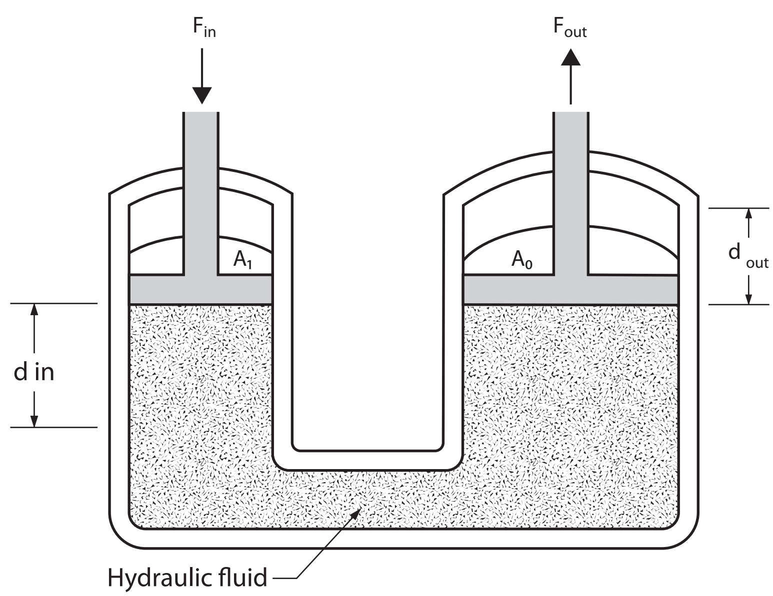


Figure 27 — Hydraulic press

Pascal's law says that the downward pressure applied by the smaller piston becomes an upward pressure on the larger piston. However, since the larger piston has a greater surface area than the smaller piston, the total force on the larger piston is much more than the force applied by the smaller piston.

It would be difficult to overemphasize the importance of Pascal's law on the hydraulic press. Its many industrial applications include lifting jacks, shock absorbers, and power steering and braking systems. Hydraulic presses are used to stamp out forms in sheet metal, to press juice from grapes, and to punch holes in metals.

Viscosity

Viscosity is a measure of a liquid's resistance to flow. The higher the viscosity of a liquid, the greater its resistance to being poured. Although the term "viscosity" can be applied to all liquids, it is most commonly associated with engine oils, paints, and machine lubricants.

A liquid's viscosity is determined by heating a precise quantity of the liquid to a specific temperature. The liquid is then timed as it drains through a special standardized funnel. The viscosity of the fluid is determined by the length of time it takes for the container to be emptied at a specific temperature.

The viscosity of a liquid changes as the temperature of the liquid changes. For example, motor oil lubricates more or less effectively depending on the temperature. At one temperature motor oil may splash adequately over parts in a splash pan, while at another temperature the same oil may be too viscous to splash.

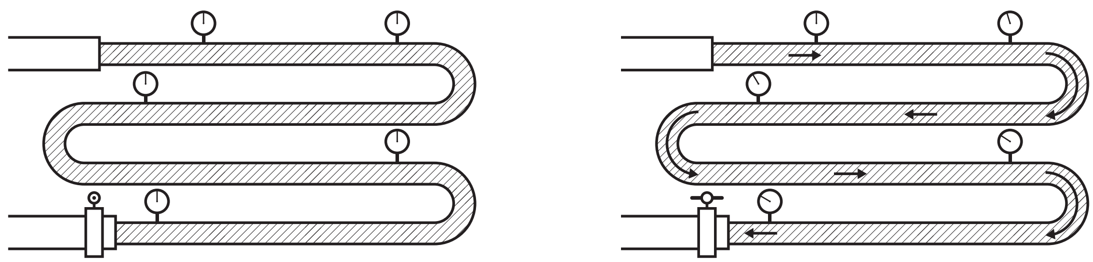
Good lubricating oil must be viscous enough to not be squeezed out of bearings, but yet not so thick as to resist the turning of the bearing. If an inappropriate lubricant in used in a situation where temperature changes can be great, the lubricating oil could very well break down and cause the bearings to burn out or to seize up.

Engine oils and other lubricants carry viscosity or SAE (Society of Automotive Engineers) numbers. The higher the SAE number, the "thicker" the oil at a given temperature. An engine operating at cold temperatures should use an oil with a lower SAE number than one operating at a higher temperatures, and vice versa. For example, SAE 10 oil is probably appropriate for cold weather operation but may be too thin to provide appropriate lubrication at hot temperatures. SAE 40 is adequate for hot weather but may not circulate properly in cold weather. The petroleum industry has a least partially solved the temperature/SAE rating problem by producing multigrade oils such as SAE 10–40 or SAE 5–30. These oils retain the optimum viscosity over a wide range of operating temperatures.

Hydrodynamic properties

Hydrodynamic properties are properties that come into play when a liquid moves. In a sense, viscosity can be considered a hydrodynamic property, as the true effects of viscosity are seen when a liquid moves.

When fluids are in a closed tube, pressure is distributed equally throughout the tube (Figure 28A). If a 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 28B).



A. Valve closed B. Valve open

Figure 28 — Pressure with liquids in motion

The loss of pressure is due to the moving liquid causing friction with any imperfections or slight constrictions in the tube. The amount of pressure drop due to friction is affected by a number of factors such as:

- viscosity of the fluid
- length of the tube
- velocity of flow (flow rate)
- size and type of tube
- number and type of fittings
- number and degree of bends

Figure 29 — Portrait of Daniel Bernoulli by Johan Jacob Haid, 18th century

> *Daniel Bernoulli (1700–1782) was a Swiss mathematician and physicist and one of the many prominent mathematicians in the Bernoulli family. He is particularly remembered for his applications of mathematics to mechanics, especially fluid mechanics, and for his pioneering work in probability and statistics.*

After studying the actions of liquids in pipes and tubes, Daniel Bernoulli concluded that:

- When the velocity of a fluid is high, the pressure is low.
- When the velocity of a fluid is low, the pressure is high.

This is known as Bernoulli's principle and is one of the fundamental ideas in fluid dynamics. There are numerous applications of Bernoulli's principle, including aeronautics design. An airplane wing is designed in such a way that the air travels slower on the bottom of the wing than on the top, creating more pressure underneath, pushing the wing upwards.

One early application of Bernoulli's principle was the venturi gauge or meter. The venturi gauge is a section of pipe containing a carefully designed constriction and thin vertical tubes called "manometers" (Figure 30). The gauge is installed as a section of a longer pipe. When the fluid is at rest in the piping system, some of the fluid will rise in the manometers. The level of fluid in the manometers will be identical, as the pressure in a closed pipe is the same at all points along the pipe. When the fluid in the system is allowed to flow, the manometer levels will drop because, as Bernoulli's principle states, when velocity in a fluid increases, pressure decreases. However, the level of the manometer in the restriction will drop more than that of the other manometers because the fluid will be moving faster through the constriction.

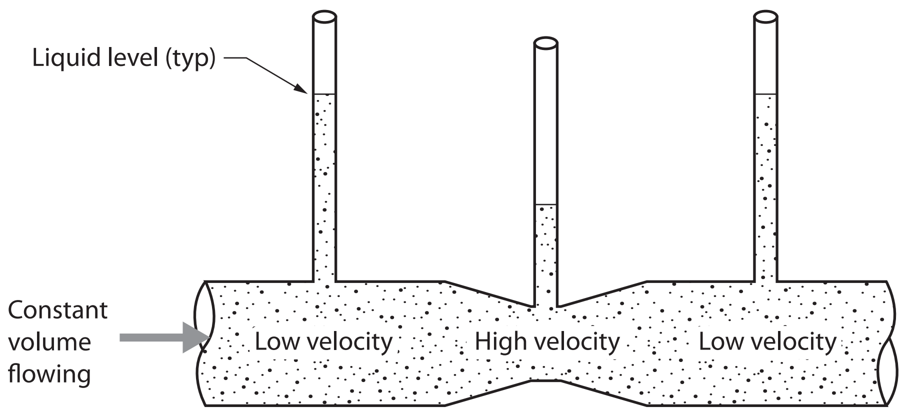


Figure 30 — Effect of fluid velocity on static pressure

By noting the difference in the heights of the manometers, the velocity of the fluid can be determined. Some air speed indicators in airplanes use the venturi meter principle.

Bernoulli's principle finds extensive application in the movement of liquids and gases. Hand garden sprayers, paint spray guns, automotive carburetors, and blowtorch nozzles all use Bernoulli's principle in their operation.

Summary of equations and relationships—liquids

You should be able to recall and use the following equations and relationships.

buoyant force: buoyant force = weight in air – weight in water

specific gravity: $\text{sp. gr.} = \dfrac{\text{weight in air}}{\text{buoyant force}}$

pressure in liquid: $\text{pressure} = \text{height} \times \text{density}$

$$P = h \times D \text{ (imperial)}$$

$$\text{pressure} = \text{height} \times \text{density} \times \text{force of gravity}$$

$$P = h \times D \times g \text{ (metric)}$$

force in liquid: $\text{force} = \text{height} \times \text{density} \times \text{area}$

$$F = h \times D \times A \text{ (imperial)}$$

$$\text{force} = \text{height} \times \text{density} \times \text{area} \times \text{force of gravity}$$

$$F = h \times D \times A \times g \text{ (metric)}$$

density of water: $D = 62 \text{ lb./ft.}^3$
$D = 1000 \text{ kg/m}^3$

☑ Now complete the Learning Task 1 Self-Test 3: Describe the basic properties of liquids.

Self-Test 3: Describe the basic properties of liquids

1. Which term best describes the force that bonds liquid molecules to other material?
   a. Specific gravity
   b. Cohesive force
   c. Adhesive force
   d. Contractive force

2. When an object is submersed in water, what force is acting on that object?
   a. Buoyant force
   b. Cohesive force
   c. Adhesive force
   d. Archimedes' force.

3. Which statement best describes Archimedes' principle?
   a. A body wholly or partially immersed in water is buoyed up with a force less than the weight of the fluid displaced by the body.
   b. A body wholly or partially immersed in water is buoyed up with a force equal to the weight of the fluid displaced by the body.
   c. A body wholly or partially immersed in water is buoyed up with a force greater than the weight of the fluid displaced by the body.
   d. A body wholly or partially immersed in water is buoyed up with a force unrelated to the weight of the fluid displaced by the body.

4. Which statement best describes the buoyant force of liquids?
   a. The specific gravity of the liquid
   b. All liquids exert the same buoyant force
   c. The liquid's specific gravity over that of fresh water
   d. The difference between an object's weight in air and its weight in water

5. Which of the following best describes pressure?
   a. An area over a force
   b. A force over an area
   c. A force over a period of time
   d. An area divided by a force squared

6. How are units of pressure expressed in the metric system?
   a. Pounds over a square metre
   b. Newtons over a square metre
   c. Kilograms over a square metre
   d. The height multiplied by the pressure

7. How does depth affect water pressure?
   a. Water pressure increases with depth.
   b. Water pressure decreases with depth.
   c. Water pressure is unaffected by depth.
   d. Water pressure only increases with a decrease in density.

8. How much pressure is created at the base of three metres of water column?
   a. 300 Pa
   b. 29.4 kPa
   c. 101.4 kPa
   d. 29.4 N/m^2

9. How much pressure is created at the base of 10 feet of water column?
   a. 433 psi
   b. 29.4 psi
   c. 9.81 psi
   d. 4.33 psi

10. When an external pressure is applied to a contained liquid, where is the point of highest pressure?
    a. The pressure would be highest at the plunger.
    b. The pressure would be uniform throughout the container.
    c. The pressure would be highest at the bottom of the container.
    d. The pressure would be highest at the deepest point of the container.

11. Which term best describes a liquid's resistance to flow?
    a. Volatility
    b. Viscosity
    c. Hydraulic
    d. Hydrodynamic

12. Which term best describes the use of Pascal's law to perform work?
    a. Volatility
    b. Viscosity
    c. Hydraulics
    d. Hydrodynamics
13. Which of the following best describes the relationship between velocity of flow and pressure of a liquid in a pipe?
    a. Velocity and pressure are unrelated.
    b. When velocity is low, pressure is low.
    c. When velocity is high, pressure is low.
    d. When velocity is high, pressure is high.
14. How does the length of tube or pipe affect the pressure drop of a moving liquid in a pipe system?
    a. Tube length and pressure drop are unrelated.
    b. The longer the tube, the less the pressure drop.
    c. The longer the tube, the higher the pressure drop.
    d. The shorter the tube, the higher the pressure drop.
15. How does the size of tube or pipe affect the pressure drop of a moving liquid in a pipe system?
    a. Tube size and pressure drop are unrelated.
    b. The smaller the tube, the less the pressure drop.
    c. The larger the tube, the greater the pressure drop.
    d. The smaller the tube, the greater the pressure drop.
16. Which of the following best describes a manometer?
    a. A water-filled instrument used to measure water pressure
    b. An instrument used to measure a person's pace and work rate
    c. A mercury-filled instrument that measures barometric pressure
    d. A unit of measurement used to describe microscopic particles such as the atom
17. A soap bubble is an example of surface tension.
    a. True
    b. False

18. A swimmer would experience the same hydraulic pressure two metres below the surface of a small swimming pool as she would two metres below the surface of a large lake.

    a. True

    b. False

19. The pressure at the base of a three-metre tank filled with fresh water would be approximately 30 kPa.

    a. True

    b. False

20. Pascal's law states that a pressure applied to an enclosed liquid is transmitted uniformly throughout the liquid.

    a. True

    b. False

21. Viscosity, flow rate, and length of tube all contribute to pressure loss of a moving liquid.

    a. True

    b. False

Describe the basic properties of gases

An understanding of the basic properties of gases is important for those people working in the trades as gases are used in many industrial situations. For example, compressed air operates pneumatic tools such as jackhammers and air-powered drills. Other gases are used as refrigerants and propellants. And even others are used in fuel welding equipment and heating systems.

A brief list of some types of industrial gases and their uses is shown in Figure 31.

Gas	Common Uses
Acetylene	Welding and cutting
Ammonia	Fertilizers, soap, and glass
Carbon dioxide	Fire extinguishers, baking powder
Chlorine	Solvents, bleaching agents
Natural gas	Fuels
R12/134-A	Refrigerants
Hydrogen	Welding
Oxygen	Welding and cutting
Water vapour	Steam in engines, turbines, and heating plants

Figure 31 — Common uses of gases

Most of the properties of liquids are also properties of gases. For example, gases obey the principles of Archimedes (buoyancy/weight displacement) and Pascal (pressure transmission). Indeed, the properties of liquids and gases are often studied together under the general heading of fluids.

Molecular properties

Gas molecules are widely spaced. This means each gas molecule acts independently, and therefore a gas does not assume a shape like a solid. Nor does a gas, given space, confine itself to a tight volume like a liquid. If left in an unconfined situation, a gas will expand indefinitely.

You must be especially careful when handling volatile liquids as the gas produced can diffuse (expand) very quickly, filling a space, and can be ignited by a spark, open flame, or some other point of ignition, some distance from the actual source of the vapour.

Elasticity

Gases possess great elasticity if they are contained. A balloon full of air, for example, will readily change its shape when a force is exerted on its surface and will then resume its original shape when the force is removed.

Gases are also highly compressible. Gases not only expand to fill any volume, but they can also be forced to occupy rather tight quarters. This combination of elasticity and compressibility allows gases, when confined, to have high resiliency. This resilience is seen in soccer balls, pneumatic tires, and other inflated items.

The compressibility property of gases is used to advantage in fire extinguishers, welding fuels, and aerosol packaging commonly used in the food and cosmetic industries (for example, whipping cream and hairspray).

Pressure

Gases are most often used when they are under pressure. Oxygen bottles, natural gas fuels, inflated automobile tires, and aerosol containers are common examples of gases being used under pressure.

You must handle pressurized gas containers with care. A small rupture in the container can cause the gas to escape. The pressure of the rushing gas can blow the container apart. Even "empty" pressurized containers can explode if heated; they may be empty of useful matter but any bit of fluid or gas left in the can will expand when heated. The relationship between pressure and temperature is dealt with later in this Learning Task.

Units of gas pressure

The units of pressure used for liquids and solids also apply to gases. Pascals (Pa), newtons per square metre (N/m^2) and pounds per square inch ($lb/in.^2$ or psi) are all used to describe gas pressures. Compressed gases used in welding are often pressure rated in pounds per square inch gauge (psig), which refers to the pressure of the gas in the cylinder as measured on the cylinder's gauges.

There are several units of pressure reserved for atmospheric (air) pressure. You may recall from the previous Learning Task that the pressure at the bottom of a liquid is determined by the height of the liquid. The same is true of gas. Our atmosphere can be described as being similar to a column of gas. The pressure at the bottom of the column is greater than the pressure above the bottom.

The atmosphere has a variable pressure that changes according to elevation (that is, height above sea level) and meteorological (weather) conditions.

Atmospheric pressure units include the atmosphere (atm), which represents the average pressure exerted by Earth's atmosphere at sea level. The atm has the following values:

1 atm = 101.3 kPa (or 101.3 kN/m^2) in metric

1 atm = 14.73 $lb./in.^2$ in imperial

The bar and millibar (mb) are widely used in meteorology. They are both metric units:

1 bar = 100 kPa (slightly less than 1 atm)

1 mb = 0.001 bar

= 100 Pa

Average sea level atmospheric pressure = 1013 mb

Atmospheric pressure is often added to a pressure found by a gauge to produce what is called absolute pressure value. That is,

absolute pressure = gauge pressure + atmospheric pressure

For example, an automobile tire might be inflated to 28 lb./in.^{2}. The absolute pressure of the tire is 28 lb./in.^{2} + 14.73 lb./in.^{2} = 42.73 lb./in.^{2}.

Atmospheric pressure must be understood and respected. A relatively small difference in air pressure can be used to support a large weight. For instance, making the pressure of the air inside the building slightly greater than the outside air pressure supports the roof of some recreational buildings such as tennis "bubbles."

Pressure gauges

There are several types of gauges used to measure the pressure of a gas. Such gauges can be classified into those that usually measure atmospheric pressures and those that measure pressures of confined gases.

Barometers

Barometers are used to measure atmospheric pressure. The schematic barometer shown in Figure 32 is a glass column at least 33 inches long (84 cm) closed at the top and filled with mercury. The column sits vertically in a vessel of mercury open to the air, and the weight of the mercury creates a vacuum in the top of the column. Air pressure on the mercury in the vessel is transmitted to the mercury in the tube. If the air pressure drops, the mercury level in the tube drops. If air pressure increases, the mercury level in the tube rises. This is consistent with Pascal's principle of the transference of pressure in a fluid (also known as "Pascal's law").

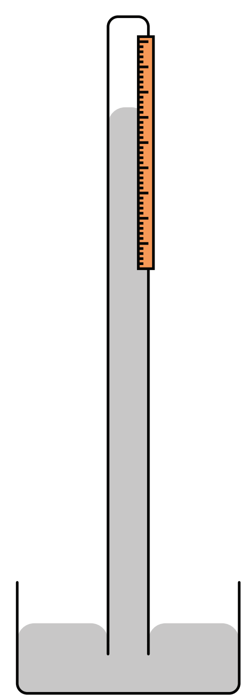


Figure 32 — Barometer

Atmospheric pressure is often measured in inches of mercury. The maximum height at sea level that mercury rises in the tube is about 30 inches or 76 cm. Thus,

1 atm = 29.92 in. Hg (Hg is the symbol for mercury)
= 78 cm Hg
= 101.3 kPa (Or kN/m^2
= 14.73 lb./$in.^2$

The sale of mercury is now restricted and the production of mercury barometers has effectively ended. Another type of barometer is the aneroid barometer (Figure 33), which consists of a sensitive, accordion-shaped evacuated and sealed chamber, called a "sylphon," "bellows," or "aneroid cell" that is attached to a pointer.

Figure 33 — Aneroid barometer

The sylphon slightly changes its volume when the pressure of outside air acting on it changes. The volume change moves the pointer along a scale that indicates the atmospheric pressure (Figure 34).

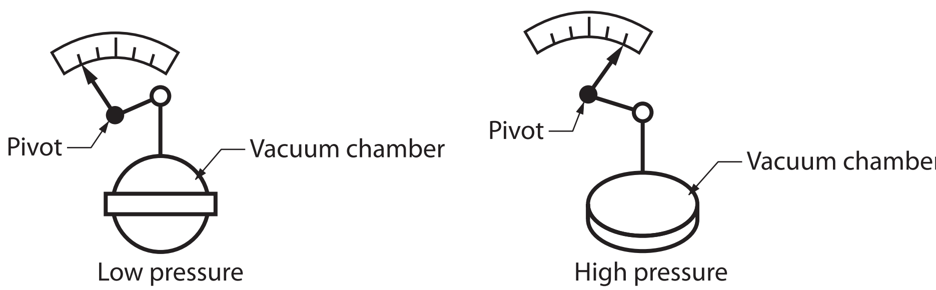


Figure 34 — Sylphon

Bourdon gauges

The bourdon pressure gauge uses the principle that a flattened tube tends to straighten or regain its circular form in cross-section when pressurized. The fluid being measured collects in a closed tube. The pressure causes the tube to straighten. This straightening motion moves a pointer across a scale, and the pressure is determined (Figure 35).

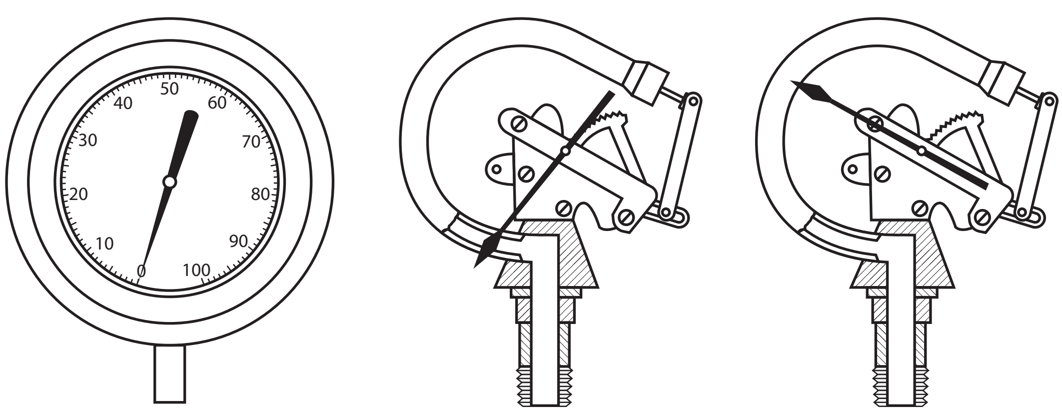


Figure 35 — Bourdon gauge

Bourdon gauges are used extensively to measure compressed gas and liquid pressures.

Manometer

The manometer (Figure 36) can also be used to determine gas pressures. The manometer is essentially a U-shaped tube open at both ends. Mercury or water is placed in the U of the tube, and one side is connected to the region of interest while the reference pressure (which may be the atmospheric pressure or a vacuum pressure) is applied to the other. The difference in liquid level represents the applied pressure.

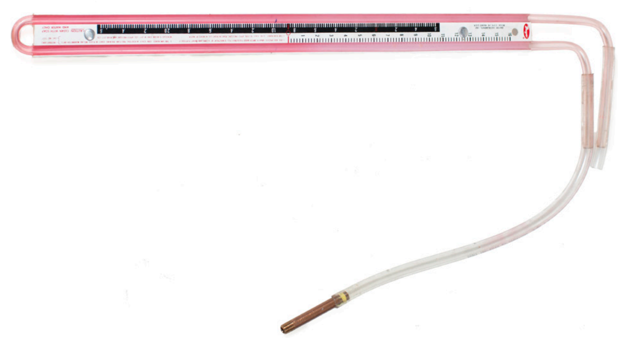


Figure 36 — Fluid-filled U-tube manometer

If the pressure is the same at both ends of the manometer, the liquid will rise to the same level in both ends of the tube. A slight difference in tube end pressures will result in the water rising higher in the lower pressure tube end (Figure 37).

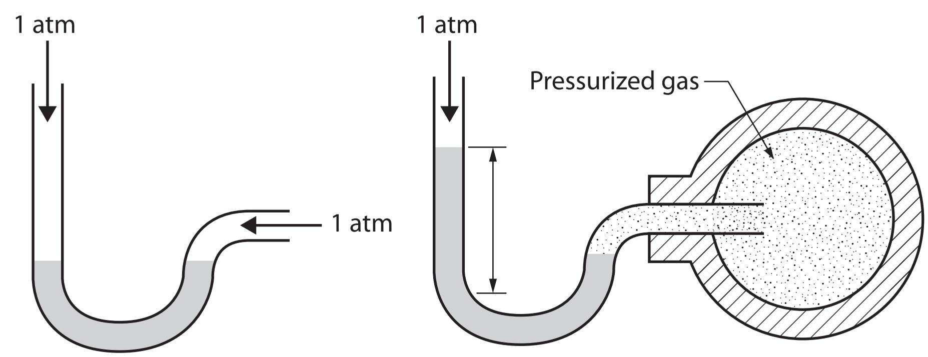


Figure 37 — Manometer

Water manometers are good for low-pressure applications, as they can detect even slight pressure variations. As discussed earlier, 12 in. (1 ft.) of water level differential would represent a pressure difference of 0.433 psi, and 1 in. of water column would be 0.0361 psi.

Manometers that are used in diesel engines measure the difference in pressure between the outside and inside of air filter systems, indicating servicing requirements. They also used to measure exhaust back pressure and crankcase pressure.

Manometers are also used to measure low pressures on propane- and natural gas-burning appliances such as fireplaces in houses.

Compound gauges

Some applications with pressures ranging from negative (i.e., a vacuum) to positive use a single gauge, called the "compound gauge." Positive pressures are read in psig or kPa, with zero at atmospheric pressure.

Negative pressures are read in inches (or millimetres) of mercury. Starting with 0 in. of mercury as atmospheric pressure, the scale increases in inches (or millimetres) of mercury as the vacuum increases, while the absolute pressure decreases to the minimum pressure of 0 psia. Figure 35 illustrates the relationship of vacuum and gauge pressure to absolute pressure.

Note that the use of inches or millimetres of mercury to indicate vacuum is purely a convention. Negative pressures in either psi or kPa can indicate vacuum as well. Also, pressures and vacuums can be indicated in positive or negative inches of mercury.

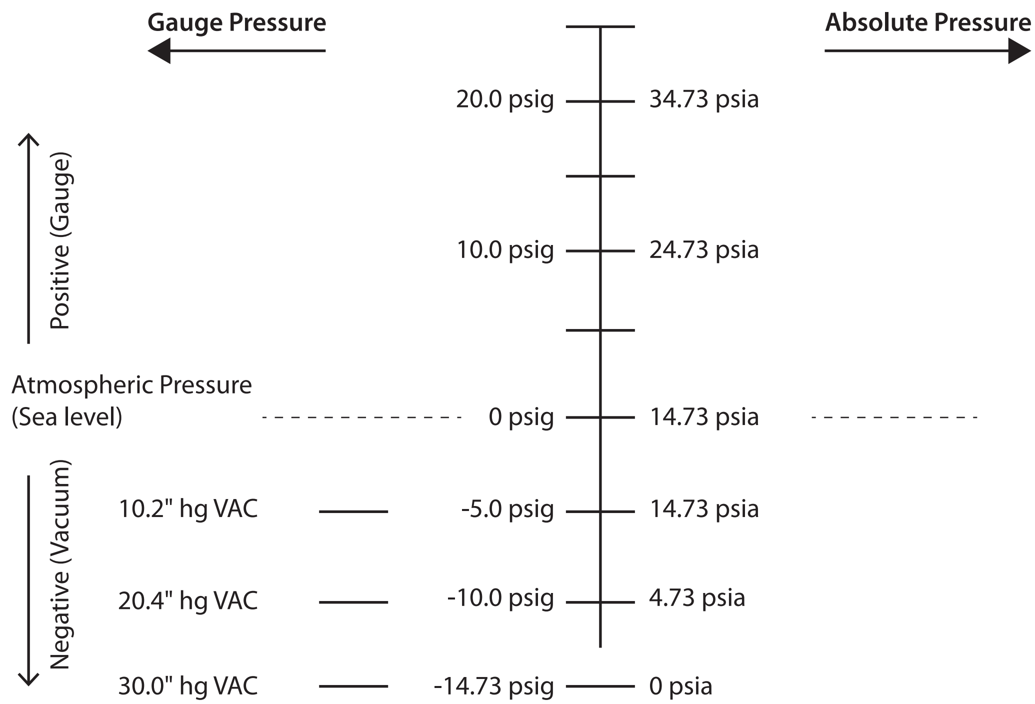


Figure 38 — Pressure scales

Gas laws

There are three gas laws that tradespeople need to be familiar with:

- Boyle's law: When the temperature of a gas is kept constant, the volume of an enclosed mass of gas varies inversely with the pressure on it.
- Charles' law 1: Within a fixed volume, the absolute pressure of a gas is proportional to its absolute temperature.
- Charles' law 2: Under a fixed pressure, the volume of a gas is proportional to its absolute temperature.

Boyle's law

Figure 39 — Portrait of Robert Boyle by Johanne Kerseboon, circa 1689

> ***Robert Boyle*** *(1627–1691) was an Irish chemist, physicist, and inventor and one of the pioneers of the modern experimental scientific method. Boyle is regarded by many as the first modern chemist, and therefore one of the founders of modern chemistry.*

When gas is compressed (that is, its volume reduced), the gas molecules become more tightly packed. The compression increases the number of moving molecules that strike the sides of the confining container. This increase in molecular activity is measurable as a pressure.

Robert Boyle studied the relationship between pressure and volume change in gases. He concluded, in what has become known as Boyle's law, that:

> *When the temperature of a gas is kept constant, the volume of an enclosed mass of gas varies inversely with the pressure on it.*

For example, if a volume of gas in a container is cut in half, then the pressure of the gas in the smaller container is doubled. Boyle's law is fairly straightforward if you consider Figure 36.

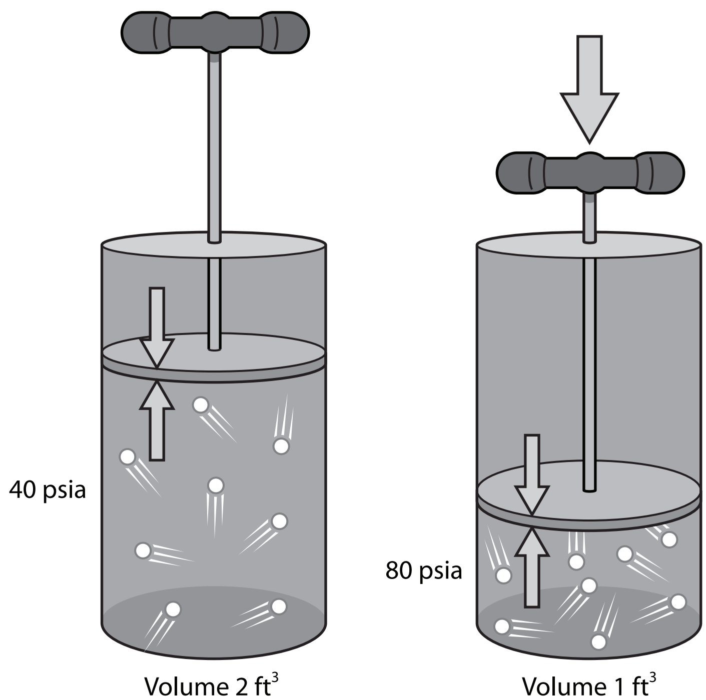


Figure 40 — Boyle's law

Boyle's law can be expressed mathematically as:

Original pressure × Original volume = New pressure x New volume

$P_1 \times V_1 = P_2 \times V_2$

Boyle's law is used to determine the pressures contained by gas cylinders used in fuel-oxygen burning and compressed air tanks used to run pneumatic equipment. Conversely, it also can be used to determine the volume of gas that can be contained in a pressure-rated cylinder.

Note that in the following example we use *absolute* values of pressure when we apply Boyle's law. Review Figure 35 for absolute pressure scales.

Example

A captive volume of gas is pressurized to 700 kPa within a 0.75 m^3 container. How much gas is available to use at atmospheric pressure, 101.3 kPa?

Solution

Find the values for the known variables, which will isolate the unknown variable to solve:

V_1 = the original volume = 0.75 m^3

V_2 = the new volume = the unknown variable. This is what you will solve for.

P_1 = the original absolute pressure = 700 kPa + 101.3 = 801.3 kPa (ab)

P_2 = the new absolute pressure = 101.3 kPa (ab)

Transpose the Boyle's law formula to isolate the unknown variable. In this example it is V_2:

$$V_2 = \frac{P_1 V_1}{P_2}$$

Substitute the known variables into the transposed equation and solve:

$$V_2 = \frac{801.3 \times 0.75}{101.3}$$

$$V_2 = 5.93 \text{ m}^3$$

Laws of Charles and Gay-Lussac

A volume of gas changes if there is a temperature change. This can be seen by inflating a balloon and putting it near a fire. The air in the balloon will expand in volume and the balloon will grow bigger. If a mass of gas is heated under a situation where the volume of the container cannot change, there will be an increase in the pressure of the gas. In the example of the balloon, the balloon will expand until it reaches the ultimate strength rating of the rubber. The pressure of the expanding heated gas will then pop the balloon.

A confined gas or liquid that is heated can build up huge pressure. Explosions can result if confined fluids or gases are stored near heat sources.

The effects of temperature change on the volume and pressure of a gas are known as Charles' laws. Although they are also referred to as "Gay-Lussac's laws," as it was Joseph Gay-Lussac who first published them in 1802, he credited them to the unpublished work of Jacques Charles.

Figure 41 — Portrait of Jacques Charles by Julien Léopold Boilly, 1820

Jacques Charles *(1746–1823) was a French inventor, scientist, mathematician, and balloonist. Charles launched the world's first hydrogen-filled balloon on August 27, 1783. He experienced great difficulty in filling the balloon completely, as the gas was hot when produced, but as it cooled in the balloon, it contracted. Around 1787, Charles conducted an experiment in which he filled five balloons to the same volume with different gases. He then raised the temperature of the balloons to 80°C and noticed that they all increased in volume by the same amount.*

Figure 42 — Joseph Gay-Lussac, 1848, photographer unknown

Joseph Gay-Lussac *(1778–1850) was a French chemist and physicist. He is known mostly for two laws related to gases, and for his work on alcohol-water mixtures.*

Charles' Law 1 says:

> *Within a fixed volume, the absolute pressure of a gas is proportional to its absolute temperature* (Figure 43).

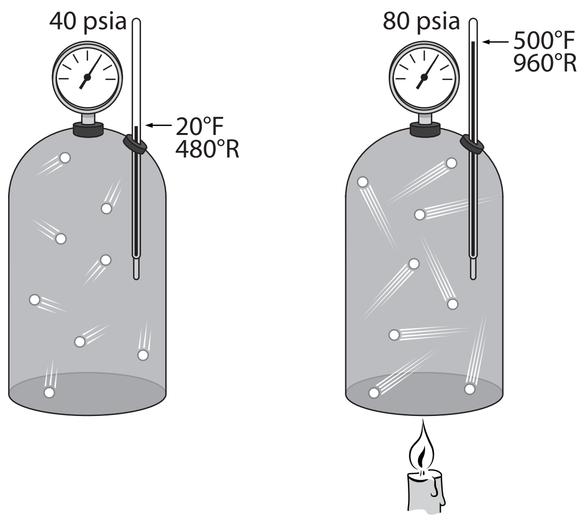


Figure 43 — Charles' law 1

Adding 273 to the centigrade reading gives you the absolute temperature of a Celsius temperature. Absolute temperatures are measured in kelvins (K). For example, 20°C = 20 + 273 = 293 K. Adding 460 to the Fahrenheit reading gives you the absolute temperature of a Fahrenheit temperature. Absolute temperatures are measured in Rankine (R). For example, 20°F = 20 + 460 = 480°R. Figure 44 shows various temperature scales.

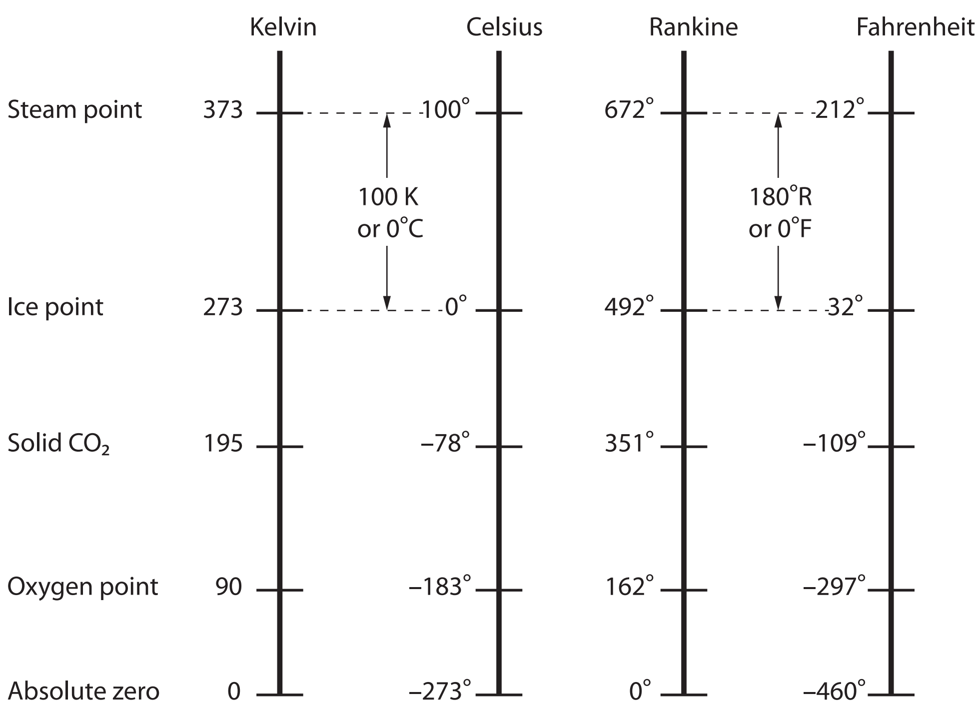


Figure 44 — Temperature scales

Charles' Law 2 says:

Under a fixed pressure, the volume of a gas is proportional to its absolute temperature (Figure 45).

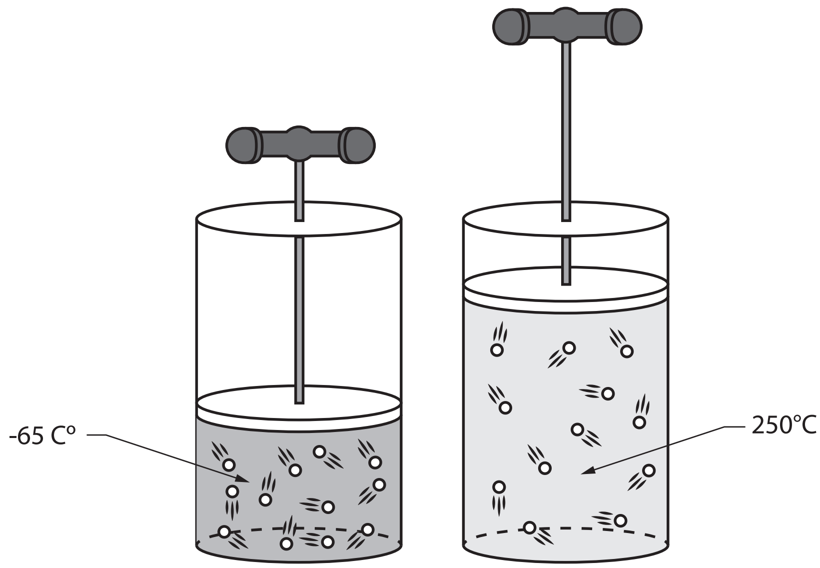


Figure 45 — Charles' Law 2, showing increase in volume for increased temperature

Gas density

Like the other states of matter, gases have densities. But unlike the specific gravity of solids and liquids (which is the ratio between the mass density of the material and the mass density of the same volume of water), the specific gravity of a gas is often stated as the ratio between the density of the gas and the density of air. A density and specific gravity table is shown in Figure 46.

Substance	Density kg/m^3 or g/litre at 0°C	Density lb./ft.^{3} at 32°F and 1 atm	Specific gravity Air = 1.000
Acetylene	1.173	0.0732	0.9073
Air	1.293	0.0807	1.000
Ammonia	0.7710	0.0481	0.5963
Carbon dioxide	1.977	0.1234	0.1529
Carbon monoxide	1.250	0.0781	0.9671
Helium	0.1785	0.0111	0.1380
Hydrogen	0.899	0.0056	0.0695
Oxygen	1.439	0.0892	1.105

Figure 46 — Density and specific gravity of gases

If it escapes confinement, a gas with a specific gravity greater than 1 will lie close to the ground. This means dangerous escaped gases such as propane and gasoline vapours will collect in depressions instead of being dispersed into the atmosphere. These filled depressions can be ignited by a stray spark or other inadvertent point of ignition; for example a truck (internal combustion engine) driven through a dip in a petroleum refinery roadway. Extreme care must be taken in areas where such gases may have escaped ("fugitive emissions").

Summary of equations and relationships—gases

You should be able to recall and use the following formulae and relationships:

Standard atmospheric pressure	$= 101.3\ kN/m^2$ $= 14.73\ lb./in.^2$
Absolute pressure	absolute pressure = gauge pressure + atm. pressure
Boyle's law	$P_1 \times V_1 = P_2 \times V_2$ (Value of P = absolute pressure)
absolute temperature	$K = °C + 273$

Now complete the Learning Task 1 Self-Test 4: Describe the basic properties of gases.

Self-Test 4: Describe the basic properties of gases

1. How will a contained gas behave when released into an unconfined space?
   a. The gas will double in volume.
   b. The gas will reduce in volume.
   c. The gas will expand indefinitely.
   d. The gas will retain its original volume.

2. Which term best describes a gas's infinite ability to take on any shape?
   a. Elasticity
   b. Viscosity
   c. Durability
   d. Compressibility

3. Which term best describes a gas's ability to occupy tight quarters?
   a. Elasticity
   b. Viscosity
   c. Durability
   d. Compressibility

4. What three terms are used to describe gas pressures?
   a. High, low, and medium
   b. Gas, liquid, and solid
   c. Absolute, gauge, and atmospheric
   d. Barometric, meteorological, and manometric

5. How are negative pressures measured?
   a. In inches of mercury
   b. In feet of water column
   c. In metres of water column
   d. In newtons over square metres

6. What is the difference between absolute pressure and gauge pressure measured in the metric system?
   a. 14.73 psi
   b. 101.3 kPa
   c. 10 000 kPa
   d. 29.92 inches Hg

7. According to Boyle's law, what happens when an enclosed mass of gas doubles in volume?
   a. The gas pressure will double.
   b. The gas pressure will be unaffected.
   c. The gas will increase in temperature.
   d. The gas pressure will be reduced by half.

8. According to Charles' law 1, what will happen if a confined gas is heated?
   a. The pressure will increase.
   b. The pressure will decrease.
   c. The volume of gas will increase.
   d. The pressure of the gas will be unaffected.

9. According to Charles' law 2, what has happened if a contained gas maintains a constant pressure but is halved in volume?
   a. The pressure has doubled.
   b. The pressure has been halved.
   c. The temperature has doubled.
   d. The temperature has been halved.

10. How is the specific gravity of a gas stated?
    a. As a product of the volume and the weight of the gas
    b. As a product of the temperature and the volume of the gas
    c. As a ratio between the density of the gas and the density of air
    d. As a ratio between the density of the gas and the density of water

11. How would propane gas, with a specific gravity of 1.53, behave when exhausted into the atmosphere?
    a. The propane would rise, as it is lighter than air.
    b. The propane would sink, as it is heavier than air.
    c. The propane would gather in the warmest parts of the space.
    d. The propane would spread evenly throughout the area, as it is as dense as air.

12. To which are all other gases compared when establishing their specific gravity?
    a. Air
    b. Water
    c. Oxygen
    d. Hydrogen

13. Which term best describes a total absence of heat?
    a. Freezing
    b. Absolute cold
    c. Absolute zero
    d. Absolute temperature

14. The compressibility of gases means they are difficult to contain and pressurize.
    a. True
    b. False

15. Absolute pressure is the final pressure at the end of a pipeline.
    a. True
    b. False

16. Inches of mercury is a measurement of a vacuum.
    a. True
    b. False

17. Absolute temperature in the metric system is measured in Kelvins.
    a. True
    b. False

LEARNING TASK 2

Describe practical applications of mechanics

In the applied sciences, "mechanics" refers to the study of motion, the effects forces have on objects, and applications of these effects.

In this Learning Task, you will be introduced to the mechanical qualities and quantities of force, velocity acceleration, work, power, and energy. These concepts are the basis for the operation of the simple machines, which in turn are the foundation for complex machinery.

When you have completed this Learning Task, you should be able to:

- define the terms "velocity," "acceleration," and "inertia"
- identify and apply Newton's laws of motion
- define the terms *work*, *power*, and *energy*
- identify potential energy and kinetic energy situations
- apply the conservation of energy law
- recognize units associated with velocity, acceleration, work, power, and energy
- describe the operation of the three basic machines
- define the terms ideal mechanical advantage, actual mechanical advantage, efficiency, and effort arm

Motion and force

We have discussed several forces, including the buoyancy force and the force of gravity. Most of the discussion has centred on the relationship between force and pressure. That is, we have looked at the effect a force has on a stationary body.

Forces, however, not only create pressure; they can also make an object move.

Motion

An object is in motion when its position is in continuous change. A bike being pedalled, a saw blade spinning, and a screw being turned are all objects in motion.

You can see from these examples that changes in position can mean several things:

- The bike's position changes in a straight line and is an example of linear motion.
- The saw blade's position changes, relative to a given spot on the blade, and is an example of rotational motion.
- The screw's motion is a combination of rotational and linear, as the twisting is one kind of motion while the boring is another.

This Learning Task is mainly concerned with linear motion. Although the concepts apply to other motions, the explanations are limited to describing straight-line movement.

Speed

Speed is the distance a body moves per unit of time.

The most common units for speed are:

- kilometers per hour - km/h
- metres per second - m/s
- miles per hour - mph
- feet per second - ft./s

The unit names may help you remember the general equation for finding uniform speed, where speed is symbolized by the letter "v."

speed = distance per time

$$v = \frac{\text{distance}}{\text{time}}$$

$$= \frac{d}{t}$$

For example, if a car travel 60 miles in 2 hours, its average speed is 30 mph.

$$v = \frac{d}{t}$$

$$= \frac{60\text{ miles}}{2\text{ hours}}$$

$$= 30\text{ mph}$$

You can solve the speed equation for d ($d = v \times t$) or for t ($t = d/v$). You can use these relationships to find how far an object travels in a set time at a constant speed, or how much time it takes an object to travel a certain distance at a constant speed.

Note that the direction of an object is ***not*** important when identifying its speed. In physics, the term "velocity" is used when considering the change in position of an object in terms of its direction over time. The letter "s" is not used to symbolize speed, so as not to confuse it with the symbol for seconds. Since speed and velocity share an association, the letter "v" is used for both.

Acceleration

If a speed changes, the movement of the object is known as an "accelerated motion." When you push the gas pedal (the accelerator) of a car and the speed of the car changes, acceleration takes place. Similarly, if you apply the brakes and the speed changes, deceleration occurs. The rate of movement of the object, in this case the car, will change over time.

Acceleration is a change in speed per unit of time. It can be expressed mathematically by the equation:

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time}}$$

If you begin with an initial speed of zero, you can use an even simpler equation for acceleration:

$$a = \frac{v}{t}$$

In this case, the speed indicated by the symbol v is the final speed.

Gravitational acceleration

The acceleration of gravity is the acceleration at which a body freely falls toward Earth. As you know, the acceleration of gravity has the values 9.8 m/s^2 and 32 $ft./s^2$. This means that the speed at which an object can fall becomes frighteningly fast. Consider a tool dropped from the top of a telephone pole. The time it takes to hit the ground is about 1.6 seconds.

You can find the speed of an accelerating object by rearranging the simple acceleration equation:

$$a = \frac{v}{t}$$

$$\begin{aligned} v &= a \times t \\ &= 9.8\ \text{m/s}^2 \times 1.6\ \text{seconds} \\ &= 15.68\ \text{m/s} \\ &= 56\ \text{km/h (approximately)} \end{aligned}$$

In 1.6 seconds, the tool has reached a speed of 15.68 m/s or approximately 56 km/h. In other words, a tool dropped from an elevation can quickly become a missile hurtling toward the ground!

Average speed

You will recall that the simple acceleration equation can be used when the initial speed is zero.

$$v = a \times t$$

This means that you will also be able to add the two speeds (initial and final) and divide the result in half to find the average speed at which the object travelled while accelerating.

This can be written mathematically as an equation:

$$\text{Average speed} = \frac{a \times t}{2} \text{ or } = \frac{1}{2}at$$

You will recall that the equation for speed involved the distance travelled over time. You can rearrange this equation to find the distance travelled:

$$v = \frac{d}{t} \text{ so, } d = v \times t = vt$$

Because you know that v = 1/2 at, you can substitute this value for v in the distance equation.

$$d = vt$$

$$\text{and because } v = \frac{1}{2}at$$

$$d = (\frac{1}{2}at)t$$

$$= \frac{1}{2}at^2$$

You can see that it is possible to use a variety of equations to calculate the required information. The equation chosen depends on information provided.

When tradespeople are problem solving, they use the information they already have to work out the information they need to do the task at hand. In other words, equations are very useful tools of any trade.

Newton's laws of motion

So far the descriptions have been concerned with how things move. Now let's turn to why things move at all. Isaac Newton's laws of motion explain why this occurs, but first you must understand force and inertia.

Force
Force is a push or a pull on an object. The force often results in the object moving, as happens when an object falls to Earth. The force of gravity causes the object to accelerate downwards.

As you know, we are constantly using forces. Examples include:

- falling water turning a turbine to produce electricity
- pressure buildup from burning gasoline moving a piston to produce power in an engine
- wind turning a wind turbine to produce electricity

These prime movers—the water, gasoline, and wind—are all used to force something to start moving, to continue moving, or to change the direction of a movement.

Similar forces stop something that is already moving. Friction braking systems and thrust-reversing deflectors are two methods of applying forces to stop an object's movement. Each of these forces is an attempt to overcome the inertia of the object.

Inertia
One of the fundamental principles of physics is that objects at rest continue to remain at rest and objects that are moving continue to move unless an external force is applied against them. This property is called "inertia."

Inertia, then, refers to an object remaining in a state of rest or uniform motion in a straight line unless that state is changed by the application of force.

Newton's first law of motion
Newton's first law of motion describes the property of inertia:

> *A body at rest will stay at rest and a body in motion will remain in motion at the same speed and direction unless acted upon by some unbalanced force.*

Consider the apparatus shown in Figure 1. A piece of string, A, is tied to the ceiling and a weight is suspended from it. A second string, B, is attached to the bottom of the weight. If string B is given a sharp tug, the string will break beneath the weight. If string B is pulled with a slow, constant increase in force, string A above the weight will break.

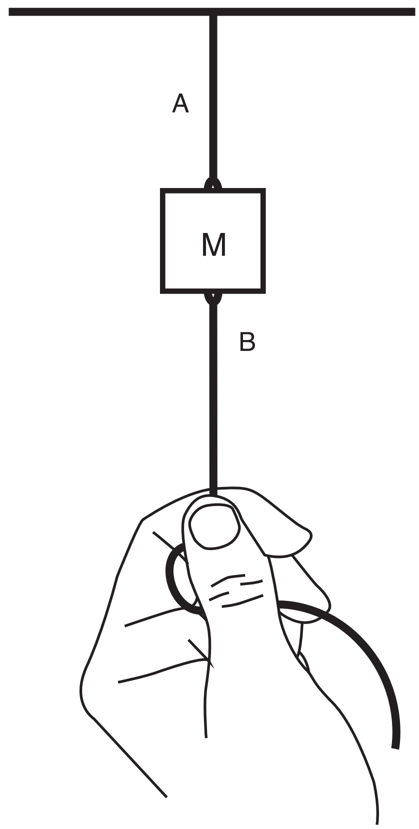


Figure 1 — Inertia demonstration

The effects of inertia have industrial implications. If a crane operator tries to raise a large weight from the ground, the operator must apply pressure to the cable slowly. A quick pull and the inertia of the mass will cause the cable to snap. A slow and steady increase in the cable tension will overcome the inertia of the load and cause it to begin to rise.

The inertia of a moving mass is illustrated if you panic stop a moving automobile. The braking effectively stops the car, but everything inside the car that is not tied down will continue to move forward. Seat belts and child seats offer the countering force that prevents the car passengers from smashing into windshields and dashboards.

A mechanical example of inertia occurs every time a reciprocating engine goes through a revolution. The up and down stroking of the pistons requires their mass to change direction, which means inertia must be overcome. This inertia creates stress and wear on individual piston parts. In addition, part of the force expended on every stroke must be used to overcome inertia, not just power the piston's movement.

Unbalanced force

Newton's first law uses the expression 'unbalanced force." An unbalanced force or net force is one that is not countered by an identical opposite force. Figure 2 shows two people attempting to push the same object from opposite sides. If the two forces are equal, there is a balanced force and the object will not move. When the forces acting on an object are balanced, the object is said to be in equilibrium.

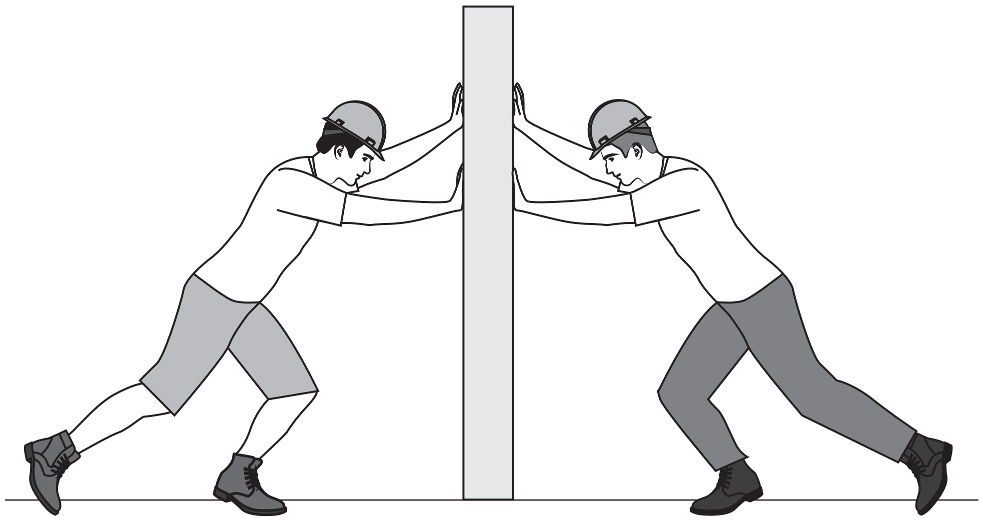


Figure 2 — Balanced forces

For example, if an object floats in a liquid, then the buoyant force and the weight of the object are balanced forces.

Newton's second law of motion

Newton's second law of motion gives a quantitative definition of force. A force is associated with a mass and an acceleration. The second law states:

> *The size of a net force upon an object is equal to the product of the mass and acceleration of the object. In addition, the direction of the force will be in the direction of the acceleration.*

Restating these words in a mathematical sentence shows how this second law is useful. It also shows how to calculate forces.

In mathematical form, Newton's second law of motion can be expressed as:

force = mass × acceleration
$F = m \times a$

The second law of motion equation ($F = m \times a$) should look familiar; the $wt = m \times g$ equation is an application of Newton's general force equation.

Since the newton (N) is the metric unit of weight, it is also the unit of force. A newton is a force that gives a mass of 1 kg an acceleration of 1 m/s^2.

In the imperial system, the pound (lb.) is the unit of force and so it is also the unit of weight.

Newton's third law of motion

Forces never occur singularly. For example:

- If you fire a rifle, the expanding gases push the bullet out the barrel, but they also exert a recoil force on your shoulder.
- The forward thrust of a jet plane is provided by the rear-directed thrust against the exhaust gases.
- If you throw a rock forward when standing on a sheet of ice, you will be propelled in the direction opposite to your throw.

All of these examples support Newton's third law of motion, which states:

For every action, there is an equal and opposite reaction.

The examples above show it is necessary to recognize and accommodate the existence, and ideally plan for the utilization, of both the desired direction of force and the opposing force.

Summary of equations and relationships

You should be able to recall and use the following equations and relationships.

Uniform velocity	$v = \frac{d}{t}$
Final velocity	$v = at$
Acceleration	$a = \frac{v}{t}$ (v = final velocity)
Distance equation	$d = \frac{1}{2} at^2$
Gravitational pull	$9.8\ m/s^2$ (metric) $32\ ft./s^2$ (imperial)
Newton's second law	$f = m \times a$
Metric values	1 km/h = 0.28 m/s
imperial values	1 mph = 1.47 ft./s

Now complete the Learning Task 2 Self-Test 1: Motion and force.

Self-Test 1: Motion and force

1. Which of the following best describes the distance a body moves over time?
    a. Inertia
    b. Speed
    c. Rotation
    d. Acceleration

2. Inertia is an object's resistance to change in its movement.
    a. True
    b. False

3. Which term best describes an applied force over a distance?
    a. Work
    b. Force
    c. Inertia
    d. Velocity

4. Applying the brakes to reduce the velocity of a vehicle is an example of accelerated motion.
    a. True
    b. False

5. The acceleration of gravity is 9.8 $ft./s^2$.
    a. True
    b. False

6. Force is a product of mass and acceleration.
    a. True
    b. False

7. The pound is the imperial unit of force.
    a. True
    b. False

8. Air resistance and friction are examples of unbalanced forces.
    a. True
    b. False

9. The amount of force required to begin moving an object is the same amount of force required to keep the object moving at a constant speed.

   a. True

   b. False

Describe work, power, and energy

In order to move something, a force is exerted. A crane lifts heavy objects at a construction site, a tractor shifts piles of earth, a mechanic pulls on a wrench to loosen a bolt, and a carpenter draws a handsaw back and forth through a board; in all these instances force is used to cause a measurable movement. In all these cases, work is being done.

Work

Force changes things. The measure of the amount of change accomplished by a force is called "work." If you exert a force but nothing changes, no work has been performed. With these basic ideas in mind, work can be thought about as a force applied through a distance. A more accurate definition is:

> *The work done on an object is equal to the force applied to the object times the distance the object moves in the direction of the force.*

Mathematically,

work = force through a distance

$$W = F \times d \text{ (imperial)}$$

$$= m \times g \times d \text{ (metric)}$$

Where

W = work

F = force

d = distance

m = mass

g = gravity

The units of work are the joule (J), kilojoule (1 kJ = 1000 J), and the newton-metre (Nm) in metric, and the foot-pound (ft.-lb.) in the imperial system.

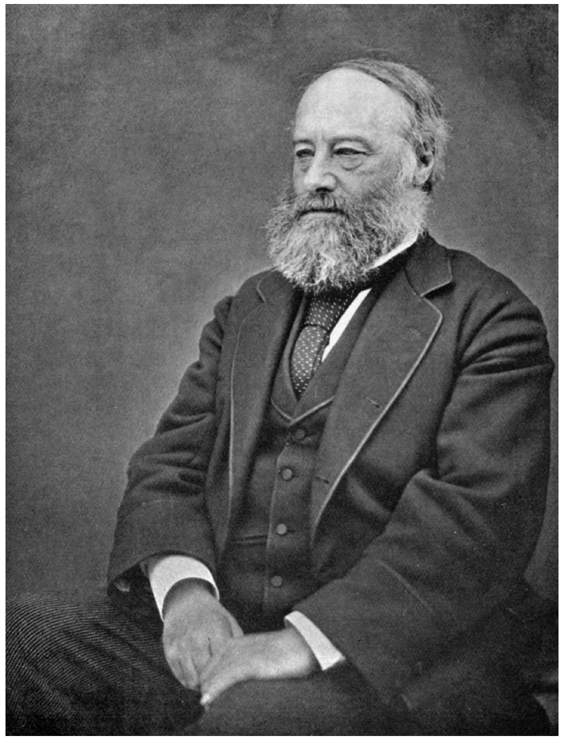


Figure 3 — Photo of James Joule by Henry Roscoe, 1906

> ***James Joule*** *(1818–1889) was an English physicist and brewer, born in Salford, Lancashire. Joule studied the nature of heat and discovered its relationship to mechanical work. This led to the law of conservation of energy, which led to the development of the first law of thermodynamics.*

By definition:

- 1 J is the work done by a force of 1 N acting for a distance of 1 m.
- 1 ft.-lb. is the work done by a force of 1 lb. acting for a distance of 1 ft.

No matter how large the force applied against an object, if the object does not move, no work has been done on the object. For instance, during a workout, you might try to lift a heavy weight that does not budge. You have not done any work on the weight because the weight has not moved. However, you have done some work on yourself by moving numerous muscles short distances within your body.

Work and gravity

When you lift an object vertically (h = height, ft. or m.) , you must work to overcome the force of gravity. In this case, the general work equation is changed slightly to:

$W = F \times h$ (imperial)

$= m \times g \times h$ (metric)

Power

We are often not concerned just with the amount of work done, but with the time it takes to do the work. For example, a small motor may be able to move a huge mass a significant distance if the motor is given a great deal of time to accomplish the task.

If the task is to be done efficiently, the rate at which it is performed becomes important. Power is the rate at which work is done. That is,

$$\text{power} = \frac{\text{work}}{\text{time}}$$

$$= \frac{\text{force} \times \text{distance}}{\text{time}}$$

$$P = \frac{W}{t}$$

$$= \frac{F \times d}{t}$$

You can express power in units of work/time (J/s, kJ/s and ft.-lb./s), but more commonly different units are used. In metric,

1 J/s = 1 watt (W)

The watt is rather a small unit of power and so power is often expressed as kilowatts, where 1000 W = 1 kW.

Electrical power is often consumed and sold in kilowatt-hours (kWh) where:

1 kWh = 1000 J/s × 3600 s
= 3600 kJ

In imperial units, foot-pounds/second (ft.-lb./s) are used for power unit.

However, just as a watt is a rather small quantity, ft.-lb. is often replaced by horsepower, where:

550 ft.-lb./s = 1 hp

In North America, the watt and kilowatt are used to express electrical power while horsepower is used only to express mechanical power. However, it is often necessary to convert from watts (or kilowatts) to horsepower and vice versa.

The conversion factors are:

1 hp = 746 W = 0.746 kW
1 kW = 1.34 hp = 737 ft.-lb./s.

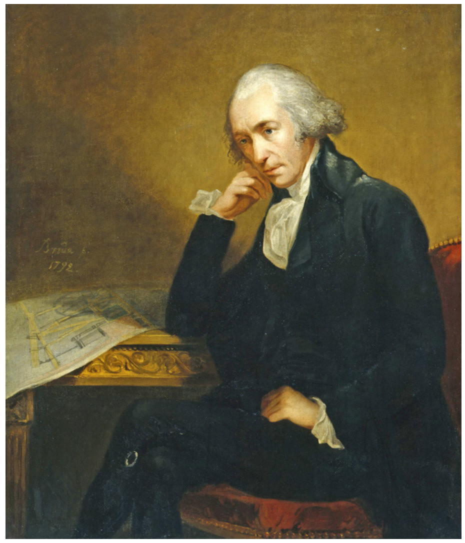


Figure 4 — James Watt

> ***James Watt** (1736–1819). The watt is named after James Watt who refined the steam engine. He needed a way to compare the amount of work his steam engine could do to the amount of work a horse could do. Watt calculated that a horse could lift 550 pounds of water a distance of one foot in one second. Watt then used this unit of horsepower to compare and rate his steam engines.*

Energy

Energy is the capacity to do work. Even if work is not being done at the moment, energy is in any object that has the potential to exert a force and so to do work.

There are two general categories of energy: kinetic and potential.

Kinetic energy

The energy found in an object in motion is called "kinetic energy." Kinetic energy is turned into work when its motion is stopped or slowed down. The kinetic energy in a moving hammer is converted into work when the hammer supplies the force to drive a nail.

Kinetic energy involves movement. The total kinetic energy in an object is the same as the energy that was required for the object to reach its present velocity. Kinetic energy is considered to be the same as the work:

$$KE = \text{work} = F \times d$$

The ability of a moving object to do work is proportional to its velocity (speed) squared. The kinetic energy of a mass moving at a velocity is stated in the equation:

$$KE = \frac{1}{2} m \times v^2$$

The severity of a high-speed car accident is a direct result of the kinetic energy of the fast-moving vehicle. A car moving at 60 km/h would have a v^2 value of 3600 units. The same car moving at 85 km/h would have a v^2 value of 7225 units, more than double the kinetic energy of the lower speed.

Potential energy

The energy found in an object at rest is called "potential energy." This is the energy an object has because of its position. The energy of a hammer held motionless over your head is potential energy until the swing of your arm converts it to kinetic energy. Something that has potential energy has had some work done on it. Again using the hammer example, work was done to raise the hammer overhead.

Potential energy comes in several forms. For example, an iron nail has the potential of moving in the presence of a magnet, and an object attached to a coiled spring has potential energy because it will move if the spring is released. However, the most common source of potential energy is the potential energy stored in a suspended mass.

Like kinetic energy, potential energy can be considered the same as work. The general equation for determining potential energy is the work equation:

$$PE = work = m \times g \times h$$

A 3 kg object sitting on a shelf at a 6 m height from the floor has a potential energy relative to the floor of:

$$PE = 3\ kg \times 9.8\ m/s^2 \times 6\ m$$

$$= 176.4\ J$$

Conservation of energy law

There are different forms of kinetic and potential energies. Those that are often used by tradespeople to perform work are mechanical, electrical, chemical, heat, and light energies.

Energy often changes form. The potential chemical energy in gasoline becomes kinetic energy when it is ignited to drive a piston in an internal combustion engine. The potential energy of water that is stored behind a dam becomes electrical energy when the water is released. The electrical energy can then be converted into heat, light, or sound energy. A flashlight battery also has the potential to energize a small motor, a light bulb, or a transistor radio.

The conservation of energy law states:

Energy can change form but energy cannot be created or destroyed.

Thus, when energy changes its form, as in the examples given, the amount of new energy is equal to the amount of original energy.

We often assume energy has been lost because only a part of the original energy may have been converted into useful or usable energy. For example a light bulb converting electrical energy into light also produces heat energy. This heat is considered a waste of energy. Or an element in an electric stove often glows red at high heat levels. In this case, it is the red glow of the element that is considered lost light energy.

Sometimes all the potential energy in an object is converted into kinetic energy. In this case, the potential energy equals the kinetic energy: PE = KE. For example, think of a tool box that falls to the ground from a scaffold. If you ignore the energy lost to air resistance, the kinetic energy of the box when it hits the ground is the same as its potential energy.

In other instances, not all the energy is converted. When this occurs, the original energy of an object is equal to its final energy plus the work done. This work done may be useful or it can be an energy loss due to friction or heat.

The relationship between original energy, final energy, and work can be expressed mathematically, as in the following equation:

Original energy = final energy + work

Summary of equations and relationships

You should be able to recall and use the following equations and relationships:

Work	$W = F \times h$ (imperial)
	$= m \times g \times h$ (metric)
Power	$P = \frac{W}{t}$
Kinetic energy	$KE = work = F \times d$
	$= \frac{1}{2} m \times v^2$
Potential energy	$PE = F \times H$ (imperial)
	$= m \times g \times h$ (metric)
Conservation of energy	1 J/s = 1 watt (W) 1 hp = 550 ft.-lb.
Original energy = final energy + work	1 kW = 1000 W 1 kWh = 3600 kJ 1 hp = 746 W 1 kW = 1.34 hp = 737 ft.-lb.

Now complete the Learning Task 2 Self-Test 2: Describe work, power, and energy.

Self-Test 2: Describe work, power, and energy

1. Which of the following is the metric unit to describe power?
    a. Watt
    b. Kilowatt
    c. Kilojoule
    d. All of the above
2. Which of the following is the imperial unit to describe power?
    a. Watt
    b. Kilowatt
    c. Horsepower
    d. Steampower
3. Which term best describes the capacity to do work?
    a. Power
    b. Inertia
    c. Energy
    d. Velocity
4. Which term best describes the energy found in an object in motion?
    a. Velocity
    b. Horsepower
    c. Kinetic energy
    d. Potential energy
5. Which term best describes the energy found in an object at rest?
    a. Velocity
    b. Horsepower
    c. Kinetic energy
    d. Potential energy
6. Which term best describes the energy stored in a load suspended by a crane?
    a. Velocity
    b. Horsepower
    c. Kinetic energy
    d. Potential energy

7. Which term best describes the potential energy found in fuel gases?
   a. Kinetic energy
   b. Electrical energy
   c. Chemical energy
   d. Mechanical energy

8. Which term best describes the potential energy found in a battery?
   a. Kinetic energy
   b. Useful energy
   c. Chemical energy
   d. Mechanical energy

9. The definition of work states if an object has not moved, regardless of the force applied to it, no work has been performed upon it.
   a. True
   b. False

10. The term that describes work over time is "force."
    a. True
    b. False

11. The unit of measurement of power in the metric system is the kilowatt.
    a. True
    b. False

12. A kilowatt is the equivalent of one joule per second.
    a. True
    b. False

13. Energy is the capacity to do work.
    a. True
    b. False

14. Energy can be classified into three separate categories: kinetic, chemical, and mechanical.
    a. True
    b. False

15. Water retained at a height behind a hydro dam is an example of potential energy.
    a. True
    b. False

16. Potential energy is the energy found in an object in motion.
    a. True
    b. False

17. The conservation of energy states that energy is never created or destroyed, it only changes form.
    a. True
    b. False

18. Which of the following is the metric unit to describe work?
    a. The watt
    b. The joule
    c. The foot-pound
    d. The metre per second^2

19. Which term best describes work performed over time?
    a. Force
    b. Power
    c. Gravity
    d. Velocity

Basic machines

A machine is a device that transmits a force to produce purposeful work. Most often, machines are used to minimize the effort force needed to overcome a much larger force of resistance.. At other times, machines are used to change the direction of a force or to decrease a force.

Although many different types of machinery are used in both home and work settings, all machines, no matter how complex, are combinations of the three simple machines: the lever, the inclined plane, and the hydraulic press.

The theory and application of simple machines are so interconnected that, like the scientific ideas in the previous Competencies, it is much easier to discuss the theory and its application together than it is to try to understand them separately.

Before looking at the lever, inclined plane, and hydraulic press individually, we will discuss several ideas common to all three simple machines.

Mechanical advantage

The amplification of an applied force is called *mechanical advantage* (MA). One of the main reasons for using a machine is to gain a force or distance advantage. The goal is usually to apply a small force in order to move a larger resistance. Simple machines are often used to multiply effort forces.

A machine's mechanical advantage can be defined and calculated in two ways: actual mechanical advantage and ideal mechanical advantage.

Actual mechanical advantage

Mechanical advantage can be determined by the comparison of the amount of force needed to move another force. The mechanical advantage determined by comparing forces is sometimes referred to as the "actual mechanical advantage" (AMA).

Using this method, mechanical advantage is determined by the ratio of the output force (that is, the force you are working against) to the input force (the force actually applied). The relationship is expressed as:

$$MA = \frac{\text{output force}}{\text{input force}}$$

$$= \frac{\text{F out}}{\text{F in}}$$

This ratio can also be expressed as the ratio of the force overcome to the force applied and is written as:

$$MA = \frac{\text{force overcome (resistance)}}{\text{force applied (effort)}}$$

$$= \frac{\text{resistance}}{\text{effort}}$$

$$= \frac{R}{E}$$

Ideal mechanical advantage

The second way to determine mechanical advantage is to compare the distance an applied force moves with the distance a resistant force moves. The mechanical advantage determined by comparing effort distance and resistance distance is sometimes referred to as the "ideal mechanical advantage" (IMA).

In this case, mechanical advantage is determined by the ratio of the distance an effort moves to the distance the resistance moves. Mathematically, this is:

$$MA = \frac{\text{effort distance}}{\text{resistance distance}}$$

$$= \frac{ED}{RD}$$

Even though AMA and IMA are different mechanical advantages, it is often advantageous to consider them as the same. In many instances the equations are used interchangeably to simply find the general mechanical advantages (MA) of the machine by assuming or by being told that there are no frictional losses.

Efficiency of basic machines

The efficiency of any machine is:

$$\text{Efficiency} = \frac{\text{work out}}{\text{work in}}$$

A more commonly used efficiency equation derived from this relationship is:

$$\text{Efficiency} = \frac{\text{actual mechanical advantage}}{\text{ideal mechanical advantage}}$$

$$\text{Eff} = \frac{AMA}{IMA}$$

Torque equation (moment of force)

If the two mechanical advantages are considered equal, then a valuable relationship can be shown. Since AMA = IMA then:

$$\frac{ED}{RD} = \frac{R}{E}$$

This relationship can be rewritten as:

$$E \times ED = R \times RD$$

This equation (sometimes called the "torque equation") is very close to the basic equation of work ($W = F \times d$) but not quite the same. However, it is useful to think of this equation as being equivalent to the conservation of energy or work rule, where:

energy in = energy out
work in = work out

You will find that the torque equation or a form of it is used when working on all types of simple machine problems.

Describe the operation of a lever

If you place a length of 2×4 across a rock, insert one end under a heavy object, and then push down on the other end, you are using a lever. A lever is a bar or rod that pivots at a point called a "fulcrum." The fulcrum divides the lever into two parts: an effort arm and a resistance arm (Figure 5).

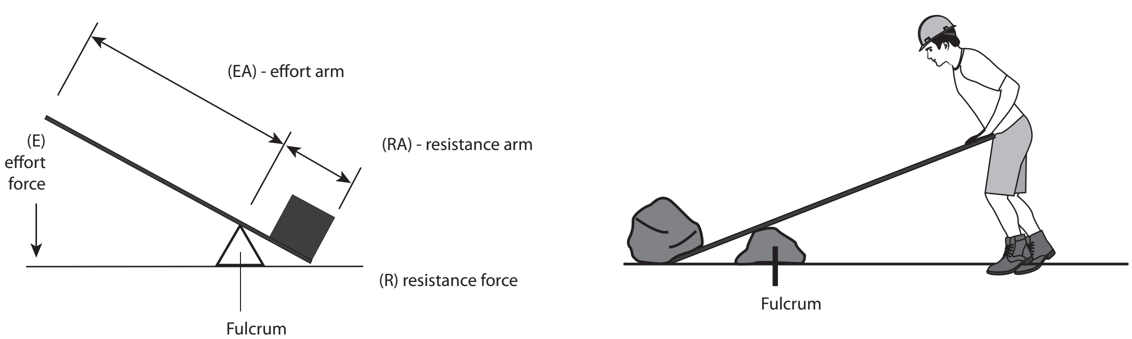


Figure 5 — Lever

In order to move an object, an effort is applied to the effort arm. This causes the lever to move distance ED and RD (Figure 6).

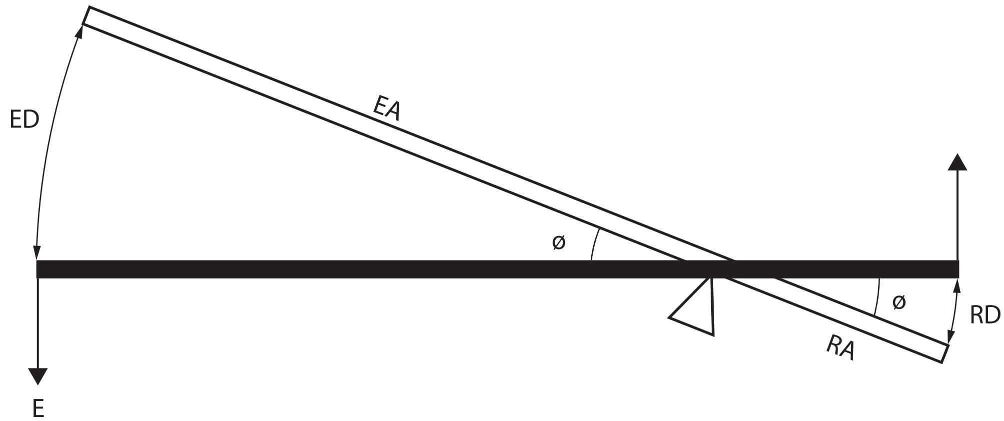


Figure 6 — Lever movement

The ratio of the effort distance (ED) to the resistance distance (RD) is the same as the ratio of the effort arm (EA) to the resistance arm (RA). This means that the torque equation can be used in a slightly different form. Generally speaking, the longer the effort arm, the greater the mechanical advantage.

$$E \times EA = R \times RA$$

The general mechanical advantage equations also apply to levers.

The following examples illustrate the principles used to solve problems involving levers.

Example 1
A 2.5 m steel bar is used as a lever to lift an 80 kg block. A fulcrum is placed under the bar 80 cm from the block. Find the effort force needed to move the block.

Solution
It often helps to draw out the situation (Figure 7), adding all the known quantities and labelling the specific parts.

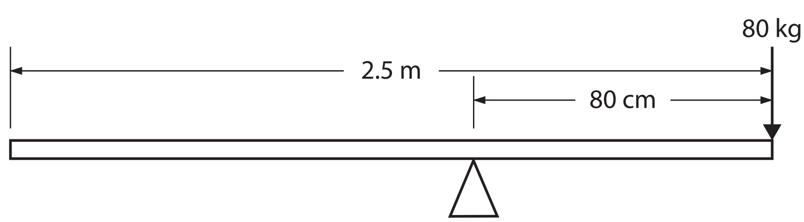


Figure 7 — Sketch for Example 1

Notice from the diagram in Figure 5 that:

$$RA = 80\text{ cm} = 0.8\text{ m}$$

$$EA = 2.5\text{ m} - 0.80\text{ m} = 1.7\text{ m}$$

Find the resistance force of the block.

$$F = m \times g$$
$$= 80\ \text{kg} \times 9.8\ \text{m/s}^2$$
$$= 784\ \text{N}$$

Use the torque equation with all known values inserted.

$$E \times EA = R \times RA$$
$$E \times 1.7\ \text{m} = 784\ \text{N} \times 0.8\ \text{m}$$
$$E = \frac{784\ \text{N} \times 0.8\ \text{m}}{1.7\ \text{m}}$$
$$= 368.9\ \text{N}$$

You would need to apply a force of about 370 N to move the block.

You can also solve this example by finding the MA of the lever:

$$MA = \frac{ED}{RD}$$
$$= \frac{1.7\ \text{m}}{0.8\ \text{m}}$$
$$= 2.125$$

Use the equation $MA = \frac{R}{E}$ solved for E.

$$MA = \frac{R}{E}$$

so

$$E = \frac{R}{MA}$$
$$= \frac{(80\ \text{kg} \times 9.8\ \text{m/s}^2)}{2.125}$$
$$= 368.9\ \text{N}$$

The result is the same using either equation series.

Example 2
A valve spring holds a valve closed with a force of 75 lb. The valve is controlled by a rocker arm arrangement as shown in Figure 8.

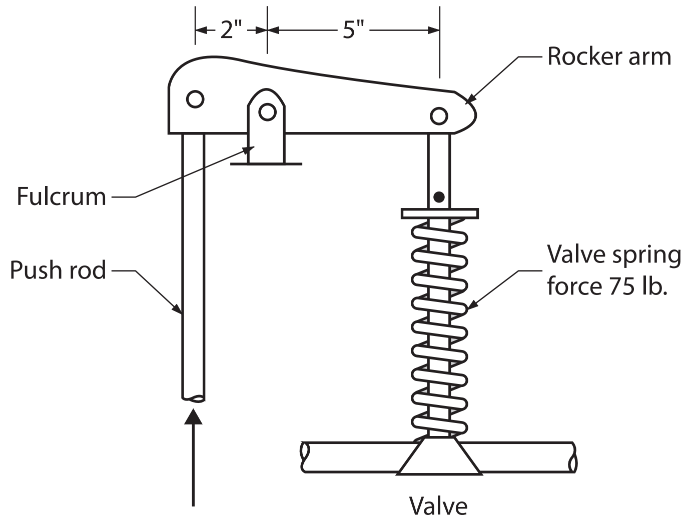


Figure 8 — Sketch for Example 2

Find the force that the push rod must exert to open the valve.

Solution
You might redraw the diagram in a simpler form, or you may be able to see directly from Figure 6 that:

$$R = 75 \text{ lb.}$$

$$RA = 5 \text{ in.}$$

$$EA = 2 \text{ in.}$$

$$E = ?$$

Substitute all the known values in the torque equation.

$$E \times EA = R \times RA$$

$$E \times 2 \text{ in.} = 75 \text{ lb.} \times 5 \text{ in.}$$

$$E = \frac{375 \text{ lb.–in.}}{2 \text{ in.}}$$

$$= 187.5 \text{ lb.}$$

The push rod must exert a force of 187.5 lb. Notice in this example that the effort is greater than the resistance. The mechanical advantage of the rocker arm described is:

$$MA = \frac{R}{E}$$

$$= \frac{75 \text{ lb.}}{187.5 \text{ lb.}}$$

$$= 0.4$$

or

$$MA = \frac{EA}{RA}$$

$$= \frac{2 \text{ in.}}{5 \text{ in.}}$$

$$= 0.4$$

Example 3

An iron rod 2 m long is used to lift a 210 kg concrete block. The maximum downward force is to be supplied by a 79 kg worker who will stand on the effort side of the fulcrum. Determine where a wooden fulcrum should be placed.

Solution

Draw a diagram as shown in Figure 9. Put in a fulcrum (although you cannot determine the EA or the RA yet).

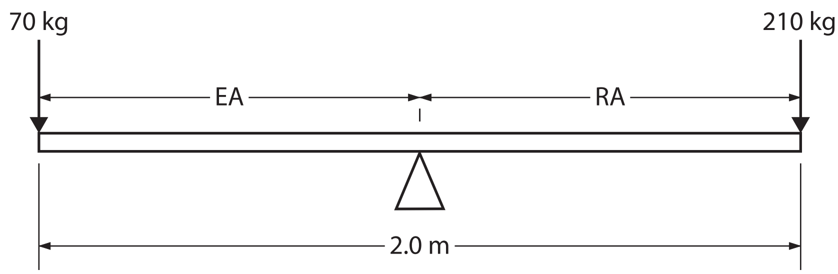


Figure 9 — Sketch for Example 3

Since there are two masses, you can determine the resistance force and the effort force.

$$E = 70\text{ kg} \times 9.8\text{ m/s}^2$$
$$= 686\text{ N}$$

$$R = 210\text{ kg} \times 9.8\text{ m/s}^2$$
$$= 2058\text{ N}$$

Use the effort and resistance values to find the mechanical advantage you need.

$$MA = \frac{R}{E}$$
$$= \frac{2058\text{ N}}{686\text{ N}}$$
$$= 3$$

This means that the ratio of the lever arms should also be 3:1. (You may have noticed that you could have found the MA by dividing the resistance mass by the effort mass as the units [kg] are the same and would cancel.)

$$\frac{EA}{RA} = 3$$
$$EA = 3\ (RA)$$

The total length of the lever is 2 m, so:

$$EA + RA = 2\text{ m}$$
$$3\ (RA) + RA = 2\text{ m}$$
$$4\ (RA) = 2\text{ m}$$
$$RA = \frac{2\text{ m}}{4}$$
$$RA = 0.5\text{ m}$$

The fulcrum should be placed 0.5 m from the concrete block.

Lever classes

There are three types or classes of levers (Figure 10).

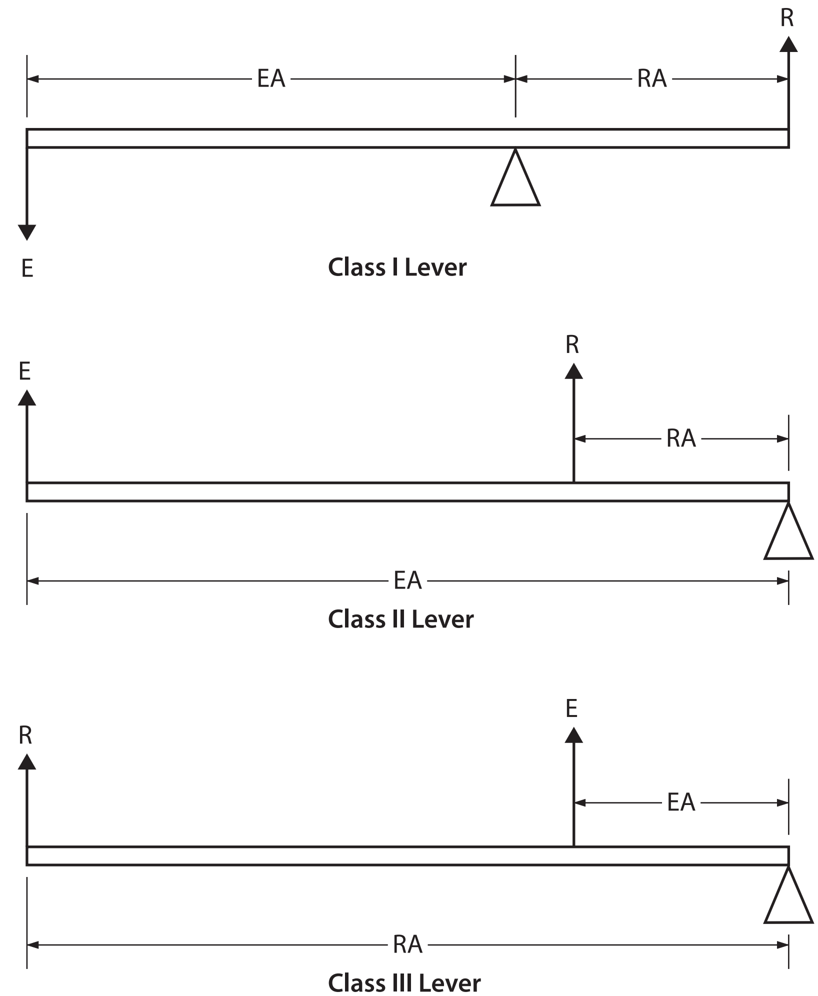


Figure 10 — Lever classes

Class I levers

Class I levers have a fulcrum between the resistant force and the effort force. All the lever examples used so far in this Learning Task have been Class I levers.

Crowbars, teeter-totters, bolt cutters, scissors, and pliers are examples of Class I levers.

Class II levers

In Class II levers, the resistance is between the fulcrum and the effort.

Two common examples of Class II levers are the nutcracker and wheelbarrow. The process of lifting one end of an object is another example of a Class II lever.

Problems involving Class II levers are solved in much the same way as Class I lever problems.

Example
A bottle opener is used to open a bottle. The length of the opener is 12 cm and the clip that fits under the bottle cap is 1.5 cm from the end. An effort of 5.0 N is needed to lift the cap. Find the resistance of the bottle cap.

Solution
Draw a diagram as shown in Figure 11 showing all the known quantities.

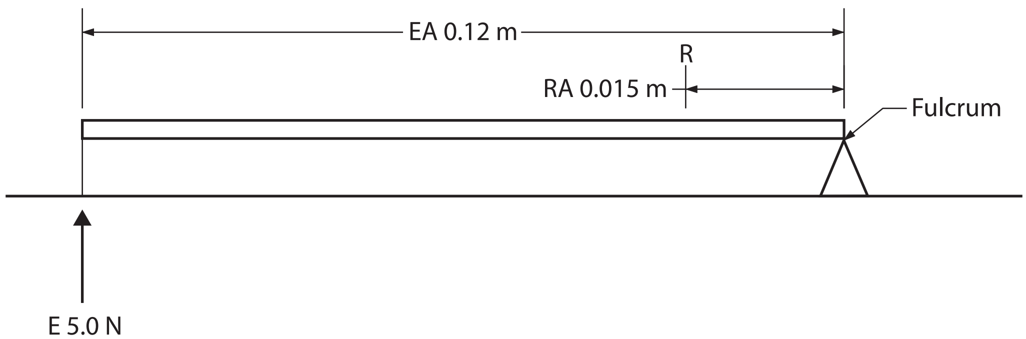


Figure 11 — Sketch for Class II lever example

Use the standard torque equation to find the resistance.

You know:

$$E = 5.0\text{ N}$$

$$EA = 12\text{ cm} = 0.12\text{ m}$$

$$RA = 1.5\text{ cm} = 0.015\text{ m}$$

$$E \times EA = R \times RA$$

$$5.0\text{ N} \times 0.12\text{ m} = R \times \frac{5.0\text{ N} \times 0.12\text{ m}}{0.015\text{ m}}$$

$$= 40\text{ N}$$

The resistance of the bottle cap is 40 N.

Class III levers
In Class III levers, the effort is applied between the resistance and the fulcrum. As the effort arm is shorter than the resistance arm in Class III levers, the effort force is always greater than the resistant force. These types of levers are used to gain a reach advantage as opposed to decreasing the effort force required, as the calculated mechanical advantage is always less than 1.

Examples of Class III levers include fishing rods, tweezers, cranes, and backhoes. When you use your arm to carry something, you are using a Class III lever.

Example

A painter carries a 10 lb. paint can in one hand. The length of the supporting forearm is 15 in. from elbow to the handle of the can. The biceps of the arm supporting the load are 3 in. from the pivoting elbow (Figure 12).

Find the effort needed to support the paint can.

First, sketch a diagram and include all the information that you already know.

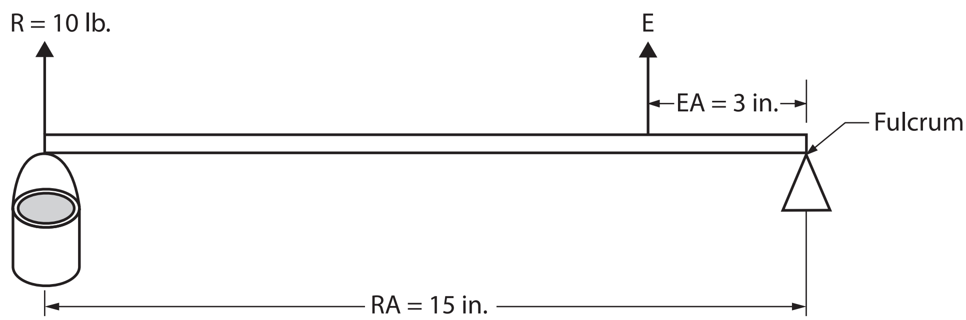


Figure 12 — Sketch for Class III lever example

Solution

From the diagram and given information, you can find three of the four quantities to insert in the torque equation. You can use the equation to find the effort force.

$$R = 10 \text{ lb.}$$

$$RA = 15 \text{ in.}$$

$$EA = 3 \text{ in.}$$

$$E \times EA = R \times RA$$

$$E \times 3 \text{ in.} = 10 \text{ lb.} \times 15 \text{ in.}$$

$$E = \frac{10 \text{ lb.} \times 15 \text{ in.}}{3 \text{ in.}}$$

$$= 50 \text{ lb.}$$

The biceps are exerting a 50 lb. effort to support the 10 lb. can of paint. Note the mechanical advantage is 5 and the ratios of effort arm to resistance arm, and effort to resistance are 5:1.

Other lever-type machines

Two other simple machines of the lever family are the wheel and axle and the pulley.

Wheel-and-axle systems

One of the drawbacks to levers is the limited angle in which they can operate. Attempts have been made to overcome this handicap by designing lever systems that are capable of continuous rotation. A wheel and axle (Figure 13) is such a device.

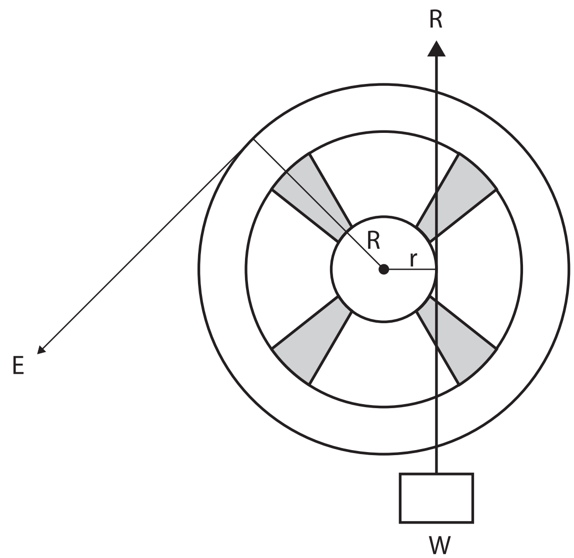


Figure 13 — Wheel and axle

A wheel of large radius, R (wheel), is attached to an axle having a smaller radius, r (axle). The radii of the wheel and axle have the same relationship to one another as the effort arm and resistance arm have in Class II levers. This means that both the torque equation for levers and the mechanical advantage equation apply to wheels and axles.

Example 1

A door handle with a radius of 3 cm is attached to a shaft having a radius of 0.5 cm. Find the mechanical advantage of this wheel-and-axle application.

First, sketch a diagram and include all the information already known (Figure 14).

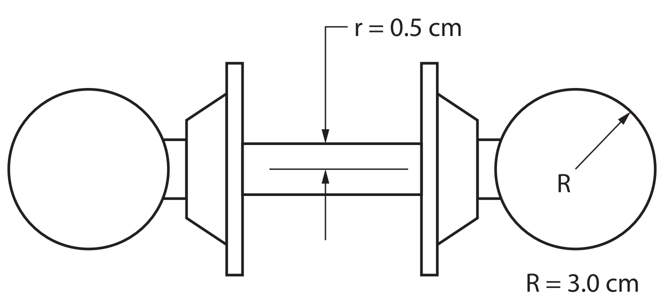


Figure 14 — Doorknob

Solution

The mechanical advantage of a lever is the ratio of the effort arm to the resistance arm.

$$MA = \frac{EA}{RA}$$

$$= \frac{r\ (\text{wheel})}{r\ (\text{axle})}$$

$$= \frac{3\ \text{cm}}{0.5\ \text{cm}}$$

$$= 6$$

The mechanical advantage of this wheel and axle assembly is 6.

Example 2

A ratchet and socket are used to loosen a tight bolt. The size of the socket is 0.5 in. and the length of the ratchet is 6 in. The mechanic applies 20 lb. of force on the end of the ratchet (Figure 15).

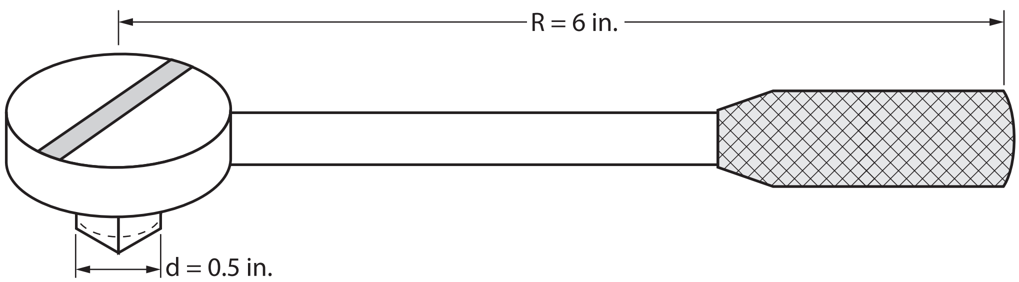


Figure 15 — Simple ratchet

Calculate the force on the bolt.

Solution

It may not look like it, but Figure 13 acts as a wheel-and-axle. As the mechanic is trying to spin a ratchet and socket, it acts much like a wheel and axle (Figure 16).

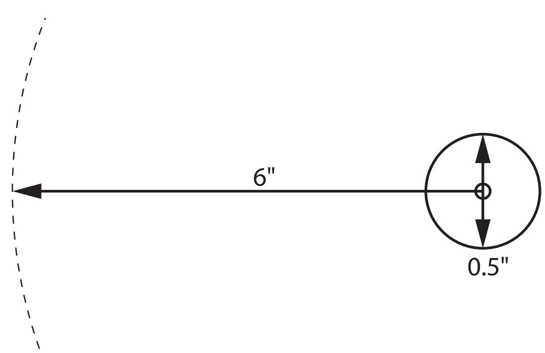


Figure 16 — Sketch for Example 2

Use the basic torque equation with the following values:

$$EA = \text{length of ratchet} = 6 \text{ in.}$$

$$RA = \text{radius of socket} = \frac{0.5 \text{ in.}}{2} = 0.25 \text{ in.}$$

$$E = 20$$

$$E \times EA = R \times RA$$

$$20 \text{ lb.} \times 6 \text{ in.} = R \times 0.25 \text{ in.}$$

$$R = \frac{20 \text{ lb.} \times 6 \text{ in.}}{0.25 \text{ in.}}$$

$$= 480 \text{ lb.}$$

By using the ratchet, the mechanic is applying 480 lb. of force on the bolt. This is a large increase in force. Care must be taken not to use too long a wrench to tighten small nuts or bolts. It is fairly easy to strip the threads or overtighten fittings. If a project calls for using a torque wrench adjusted to a given force, such a wrench must be used. We will look further at the force applied to bolts when we discuss screw threads.

Other wheel-and-axle applications include pedals and sprocket wheels on bicycles, screwdrivers, faucet taps, winches, and cranks.

Pulleys

A single pulley is also considered a continuous lever, but one with equal effort and resistance arms (Figure 17), therefore possessing a mechanical advantage of 1.

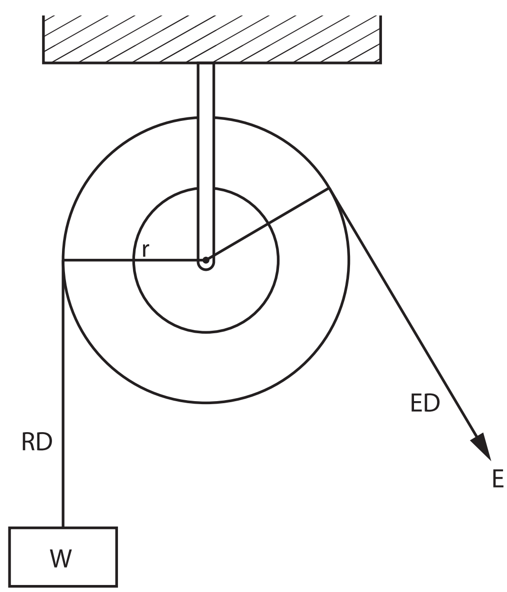


Figure 17 — Single pulley

When dealing with pulleys (and some other applications of the basic machines), the term "effort distance" (ED) is used in place of "effort arm," and "resistance distance" (RD) is used in place of resistance arm. In a single pulley machine, pulling on the effort arm moves the resistance side rope exactly the same length.

Since ED = RD (that is, EA = RA), in a single fixed pulley system the MA = 1. Such a machine does not increase a force but simply allows a force to change direction.

However, in multiple-pulley systems, the MA is much greater than 1.

A block and tackle consists of several pulleys arranged in such a way that a single rope is threaded through them (Figure 18).

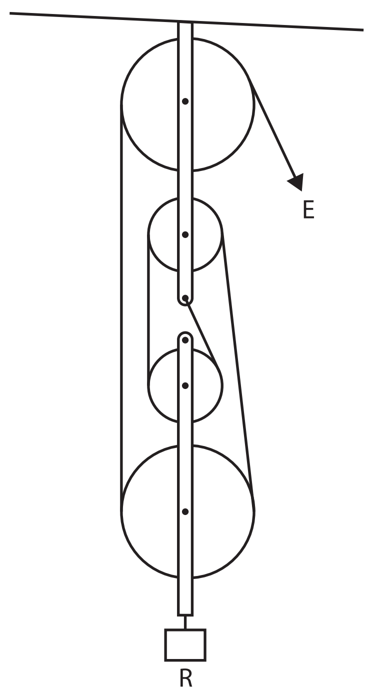


Figure 18 — Block and tackle pulley system

When the effort end of the rope is pulled, all the supporting ropes woven through the pulleys also move but each for a shorter distance than the effort end. Thus, the load moves a shorter distance than the effort.

As with all machines, the ideal mechanical advantage of the system is: $\frac{ED}{RD}$.

The MA of a pulley system can be found quickly by counting the number of supporting lines holding the load. In Figure 16, there are four supporting lines; therefore, the MA = 4.

You can solve problems associated with pulley systems by using the same torque equation used with other basic machines. More often, though, solutions are found quickly using the MA of the system.

Example
An engine with a mass of 175 kg must be raised 1.5 m to remove it from a car. The friction-free block and tackle to be used is shown in Figure 17.

Find the effort needed to remove the engine and the length of rope that needs to be pulled to remove the engine.

Solution
First, sketch a diagram and include all the information already known (Figure 19).

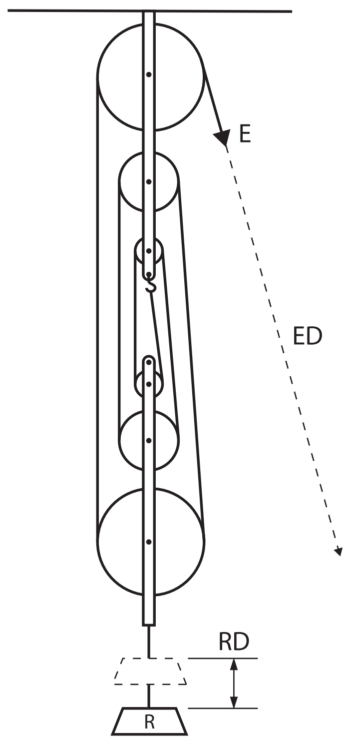


Figure 19 — Sketch for block-and-tackle example

An effort of 285.8 N (175 kg × $^{9.8}/_{6}$) is needed to overcome the resistance of the engine.

$$\text{Mechanical Advantage} = \frac{\text{Effort distance}}{\text{Resistance distance}}$$

$$MA = \frac{ED}{RD}$$

$$ED = MA \times RD$$

$$= 6 \times 1.5 \text{ m}$$

$$= 9.0 \text{ m}$$

The rope must be pulled a distance of 9.0 m.

Belt drives are a special type of pulley system used to connect a driving motor to a driven machine (Figure 20).

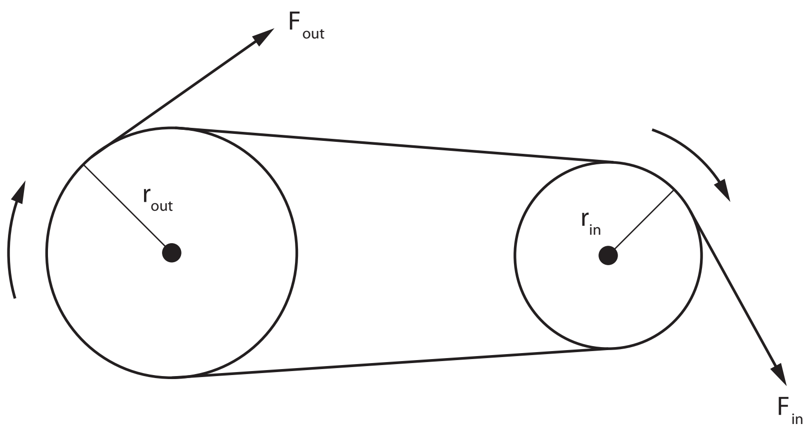


Figure 20 — Belt drive pulley system

The ideal mechanical advantage of belt drives is the ratio of the distances moved by each pulley. Although these distances are the circumferences of the pulleys, diameters or radii can be used. In fact, the diameters of these two pulleys are usually compared.

$$MA = \frac{\text{radius (driven pulley)}}{\text{radius (driving pulley)}}$$

$$MA = \frac{\text{diameter (driven pulley)}}{\text{diameter (driving pulley)}}$$

The MA is then used as a speed ratio:

- If the driven pulley is larger that the driving pulley, the revolutions per minute (rpm) of the driven pulley are less than the rpm of the driver.
- If the driven pulley is smaller than the driving pulley, the rpm of the driven pulley is greater than the rpm of the driver.

You can use a modification of the torque equation to solve problems associated with belt systems.

$$\text{rpm (driver)} \times \text{d (driver pulley)} = \text{rpm (driven)} \times \text{d (driven pulley)}$$

Example

A furnace motor operating at 1750 rpm is connected to a fan designed to rotate at 500 rpm. If the fan is equipped with a 12 in. diameter pulley, find the pulley size needed for the motor. Assume there are no friction losses.

Solution

See if you can follow the procedure.

$$\text{rpm (driver)} \times \text{d (driver pulley)} = \text{rpm (driven)} \times \text{d (driven pulley)}$$

$$\text{rpm (motor)} \times \text{d (motor pulley)} = \text{rpm (fan)} \times \text{d (fan pulley)}$$

$$1750\text{ rpm} \times D = 500\text{ rpm} \times 12\text{ in.}$$

$$D = \frac{500\text{ rpm} \times 12\text{ in.}}{1750\text{ rpm}}$$

$$= 3.43\text{ in.}$$

$$= 3\frac{7}{16}\text{ in.}$$

The motor needs a 3.4 in. (3 $\frac{7}{16}$ in.) diameter pulley.

Gear systems

Gear systems (Figure 21) are closely related to belt pulleys and wheel-and-axle systems. Gears are wheels with teeth that mesh together.

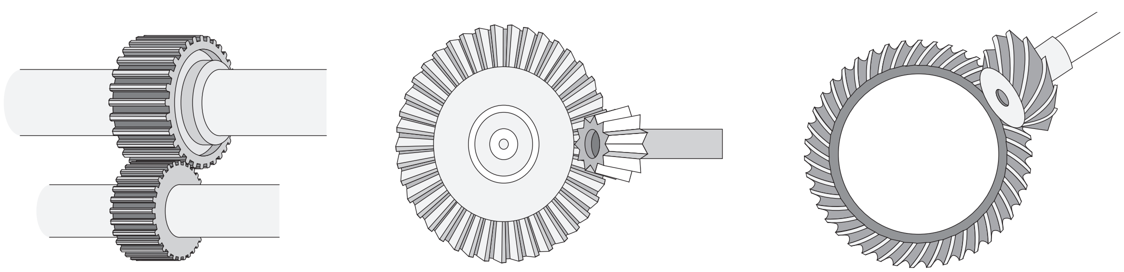


Figure 21 — Gear systems

Gear systems are used much like belt pulleys to transfer torques (rotational forces) but have one great advantage over belt systems—they eliminate slippage.

A drawback to gear systems is that the driving gear and driven gear move in opposite directions as illustrated in Figure 22.

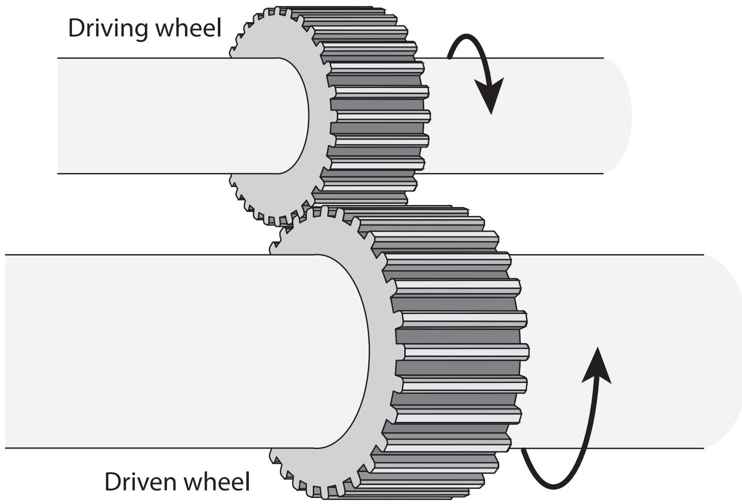


Figure 22 — Direction of rotation

To have the same direction of rotation, an odd number of gears are required. This adds to the already costly gear system and explains why belt systems still find wide use.

The MA between two gears is the ratio of the driven force to the driving force. However, the ratio of the number of teeth to diameter sizes or radius sizes can also be used. When the MA is expressed as a fraction with a denominator of one, it is called the gear ratio.

$$\text{MA} = \frac{\text{driven force}}{\text{driving force}}$$

$$\text{MA} = \frac{\text{driven teeth number}}{\text{driving teeth number}}$$

or

$$\text{MA} = \frac{\text{d (driven)}}{\text{d (driving)}}$$

where d = diameter of gears

or

$$\text{MA} = \frac{\text{r (driven)}}{\text{r (driving)}}$$

where r = radius of gears

gear ratio = MA:1

You use the same torque equation that was used for pulley systems:

$$\text{rpm (driver)} \times \text{r (driver)} = \text{rpm (driven)} \times \text{r (driven)}$$

The radius of the driver and the radius of the driven gears can be replaced by their respective diameters or number of teeth.

Example

A gear wheel, rotating at 300 rpm, has a radius of 0.1 m and drives a second gear of radius 0.40 m. The original force applied is 66 N. Find the MA, gear ratio, output force, and the second gear's rpm.

Solution

Draw a diagram.

Find the MA:

$$\text{MA} = \frac{\text{r (driven)}}{\text{r (driver)}}$$

$$= \frac{0.40 \text{ m}}{0.1 \text{ m}}$$

$$= 4.0$$

Express the MA as a gear ratio:

$$\text{gear ratio} = \text{MA:1}$$

$$= 4:1$$

Compute the output force (the driven force)

$$\text{MA} = \frac{\text{d (driven)}}{\text{d (driving)}}$$

$$\text{driven force} = \text{MA} \times \text{driving force}$$

$$= 4 \times 66 \text{ N}$$

$$= 264 \text{ N}$$

Determine the second gear's rpm. Use the torque equation.

$$\text{rpm (driver)} \times \text{r (driver)} = \text{rpm (driven)} \times \text{r (driven)}$$

$$300 \text{ rpm} \times 0.1 \text{ m} = \text{rpm (driven)} \times 0.4 \text{ m}$$

$$\text{rpm (driven)} = \frac{300 \text{ rpm} \times 0.1 \text{ m}}{0.4 \text{ m}}$$

$$= 75 \text{ rpm}$$

Notice that this is ¼ the rpm of the driving gear.

Summary of equations and relationships

You should be able to recall and use the following equations and relationships:

mechanical advantage	$\text{AMA (or MA)} = \frac{R}{E}$
	$\text{IMA (or MA)} = \frac{ED}{RD} = \frac{EA}{RA}$
efficiency of simple machine	$\text{Eff} = \frac{AMA}{IMA} = \frac{\text{smaller MA}}{\text{larger MA}}$
torque equation	$E \times ED = R \times RD$
	$E \times EA = R \times RA$
MA of wheel and axle	$MA = \frac{\text{r (wheel)}}{\text{r (axle)}}$
MA of pulley system	MA = number of supporting lines of cable
MA of belt drive	$MA = \frac{\text{r (driven)}}{\text{r (driver)}}$
MA of gear system	$MA = \frac{\text{driven teeth}}{\text{driver teeth}}$
	$= \frac{\text{d (driven)}}{\text{d (driver)}}$
	$= \frac{\text{driven force}}{\text{driving force}}$
torque equation	$\text{rpm (driver)} \times \text{r (driver)} = \text{rpm (driven)} \times \text{r (driven)}$

Describe the operation of the inclined plane

If you have ever used a ramp to raise an object from one height to another, you have used an inclined plane. By spreading the work over a longer distance, inclined planes reduce the amount of force needed to move an object. Ramps, stairways, escalators, wedges, and screws are examples of inclined planes (Figure 23).

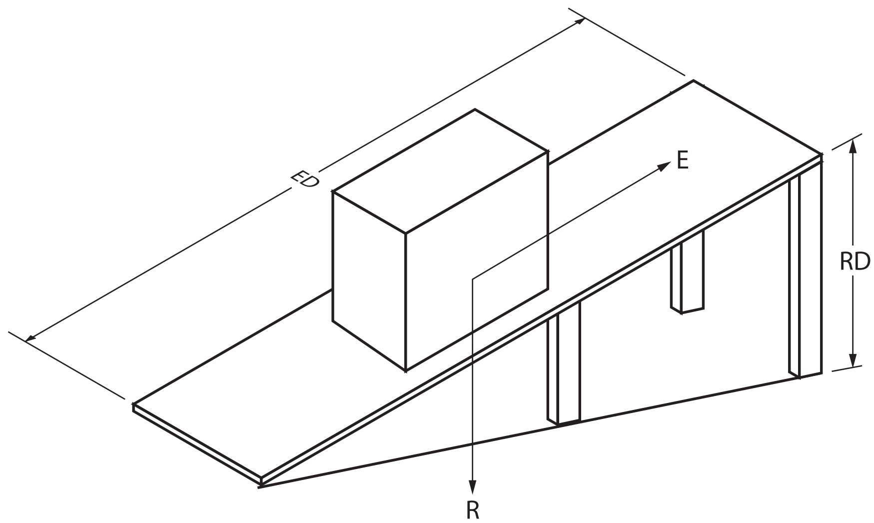


Figure 23 — Inclined plane

The inclined plane is a machine that allows a person to exert a small effort (effort) over a long distance (effort distance) to act on a greater force (resistance) over a shorter distance (resistance distance). Since work in = work out, all these factors are related by equations that look like lever equations:

$$E \times ED = R \times RD$$

$$AMA = \frac{\text{Force out}}{\text{Force in}}$$

$$= \frac{\text{Resistance}}{\text{Effort}}$$

$$= \frac{R}{E}$$

$$IMA = \frac{\text{Effort distance}}{\text{Resistance distance}}$$

$$= \frac{ED}{RD}$$

$$\text{efficiency} = \frac{AMA}{IMA}$$

The equations can be used to solve inclined plane problems. Again, as we did with levers, assume that AMA = IMA and solve for a general MA using the relationships:

$$MA = \frac{R}{E} \quad \text{and} \quad MA = \frac{ED}{RD}$$

Example 1

A cart filled with concrete has a mass of 90 kg and must be dumped into a foundation footing. The footing is 2 m above the ground. If a 6 m ramp is used, find the effort that must be exerted on the cart to push it up the ramp.

Solution

Draw a diagram (Figure 24) and list what is known.

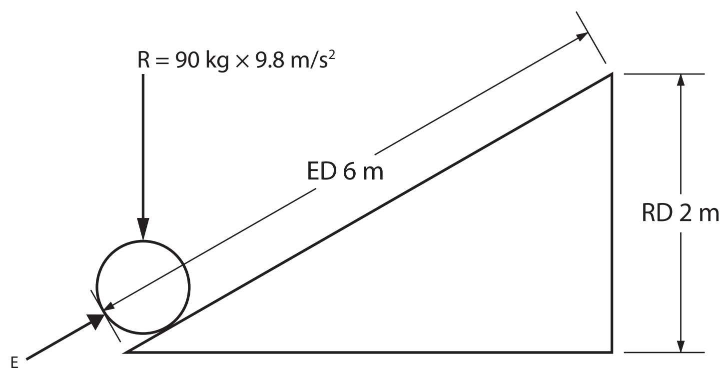


Figure 24 — Sketch for Example 1

Use the general equation:

Effort × Effort distance = Resistance × Resistance distance

$E \times ED = R \times RD$

Where:

$$E = ?$$

$$ED = 6\text{ m}$$

$$R = 90\text{ kg} \times 9.8\text{ m/s}^2$$

$$= 882\text{ N}$$

$$RD = 2\text{ m}$$

$$E \times ED = R \times RD$$

$$E = \frac{R \times RD}{ED}$$

$$= \frac{882\text{ N} \times 2\text{ m}}{6}$$

$$= 294\text{ N}$$

The effort needed is 294 N. You could have also solved this problem by finding the general mechanical advantage.

$$MA = \frac{ED}{RD}$$

$$= \frac{6\ m}{2\ m}$$

$$= 3$$

$$MA = \frac{R}{E}$$

$$E = \frac{R}{MA}$$

$$= \frac{882\ N}{3}$$

$$= 294\ N$$

Example 2

A truck pulls a 300 kg boat sitting on an 80 kg trailer up a 25 m boat ramp. The effort needed is 180 N. Find the height of the ramp.

Solution

Draw a diagram (Figure 25) and fill in all the known values. Notice that the mass being acted on is the boat plus the trailer; that is, a total of 380 kg.

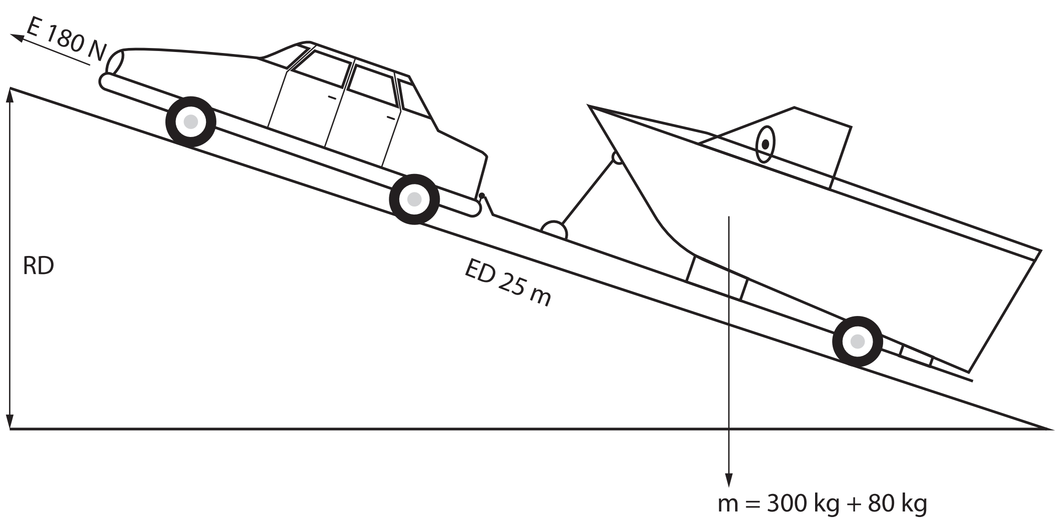


Figure 25 — Sketch for Example 2

Use the standard equation and solve for the resistance distance.

$$E \times ED = R \times RD$$

Where:

$$E = 180\text{ N}$$

$$ED = 25\text{ m}$$

$$R = 380\text{ kg} \times 9.8\text{ m/s}^2$$

$$= 3724\text{ N}$$

$$RD = ?$$

$$E \times ED = R \times RD$$

$$RD = \frac{E \times ED}{R}$$

$$= \frac{180\text{ N} \times 25\text{ m}}{3724\text{ N}}$$

$$= 1.21\text{ m}$$

The height of the ramp is 1.21 m.

Applications of inclined planes

The two main applications of inclined planes are the wedge and the screw.

Wedge

The wedge is a V-shaped device consisting of two inclined planes joined along their bottom edge (Figure 26). Wedges are used to split wood, separate stacked steel plates, and level objects such as furniture or machinery. In addition, they are the basic machine used in all cutting tools such as chisels, axes, and knives.

The ideal mechanical advantage of a wedge is its length divided by its thickness:

$$IMA = \frac{L}{t}$$

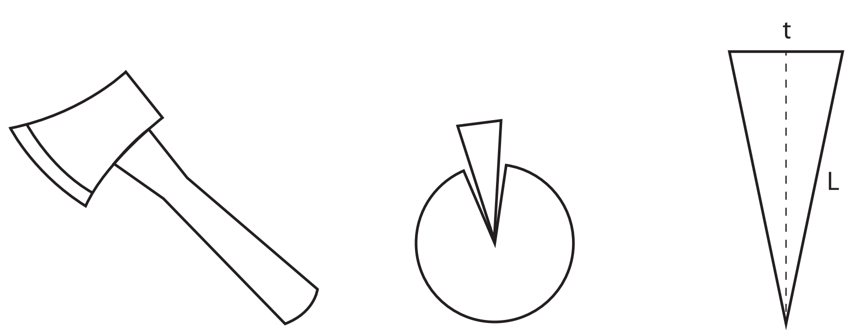


Figure 26 — Wedge

Cams

Cams are another application of the wedge. Cams are used to operate valves in internal combustion engines. They are rotating wedges that use a turning motion to produce a force (Figure 27).

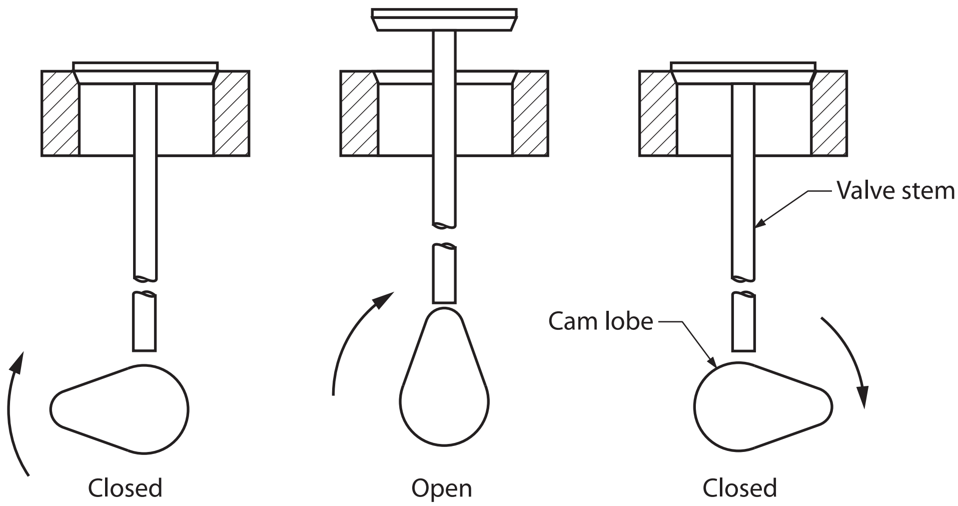


Figure 27 — Cams

Bolts and screws

One of the most important applications of the inclined plane is bolt and screw threads. A bolt is simply an inclined plane wrapped around a cylinder (Figure 28).

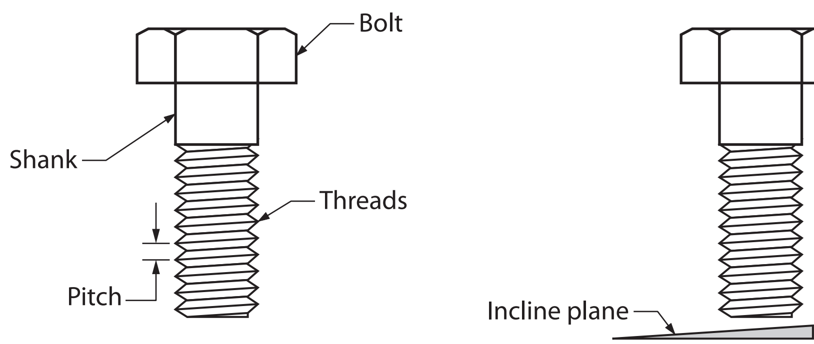


Figure 28 — Bolt

The distance between two adjacent threads of a bolt is called the "pitch" of the bolt. When the screw is turned one complete rotation, the distance the screw travels is the same as the pitch.

The mechanical advantage of a bolt depends on the length of the lever arm used to turn it. This lever arm can be the radius of a nut driver or a wrench (Figure 29).

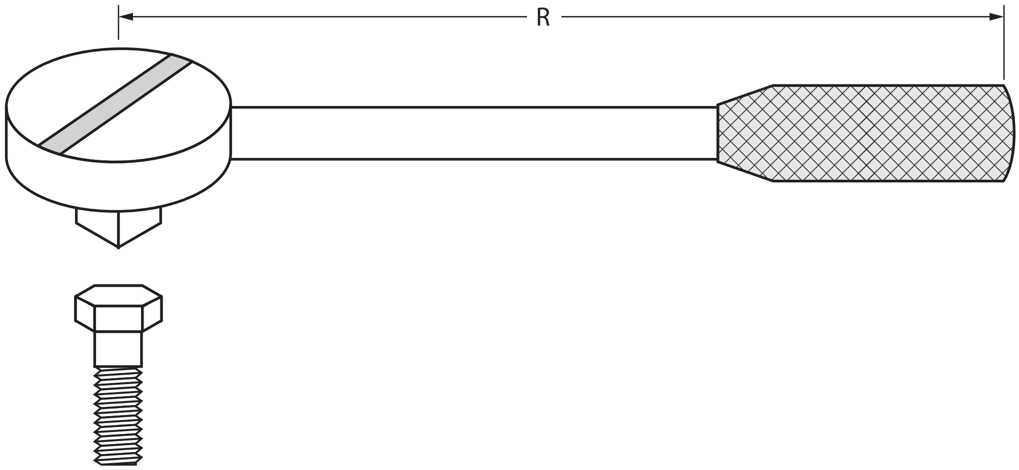


Figure 29 — Lever arm

When the length of the lever arm is known, the ideal mechanical advantage (IMA) is the ratio of the lever arm circumference and the pitch of the bolt.

That is:

$$\text{IMA} = \frac{2 \times L \times 3.14}{p}$$

Where:

L = length of lever arm
p = pitch of bolt

The actual mechanical advantage (AMA) of a screw is derived in the same manner as it is for other basic machines:

$$\text{AMA} = \frac{\text{F out}}{\text{F in}}$$

$$= \frac{R}{E}$$

Bolts and screws can have huge ideal mechanical advantages. However, they are actually inefficient because of the amount of friction developed between the threads and the connecting material or nut. This friction level has a plus side: it prevents bolts from loosening quickly.

As with other basic machines, the efficiency of a bolt thread is:

$$\text{Efficiency} = \frac{\text{AMA}}{\text{IMA}}$$

These equations can be used to solve problems involving bolts.

Example

A 20 cm wrench is used to tighten a nut onto an anchor bolt that is holding a stud wall to a concrete foundation. The pitch of the nut is 1.5 mm. A force of 50 N is applied to the wrench, which produces a force of 2100 N by the nut on the wood.

Find the efficiency of the bolt.

Solution

Find the IMA and AMA. Then use the two mechanical advantages to compute the efficiency.

$$\text{IMA} = \frac{2\,\pi\,L}{p}$$

$$= \frac{2 \times 3.14 \times 20\text{ cm}}{1.5\text{ mm}}$$

$$= 837.3$$

$$\text{AMA} = \frac{\text{F out}}{\text{F in}}$$

$$= \frac{2100\text{ N}}{50\text{ N}}$$

$$= 42$$

$$\text{efficiency} = \frac{\text{AMA}}{\text{IMA}}$$

$$= \frac{42}{837.3}$$

$$= 0.050$$

$$= 5\%$$

The efficiency of the nut is only 5%. However, even the AMA of 42 is impressive.

Bolt threads have many applications. They are used to make extremely accurate measuring micrometers. They provide the holding power in vises and the pressure in presses. Screw jacks are able to lift and hold in place impressive weights. All of these applications use the same equations as were introduced for the bolt.

Summary of equations and relationships

You should be able to recall and use the following equations and relationships:

$$\text{MA of a screw IMA (or MA)} = \frac{2 \times 3.14 \times L}{p}$$

$$\text{AMA (or MA)} = \frac{F\ out}{F\ in}$$

Describe the operation of the hydraulic press

The hydraulic press is the third simple machine. The lever and inclined plane both transfer forces by means of a solid. The hydraulic press transfers a force through a liquid.

Pascal's principle

To review, Pascal's law states:

An external pressure applied to an enclosed liquid is transmitted uniformly throughout the liquid.

Pascal's principle means that if a liquid is confined in a container that has two pistons, pressure on one of the pistons will act on the other piston (Figure 30).

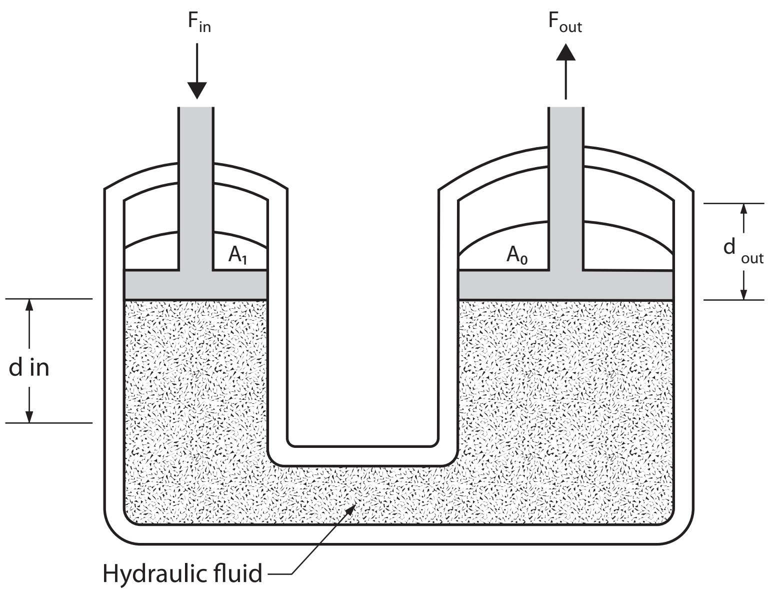


Figure 30 — Hydraulic press

Not only will the second piston move, but the fluid pressure on the second piston will be equal to the pressure on the first piston.

This is another application of the general conservation principle:

input pressure = output pressure

Mechanical advantage of a hydraulic press

The hydraulic press transfers a force and is, therefore, a machine. The hydraulic press, therefore, has a mechanical advantage.

You may recall that pressure is force divided by area. With this idea in mind, you can restate the pressure conservation equation as:

input pressure = output pressure

$$\text{P in} = \text{P out}$$

$$\frac{\text{F in}}{\text{area in}} = \frac{\text{F out}}{\text{area out}}$$

The pressure equation components can be arranged to produce several relationships:

$$\frac{\text{F out}}{\text{F in}} = \frac{\text{area out}}{\text{area in}}$$

$$\frac{\text{Resistance}}{\text{Effort}} = \frac{\text{Resistance area}}{\text{Effort area}}$$

$$\frac{\text{R}}{\text{E}} = \frac{\text{R area}}{\text{E area}}$$

$$\text{R} \times \text{E area} = \text{E} \times \text{R area}$$

The mechanical advantage of a hydraulic press is:

$$\text{AMA} = \frac{\text{R}}{\text{E}}$$

$$\text{IMA} = \frac{\text{R area}}{\text{E area}}$$

Just as with the other simple machines, the AMA and IMA are often used interchangeably and simply stated as:

$$\text{MA} = \frac{\text{R}}{\text{E}}$$

$$\text{MA} = \frac{\text{R area}}{\text{E area}}$$

You can also derive a modification of the torque equation for the hydraulic press.

Using the hydraulic press shown in Figure 31 and the conservation of work principle (work in = work out), you can conclude that:

F in × distance in = F out × distance out

This equation is equivalent to:

$$E \times ED = R \times RD$$

$$\frac{R}{E} = \frac{ED}{RD}$$

Since $\frac{R}{E} = \frac{ED}{RD}$ you have a third way of finding the MA of a hydraulic press:

$$MA = \frac{ED}{RD}$$

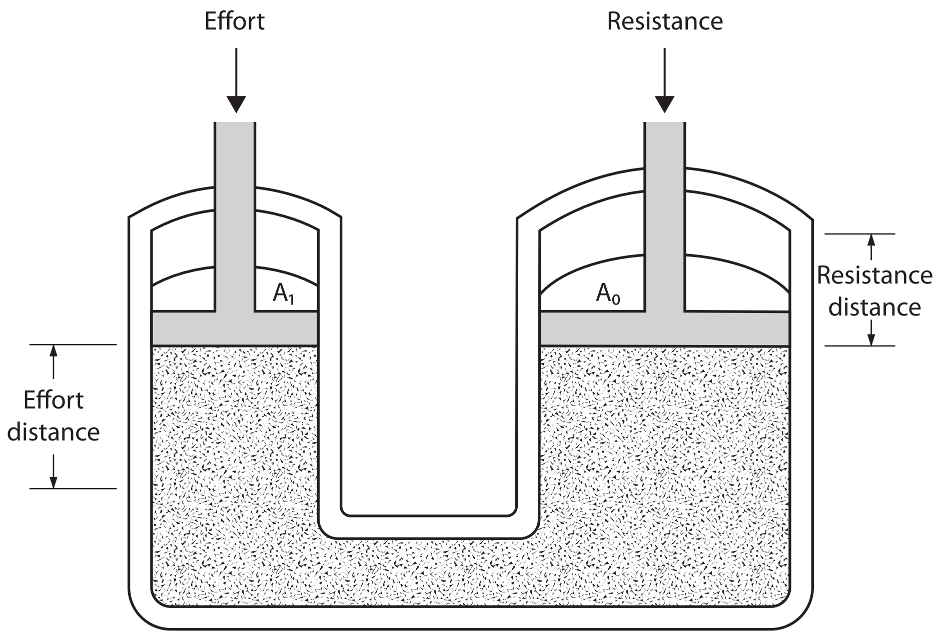


Figure 31 — Hydraulic press

And just as with other simple machines, hydraulic press problems are often solved by finding the general mechanical advantage using one MA equation and then inserting the result in the second MA equation to find the desired quantity.

The relationship of these terms may become clearer after working through an example using the hydraulic press.

Example

A hydraulic press is used to lift a 1200 kg automobile 2 m in the air. The surface area of the input piston is 10 cm^2 and the area of the output piston is 700 cm^2.

Find the input force and the distance the input piston moves assuming there are no friction losses.

Solution

Draw a diagram (Figure 32).

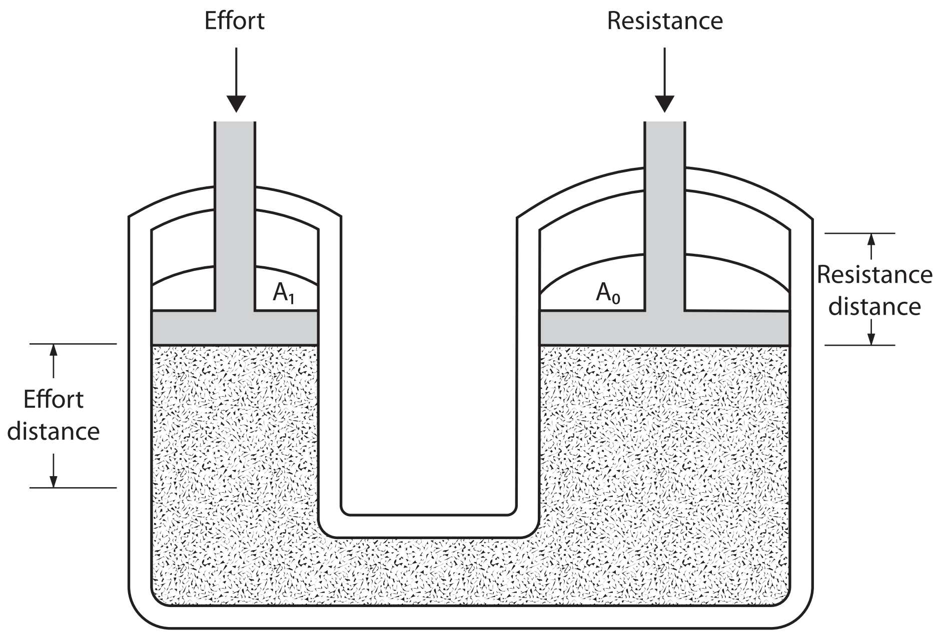


Figure 32 — Sketch for hydraulic press example

Determine the MA:

$$MA = \frac{A\ out}{A\ in}$$

$$= \frac{700\ cm^2}{10\ cm^2}$$

$$= 70$$

Now list all the information that you already have about this hydraulic press:

MA = 70
R = force of lifted automobile = 1200 kg × 9.8 m/s^2
= 11 760 N
RD = height of lifted automobile = 2 m
E = force applied to input piston = ?
ED = distance input piston moves = ?

Now find ED (effort distance) by using the equation $MA = \frac{ED}{RD}$ solved for ED:

$$MA = \frac{ED}{RD}$$

so

$$\begin{aligned} ED &= MA \times RD \\ &= 70 \times 2 \text{ m} \\ &= 140 \text{ m} \end{aligned}$$

Next, find E by using the equation $MA = \frac{R}{E}$ solved for E:

$$MA = \frac{R}{E}$$

so

$$\begin{aligned} E &= \frac{R}{MA} \\ &= \frac{11\ 760 \text{ N}}{70} \\ &= 168 \text{ N} \end{aligned}$$

Check the accuracy of your calculations by using the work equation:

$$\begin{aligned} F \text{ in} \times D \text{ in} &= F \text{ out} \times D \text{ out} \\ E \times ED &= R \times RD \\ 168 \text{ N} \times 140 \text{ m} &= 11\,760 \text{ N} \times 2 \text{ m} \\ 23\,520 \text{ N m} &= 23\,520 \text{ Nm} \end{aligned}$$

As you can see, the results are equal.

The small input piston must move the equivalent of 140 m in order to move the large output piston 2 m.

The answer to the above example suggests that the smaller piston must have a long chamber (cylinder) to move through. Indeed, in this example, the smaller piston seems to need a 140 m long cylinder, which is impractical. In place of a single 140 m stroke, the small piston takes a series of short strokes by refilling its cylinder from a reservoir of fluid. This operation can be seen in Figure 33.

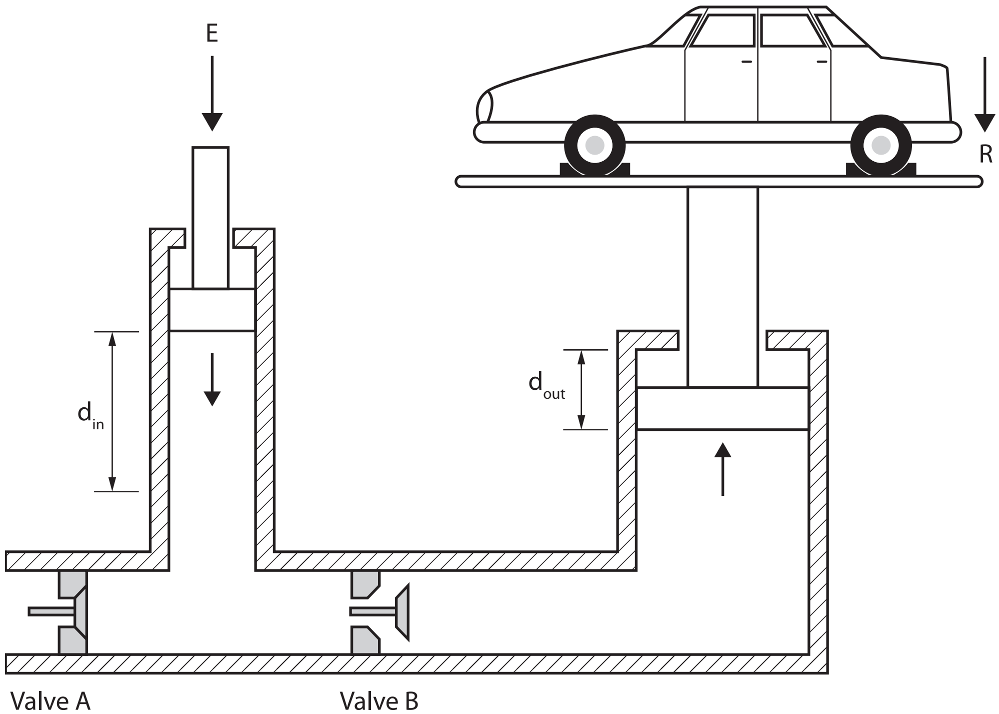


Figure 33 — Hydraulic lift with valves

In Figure 31, when an input force is applied, valve B is forced open and the fluid in the input chamber is pushed into the output chamber. When the input piston is pulled upwards, valve B closes and valve A opens, allowing fluid to be drawn from the reservoir into the input chamber. The input cylinder can then make another stroke. The reservoir and the operation of the two valves allow the input distance to be a series of relatively short strokes, which is a practical physical arrangement that can be contained in a relatively small area.

Overall mechanical advantage

Sometimes two or more simple machines are coupled together. This often results in the output of one machine being the input of the second machine, which becomes the input of a third machine, and so on. In such cases, the overall mechanical advantage of the compound machine is the product of the individual mechanical advantages.

MA overall = MA × MA × MA ...

Hand-operated hydraulic presses sometimes have a compounded mechanical advantage. For example, hydraulic jacks often use a lever to input a force.

Example

The input and output pistons of a hydraulic hand jack (Figure 34) have diameters of 1 in. and 4 in. respectively. The handle of the jack is actually a lever with a mechanical advantage of 8. If friction is not a factor in the system, find the weight that the jack can lift when a force of 45 lb. is applied to the jack handle.

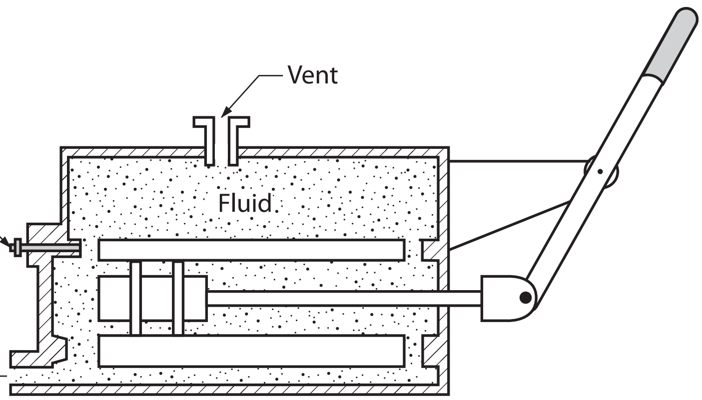


Figure 34 — Hydraulic jack

Solution

Find the MA of the hydraulic jack.

$$MA = \frac{A\ out}{A\ in}$$

$$= \frac{r^2\ out}{r^2\ in}$$

Where:

$$r\ out = \frac{d\ out}{2}$$

$$= \frac{4\ in.}{2}$$

$$= 2\ in.$$

And:

$$r\ in = \frac{d\ in}{2}$$

$$= \frac{1\ in.}{2}$$

$$= 0.5\ in.$$

$$MA = \frac{3.14 \times 2\ in. \times 2\ in.}{3.14 \times 0.5\ in.}$$

$$= 16$$

Determine the overall mechanical advantage of the system.

$$\text{MA overall} = \text{MA lever} \times \text{MA hydraulic press}$$
$$= 8 \times 16$$
$$= 128$$

Now use the overall mechanical advantage as the actual mechanical advantage.

$$\text{AMA} = \frac{\text{F out}}{\text{F in}}$$
$$\text{F out} = \text{AMA} \times \text{F in}$$
$$= 128 \times 45 \text{ lb.}$$
$$= 5760 \text{ lb.}$$

The hydraulic jack can lift a weight of 5760 lb. using an input force of only 45 lb.

You may have noticed in this last hydraulic jack problem that the MA of the jack (16) could have been found more quickly by squaring the ratio of the diameters instead of the ratio of the areas. This is also an acceptable method for finding the MA of the jack. So:

$$\text{MA} = \frac{\text{A out}}{\text{A in}}$$
$$\text{MA} = \frac{\text{R out}^2}{\text{R in}^2}$$
$$\text{MA} = \frac{\text{d out}^2}{\text{d in}^2}$$

Hydraulic press principles are used in tire pumps; shock absorbers; braking systems; dentist, hairdressing, and barber chairs; hydraulic cutters, and heavy-duty presses.

Summary of equations and relationships

You should be able to recall and use the following equations and relationships:

MA hydraulic press

$$\text{IMA (or MA)} = \frac{\text{R area}}{\text{E area}}$$

$$= \frac{\text{r out}}{\text{r in}}$$

$$= \frac{\text{d out}}{\text{d in}}$$

$$\text{AMA (or MA)} = \frac{\text{R}}{\text{E}}$$

$$\text{MA} = \frac{\text{ED}}{\text{RD}}$$

Torque equation

$\text{E} \times \text{ED} = \text{R} \times \text{RD}$

Overall mechanical advantage

$\text{MA overall} = \text{MA} \times \text{MA} \times \text{MA} \ldots$

☑ Now complete the Learning Task 2 Self-Test 3: Basic machines.

Self-Test 3: Basic machines

1. Which phrase best describes a basic device that transmits a force to produce purposeful work?
   a. Employee
   b. Power tool
   c. Transmitter
   d. Simple machine

2. Which of the following is an example of a simple machine?
   a. The lever
   b. The inclined plane
   c. The hydraulic press
   d. All of the above

3. Which term best describes a simple machine's capacity for multiplying an applied force?
   a. Applied effort
   b. Resistance force
   c. The inclined plane
   d. Mechanical advantage

4. Which phrase best describes the comparison of the applied force distance with a simple machine to the resistance force distance?
   a. Force equation
   b. Force-overcome resistance
   c. Ideal mechanical advantage
   d. Resistance mechanical equation

5. What is the approximate mechanical advantage found in a lever with an effort arm of 2 m and a resistance arm of 0.5 m?
   a. MA = 5:2
   b. MA = 4:1
   c. MA = 2:1
   d. MA = 1:5

6. What term is used to describe the pivot point that divides a lever into two parts?
   a. Fulcrum
   b. Effort arm
   c. Effort force
   d. Resistance arm

7. What effect would increasing the length of a lever have on its mechanical advantage?
   a. Shorten the MA
   b. Increase the MA
   c. Decrease the MA
   d. No effect on the MA

8. How much force is required to move a 100 kg block with a 3 m lever and the fulcrum 1 m from the load?
   a. 50 kg
   b. 980 N
   c. 490 N
   d. 490 kg

9. How can the mechanical advantage of a wheelbarrow be increased?
   a. Increase the length of the handles
   b. Decrease the length of the handles
   c. Move the load further from the wheel
   d. There is no technique for increasing the MA of a wheelbarrow.

10. What is the mechanical advantage of a 50 cm radius wheel handle that controls a 2 cm radius drive shaft on a valve body?
    a. 25
    b. 48
    c. 52
    d. 325

11. How long of a wrench would provide a mechanical advantage of 20 to a socket with a diameter of 20 mm?
    a. 40 mm
    b. 200 mm
    c. 400 mm
    d. 480 mm

12. What is the mechanical advantage of a single pulley machine?
    a. 0.5
    b. 1
    c. 2
    d. 3

13. With a three-pulley system, how long would the resistance distance be if the effort distance is 45 cm?
    a. 15 cm
    b. 48 cm
    c. 90 cm
    d. 135 cm

14. What is the mechanical advantage of a four-pulley system?
    a. ¼
    b. .25
    c. 4
    d. 40

15. A chiller motor operates at 1800 rpm and is connected to a fan designed to rotate at 600 rpm. Assuming zero friction loss with a fan pulley sized at 30 cm, what is the appropriate sized motor pulley?
    a. 10 cm
    b. 18 cm
    c. 30 cm
    d. 90 cm

16. What advantage does a gear system have over a belt-pulley system?
    a. Eliminate slippage
    b. There are no advantages.
    c. Increased energy consumption
    d. Increased mechanical advantage

17. A gear wheel, rotating at 500 rpm, has a radius of 150 mm and drives a second gear with a radius of 600 mm. If the input force is 100 N, what is the output force?
    a. 150 N
    b. 200 N
    c. 150 kg
    d. 400 N

18. A gear wheel, rotating at 500 rpm, has a radius of 150 mm and drives a second gear with a radius of 600 mm with a force of 100 N. Which of the following describes the mechanical advantage?
    a. 1
    b. 2
    c. 3
    d. 4

19. A gear wheel, rotating at 500 rpm, has a radius of 150 mm and drives a second gear with a radius of 600 mm with a force of 100 N. Which of the following describes the second gear's rpm?
    a. 100 rpm
    b. 125 rpm
    c. 150 rpm
    d. 600 rpm

20. Which simple machine are ramps, escalators, wedges, and screws examples of?
    a. The lever
    b. The staircase
    c. The pulley system
    d. The inclined plane

21. A barrel weighing 100 kg is to be rolled up a ramp 3 m long and 1 m high. What force is required to roll the barrel up the ramp?
    a. 300 N
    b. 326 kg
    c. 326 N
    d. 2940 N

22. Which of the following best describes the mechanical advantage of a ramp?
    a. MA = ramp length/ramp height.
    b. MA = ramp height/ramp length.
    c. MA = ramp height × ramp length.
    d. MA = ramp height + ramp length.

23. Which of the following best describes the mechanical advantage of a wedge?
    a. MA = wedge length × wedge angle.
    b. MA = wedge length/wedge thickness.
    c. MA = wedge thickness/wedge length.
    d. MA = wedge angle/wedge thickness + length.

24. Which of the following best describes the distance between two adjacent threads of a bolt?
    a. Kerf
    b. Pitch
    c. Screw advantage
    d. Nominal thread count

25. Which of the following best describes the transfer of a force through a contained liquid?
    a. Waves
    b. Turbulence
    c. Hydraulic pressure
    d. The hydraulic press

26. Which of the following is equal to the input pressure applied to a hydraulic press?
    a. The effort arm
    b. The resistance arm
    c. The output pressure
    d. The mechanical advantage

27. Which of the following describes the mechanical advantage of a hydraulic press?
    a. Resistance arm/effort arm
    b. Effort force/resistance force
    c. Effort angle/resistance angle
    d. Area of resistance cylinder/area of effort cylinder

28. A hydraulic press is used to lift a 1000 kg pump so a millwright can bolt it to the piping system. The hydraulic press handle applies force to a piston with an area of 5 cm^2; the press piston lifts the pump with an area of 80 cm^2. How much force will the millwright need to apply to the handle to lift the pump?
    a. 62.5 N
    b. 1000 N
    c. 6125 N
    d. 81.25 N

LEARNING TASK 3

Describe the basic properties of thermal energy

Thermal energy has a major role in all trades. Welders must be aware of the heat conductivity and melting points of materials they work with. Heating technicians use their knowledge of the expansion, conduction, and insulating qualities of building materials. Those working in appliance repair need a conceptual understanding of the energy principles of refrigeration and air conditioning systems. Automotive and heavy-duty mechanics use cylinder and exhaust temperatures for maintenance diagnostics.

When you have completed this Learning Task you should be able to:

- distinguish between the terms "temperature," "heat," and "internal energy"
- recognize and use the units associated with heat and temperature
- describe changes of state associated with heat
- define "heat of fusion" and "heat of vaporization"
- describe conduction, convection, and radiation, and factors associated with these types of heat transfer

Measurement and effects of heat

All matter is composed of molecules. At most temperatures, a material's molecules are in constant random motion. This molecular movement is an energy form called "thermal energy" or, as it is sometimes named, 'internal energy."

Thermal energy and heat

The higher the temperature an object has, the greater the vibration of molecules within the object. As an object cools, the molecular movement decreases.

If a "hot" object comes in contact with a "cool" object, the more energetic molecules of the hotter item transfer some of their internal energy to the second item by colliding with the less energetic cool molecules. This causes the molecules in the cool object to vibrate more vigorously. The increased molecular activity generates "heat" in the cooler object. The hot object will eventually lose its movement advantage and both objects will soon be in a state of equilibrium. That is, both objects will have the same temperature.

The energy that is transferred from the hot object to the cooler one is called "heat."

Heat has a formal definition:

> *Heat is internal energy being transferred from one object to another as a result of a temperature difference between the objects.*

The heat transfer from one object to another is always flowing from the object with the higher temperature to the object with the lower temperature.

Temperature

The discussion above used the word "temperature." Temperature is a measure of the intensity of the internal energy of an object; that is, a measure of molecular motion. When a body's temperature drops, the level of the thermal energy and molecular motion in the body also drops.

If two objects have the same intensity of thermal energy, the objects are at the same temperature and no heat transfer will take place.

It is important to understand the difference between temperature and thermal energy. For example, a 1 L container of water and a 2 L container of water may both have a temperature of 100°C. Their temperatures are the same but the total amount of thermal energy is different. Or consider a bathtub full of water at 45°C, which has more thermal energy than a cup of tea at 90°C even though the temperature of the tea is higher.

Measuring temperature

Since temperature is really a rate of molecular vibration, it would seem that temperatures would be difficult to determine, as such vibrations cannot be readily seen or evaluated. However, the fact that matter behaves in predictable ways when heated gives us methods to measure temperature. For example, matter expands when heated. This property is used to indirectly determine temperatures.

Temperatures are usually determined by using a thermometer. There are several types of thermometers. Almost all thermometers are calibrated in either Celsius or Fahrenheit degrees. Both of these degree systems are based on the freezing point (0°C and 32°F) and the boiling point (100°C and 212°F) of water.

The major difference in types of thermometers is not in calibration but in the method used to arrive at the reading.

Liquid expansion thermometer

The most common thermometers consist of a small reservoir and a fine tube (Figure 1). The reservoir is filled with a fluid such as coloured alcohol or mercury.

A change in temperature will change the volume of the liquid. This change in volume is indicated by the level of the liquid in the tube. The tube or column is calibrated directly in degrees Celsius or Fahrenheit.

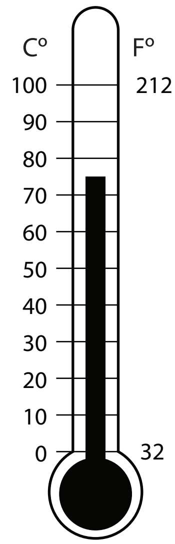


Figure 1 — Liquid expansion thermometer

The range of most liquid expansion thermometers makes them ideal for home and medical use. For extremely high or low temperatures, other types of thermometers must be used.

Bimetallic thermometer

When a metal is heated, it expands in length. Two unlike metals expand at different rates. If two unlike metals are layered together to make a bimetallic strip, the different rates of expansion will cause the bimetallic strip to bend one way when being heated and the opposite way when being cooled (Figure 2).

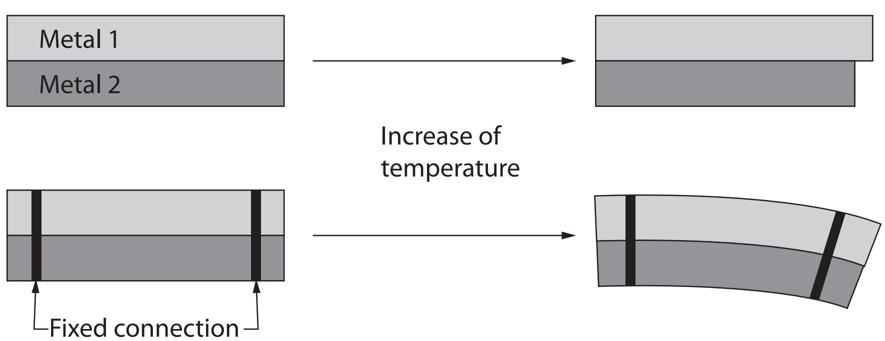


Figure 2 — Bimetallic strip

The bimetallic strip can be coiled and linked to a pointer that will indicate the amount of movement on a calibrated dial face (Figure 3). Bimetallic strip thermometers are much more rugged and can be made with a wider temperature range than glass thermometers, but they tend to be less accurate.

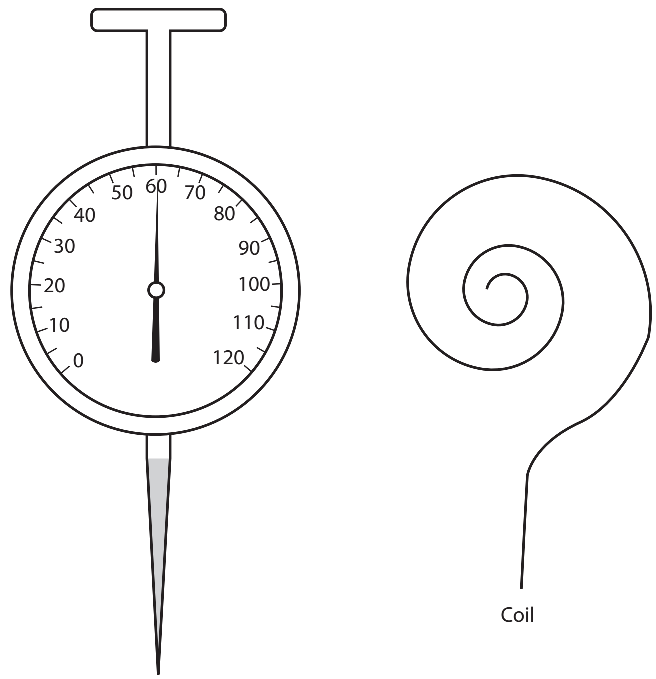


Figure 3 — Bimetallic coil thermometer

Oven and kiln thermometers, hot water heating lines, candy thermometers, and thermostat controls often use bimetallic strips. Several types of bimetallic strips are used in automatic chokes and exhaust manifold heat control valves found on many automobile engines.

Resistance thermometers

Electrical conductors change their electrical resistance as their temperature changes. Resistance drops as temperature drops and rises as temperatures rise.

A platinum resistance thermometer (Figure 4) consists of a coil of platinum wire sealed inside a quartz container. The coil of wire is connected to a power source and an ohmmeter that will measure the resistance of the wire. If the resistance of the platinum wire at a certain temperature is known, you can use this information to determine the temperature of the wire when the resistance changes.

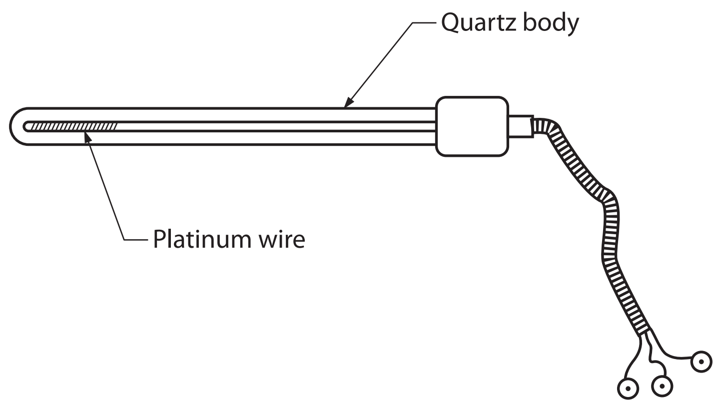


Figure 4 — Platinum resistance thermometer

Platinum and quartz have high melting points, so the platinum thermometer can be placed in locations where high temperatures may occur such as steel and other metallurgical industries, with accurate temperature readings of up to 1350°C (2460°F).

Thermocouples

Where the platinum and quartz thermometers use resistance change to read temperatures, the thermocouple uses voltage. If two unlike metal wires joined together in a closed loop are located so that the joined ends are at different temperatures, a voltage will be detected by a sensitive voltmeter placed in the loop (Figure 5).

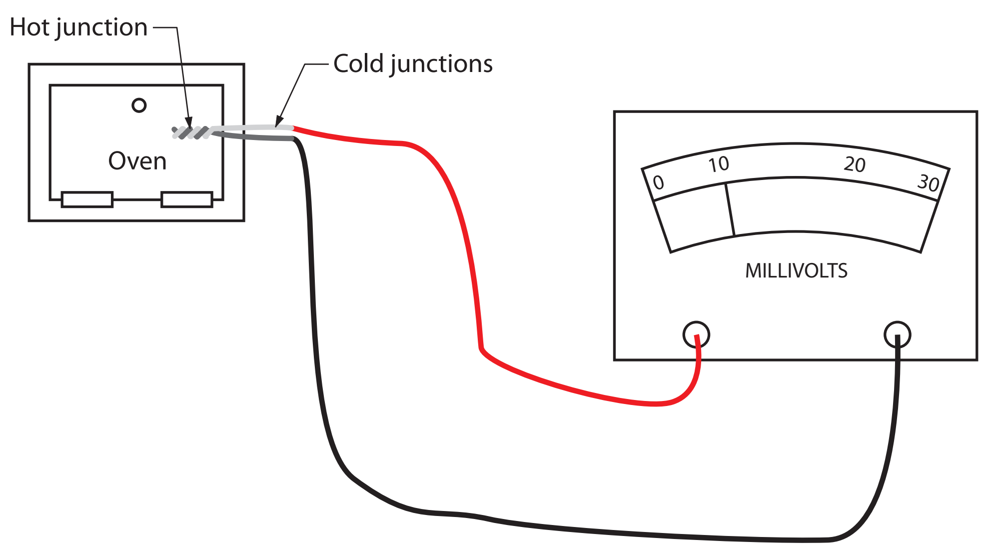


Figure 5 — Thermocouple

If the temperature at the cool end of the junctions is known, then the temperature at the other high-temperature junction can be determined from the size of the created voltage.

Thermocouples, sometimes called "pyrometers," are widely used in industry for tasks such as diagnosing diesel engine performance by measuring exhaust temperatures, or as a safety device in a gas-fired appliance that confirms that a pilot light has not gone out (Figure 6). They are extremely accurate and, depending on the two metals chosen, can reliably indicate temperature up to 1500°C (2700°F).

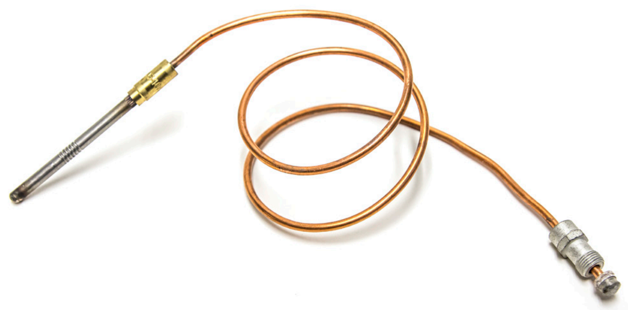


Figure 6 — Gas appliance thermocouple

Optical pyrometers

Temperatures of molten iron, steel, and other metals can be determined by their brightness or shade of colour. For example, steel changes colour as its temperature increases.

Optical pyrometers are instruments designed to compare the colour and brightness of a glowing mass with the colour and brightness of a filament similar to the filament found in lightbulbs. By matching the filament colour to that of the molten metal, the optical pyrometer reads the temperature of the material.

Optical pyrometers are used in steel mills, foundries, and other heat-intensive industries. They are also used to determine the temperature of molten lava in active volcanoes.

Measurement of heat

Temperature is measured in degrees. Temperature is only one factor in deciding the total amount of heat in an object. Other factors are the mass and the type of material.

Heat units

Heat is a form of energy and so is measured in joules (J) and kilojoules (kJ), which are standard energy units in the metric system. Calories (cal), kilocalories (kcal or sometimes Cal), and British thermal units (Btu) are used in the imperial system.

These units are defined below and their relationship is given in Figure 7:

- One calorie is the amount of heat energy needed to change the temperature of one gram of water by one degree Celsius.
- One kilocalorie is the amount of heat energy needed to change the temperature of one kilogram of water by one degree Celsius.

- One British thermal unit is the amount of heat energy needed to change the temperature of one pound of water by one degree Fahrenheit.

Notice that the definitions say "change" the temperature. This is important, as the amount of heat absorbed by a substance to raise its temperature by a degree is equal to the amount of heat lost by a substance when its temperature drops by a degree.

1 kcal	=	1000 cal
1 J	=	0.000 239 kcal
1 kcal	=	4185 J
1 kJ	=	0.239 kcal
1 kcal	=	4.185 kJ
1 Btu	=	1054 J
1 Btu	=	252 cal
1 Btu	=	0.252 kcal

Figure 7 — Table of relationships between joules, kilocalories, and British thermal units

Specific heat capacity

By definition 1 kcal of heat will raise the temperature of 1 kg of water by 1°C. However, 1 kcal of heat will raise the temperature of 1 kg gold by 33°C and 1 kg of concrete by 1.42°C. The reason for this increase in temperature rise is because different materials have different specific heat capacities.

The specific heat capacity of a material is the amount of heat that must be added or taken from 1 kg (or 1 lb.) of material to change the material's temperature by 1°C (or 1°F). The specific heat chart is shown in Figure 8.

Table of Specific Heats		
Substance	Specific Heat	
	kcal/kg per °0 / Btu/lb. °F	Joules/kg per °C
Mercury	0.033	138
Lead	0.032	130
Copper	0.093	390
Steel	0.1175	493
Cast iron	0.1189	498
Aluminum	0.22	920
Water	1.0	4189
Ice	0.5	2093
Steam	0.48	2009
Glass	0.20	840

Figure 8 — Specific heat coefficients

As can be seen in Figure 8, water has by far the highest specific heat capacity. This means that water needs to absorb a large amount of energy to raise its temperature by even a degree. This makes water a good "heat trap."

On the other hand, because the amount of heat absorbed by a substance when it is heated is equal to the amount it gives off as it cools, water is a good liquid to transport, store, and emit heat. This makes water an excellent choice as a medium in heating and cooling systems.

As well, many solar-energy heating designs use the sun to heat containers of water during daylight hours and then allow the heat of the warm water to escape at night to warm the air around the containers.

Conservation of heat

Heat transfer has its own conservation rule:

heat loss of hot item = heat gain of cooler item
Q (lost) = Q (gained)

The heat conservation rule is important when designing cooling systems for machinery that develops a great deal of heat when operating. The cooling systems on internal combustion engines, particularly diesel units, must constantly move a large volume of water through cooling jackets around the cylinders to ensure that the engine does not overheat.

Change of state

You may recall that some matter can change its state from solid to liquid or liquid to gas and vice versa. Freezing water into ice, melting ice into water, boiling water into steam, and condensing steam into water are the most common examples of matter (in this case, water) changing its state.

Latent heats of fusion and vaporization

Before a solid can change into a liquid, its temperature must reach the melting point. For example, a block of frozen water (ice) can change into liquid water only when the ice reaches a temperature of 0°C (32°F). When this temperature is reached, the ice absorbs additional heat to change its state from a solid into a liquid.

While the ice is melting, the solid ice and the melted ice are still at 0°C (32°F). In order to melt, the ice needs to acquire 335 kJ of thermal energy for every kg of its mass (or 144 Btu/lb.). But this absorbed heat does not change the temperature of the ice and water. Instead, it is used to weaken the tight intermolecular bonds between the water molecules in the ice and so turn the solid (ice) into a liquid (water), a change of state.

In similar fashion, when liquid water reaches its freezing point, it must lose more heat before it can change its state from liquid to solid. Again this loss of heat does not change the temperature of the liquid water and the solid being formed. This loss of energy causes the bonds between the molecules in liquid water to strengthen and so turn a liquid into a solid.

This seemingly magical heat that does not change temperature but causes a material to change states (a solid into a liquid or a liquid into a solid) is called the latent heat of fusion (Lf).

Similarly, a liquid can change into a gas only when its boiling point is reached and when additional heat is absorbed by the liquid. When liquid water reaches 100°C (212°F), the water is almost ready to change into a gas (steam), but it must first acquire additional thermal energy. As when changing state from solid to liquid, this additional thermal energy (2260 kJ/kg or 972 Btu/lb.) does not change the temperature of the water, but is used to weaken the bonds between the liquid molecules and so turn a liquid into a gas.

When steam cools to 100°C (212°F), it must lose that same amount of thermal energy before the steam changes into a liquid. Again, the quantity of heat needed to change a liquid to a gas or a gas to a liquid is the "latent heat of vaporization" (Lv).

Although water is used in this explanation and example of the latent heat needed by matter to change from one state to another, change of state conditions occur in many industrial processes with a variety of substances.

Heat engines

A machine that converts heat energy into a motion is called a heat engine. Internal combustion engines and steam boilers are heat engines.

The fuel used in most internal combustion engines is a liquid (gasoline) that is turned into a vapour before it passes into the cylinder for detonation. The liquid is partially changed to a vapour by the carburetor and then further atomized by the heat of the engine, thus completing a change of state process.

Steam boilers change water into steam. The steam is used to drive a turbine that supplies the desired work. After acting on the turbine, the steam passes into a condenser where cool water changes the steam back into liquid water and so on.

Refrigeration system

The process of refrigeration involves transferring unwanted heat from one area to another area where the heat can be released as waste energy. This is accomplished by having a confined fluid (called a "refrigerant fluid") circulate through a closed coiled system in which the fluid changes from liquid to gas and then back to liquid (Figure 9).

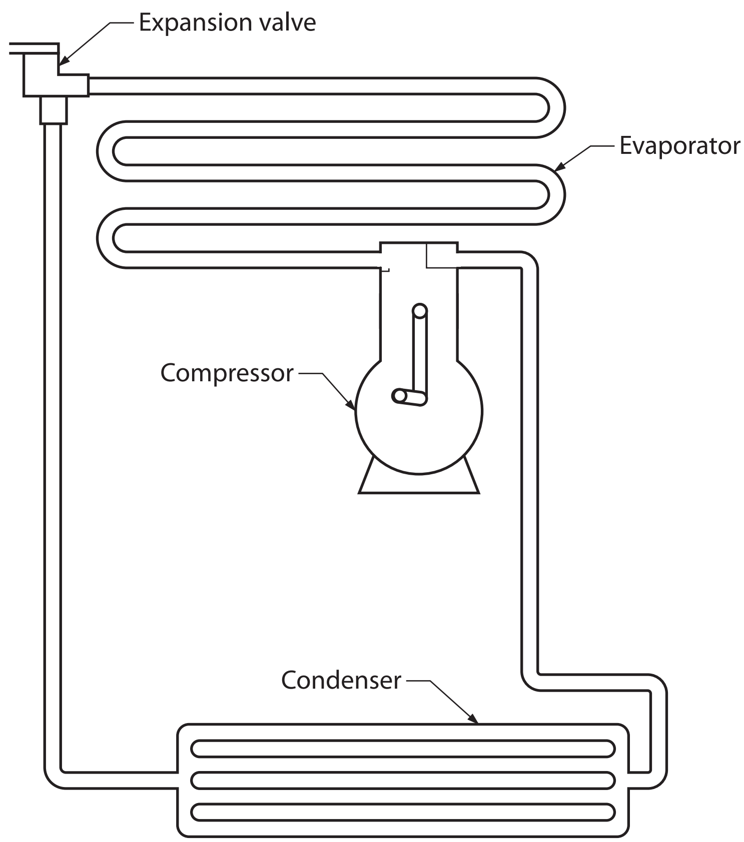


Figure 9 — Simplified refrigeration system

The whole refrigeration process is based on the principle that when a liquid changes to a gas it will absorb the needed latent heat of vaporization from its surroundings. Conversely, when a gas or vapour changes back to a liquid, it will give up its latent heat of vaporization to its surroundings.

The refrigerant is a liquid that has a low boiling temperature, well below that of water. It will begin to boil after it has absorbed the latent heat from surrounding air. To make practical use of the refrigerant, it is pressurized to increase its boiling point to just several degrees below the freezing point of water. This pressurized refrigerant is what is circulated inside the refrigerator.

The liquid-vapour mixture becomes more of a vapour as it acquires the needed latent heat of vaporization from the air surrounding the coils within the refrigerator. It is then circulated through the compressor and outside the refrigerator (still in a pressurized system) and into the condenser to lose its latent heat to the surrounding air and return to a liquid state.

This constant cycling of the refrigerant allows it to remove heat from within the closed refrigerator.

☑ Now complete the Learning Task 3 Self-Test 1: Measurement and effects of heat.

Self-Test 1: Measurement and effects of heat

1. Which of the following terms best describes molecular movement?
   a. Thermal energy
   b. Electrical energy
   c. Chemical energy
   d. Mechanical energy

2. Which of the following terms best describes an internal energy transferred from one object to another as a result of temperature difference between the objects?
   a. Heat
   b. Vibration
   c. Mechanical
   d. Temperature

3. Which of the following terms is used to describe the measurement of internal energy of an object?
   a. Heat
   b. Chemical
   c. Mechanical
   d. Temperature

4. Which of the following thermometers uses two strips of unlike metals that expand and contract at different rates?
   a. Bimetallic strip thermometer
   b. Glass expansion thermometer
   c. Liquid expansion thermometer
   d. Bimetal calibrated thermometer

5. Which of the following thermometers utilize the predictable change in a metal's conductivity as its temperature changes?
   a. Platinum thermometers
   b. Resistance thermometers
   c. Bimetallic strip thermometers
   d. Glass expansion thermometers

6. Two specific dissimilar metals, when joined, can create a voltage when heated. Which of the following best describes a thermometer that measures this voltage to in turn measure high temperatures?
   a. Thermostat
   b. Thermocouple
   c. Resistance thermometer
   d. Bimetallic strip thermometer

7. Which of the following terms best describes a thermometer that measures temperatures by brightness or shade of colour of molten metals?
   a. Thermocouple
   b. Optical pyrometer
   c. Exhaust pyrometer
   d. Bimetallic strip thermometer

8. Which of the following is the standard unit of measurement of heat energy in the metric system?
   a. Joule
   b. Kilo thermal unit.
   c. British thermal unit
   d. Metric thermal unit

9. How many degrees Celsius will 1 kcal of heat raise the temperature of 1 kg of water?
   a. 1°F
   b. 1.5°F
   c. 1.0°C
   d. 10°C

10. Which of the following terms defines the amount of heat (kcal) required to raise the temperature of a kg of a particular material 1°C?
    a. Specific heat
    b. Specific gravity
    c. British thermal unit
    d. Metric thermal unit

11. Which of the following terms describes heat that causes a change of state in a substance?
    a. Fusion
    b. Latent heat
    c. Sensible heat
    d. Vaporization

12. Which of the following terms describes the quantity of heat needed to change a liquid to a gas or a gas into a liquid?
    a. Latent heat of fusion
    b. Sensible heat of fusion
    c. Latent heat of vaporization
    d. Sensible heat of vaporization

13. What occurs when a liquid changes into a gas?
    a. The volume of the substance increases.
    b. The volume of the substance decreases.
    c. The change depends upon the substance.
    d. The volume of the substance remains the same.

14. Which term best describes a fluid that, with controlled pressure, can be manipulated to boil at a temperature below the freezing point of water?
    a. Ice
    b. Glycol
    c. Water
    d. Refrigerant

15. Which of the following terms best describes the amount of heat energy required to raise 1 lb. of water 1°F?
    a. Kilocalorie
    b. British thermal unit
    c. Specific thermal unit
    d. American thermal unit

16. Molecular movement in an object is thermal energy or heat.
    a. True
    b. False

17. Temperature and heat are the same thing.
    a. True
    b. False
18. Temperature is a measurement of the intensity of the internal energy of an object.
    a. True
    b. False
19. A one litre container of water at 75°C has the same amount of heat as a two litre container of water also at 75°C.
    a. True
    b. False
20. Many common thermometers work on the premise that material expands as its temperature lowers and contracts as its temperature rises.
    a. True
    b. False
21. Resistance thermometers work on the premise that a material's electric resistance will change as its temperature changes.
    a. True
    b. False
22. Thermocouples work on the premise that two dissimilar metals joined together in a closed loop will generate a voltage when heated.
    a. True
    b. False
23. Temperature is the single factor in determining the total heat energy found in an object.
    a. True
    b. False
24. The imperial unit of heat energy is the British thermal unit.
    a. True
    b. False
25. The metric unit of heat energy is the kilopascal.
    a. True
    b. False

26. A metric unit of heat is the kilocalorie.
    a. True
    b. False

27. One Btu of heat will change the temperature of one pound of water by one degree Fahrenheit.
    a. True
    b. False

28. The higher a substance's specific heat capacity is, the less heat the substance will require to raise its temperature.
    a. True
    b. False

29. The higher a substance's specific heat capacity is, the more heat the substance will require to raise its temperature.
    a. True
    b. False

30. Water is considered a poor heat trap as a result of its high specific heat capacity.
    a. True
    b. False

31. The heat exchange that raises or lowers a substance's temperature is called latent heat.
    a. True
    b. False

32. The heat exchange that changes a substance's state—solid to liquid, liquid to gas etc.—is called "latent heat."
    a. True
    b. False

33. A refrigeration system removes unwanted heat through the manipulation of a fluid's (refrigerant) latent heat of vaporization.
    a. True
    b. False

Thermal expansion and heat transfer

In the last section, you learned that most materials expand when heated. A bimetallic strip can be used as a thermometer or thermostat control because of the relationship between heat and the different expansion rates of two materials.

Thermal expansion

The common household glass thermometer works in similar fashion to the bimetallic strip as the fluid in the reservoir expands and contracts in reaction to a change in temperature. These thermometers are applications of thermal expansion.

Not only does almost all matter expand when heated, but the amount of thermal expansion of a given material is predictable. The thermal expansion of a material is proportional to the change in its temperature; however, different materials expand at different rates.

For example, a change of 5°C produces a different change in length in a steel rod than it does in a copper rod of the same original length. The same is true for the volume of the two rods; the volumes of both rods will change, but they will do so at different rates.

Linear expansion

"Linear expansion" refers to a change in length. To calculate the change in length in a piece of material caused by a change in temperature, you can use equations that make use of a multiplier, or factor, that measures this property.

This multiplier is called the "coefficient of linear expansion," and specific substance coefficients are shown in Figure 10.

Linear expansion is expressed as ΔL (Δ = delta, meaning change), and the following equation is used:

$$\Delta L = aL_o \Delta T$$

Where:

L = change in length

a = coefficient of length (from Figure 10)

L_o = original length

T = change in temperature

Substance	Per F°	Per C°
Plastic	0.000 06	0.000 11
Aluminum	0.000 012 3	0.000 022 1
Tin	0.000 011 5	0.000 020 7
Brass	0.000 010 5	0.000 018 9
Copper	0.000 009 5	0.000 017 1
Steel	0.000 006 7	0.000 012 1
Glass	0.000 004 9	0.000 008 82

Figure 10 — Coefficients of linear expansion

This equation is used to anticipate the expansion of lengths of steam piping, for example, providing the necessary data used to design an expansion loop. It is also used to compute the expansion of valve rod clearance that will allow for a smooth running engine at high operating temperatures.

Volume expansion

As mentioned above, the volume of a heated material also tends to expand. Volumes, when heated, change in much the same manner as lengths, but you replace the coefficient of linear expansion with a coefficient of volume expansion.

The coefficient of volume expansion for a material is three times greater than its linear coefficient.

The volume of a liquid expands in the same way the volume of a solid does. A table of coefficients of volume expansion for liquids is shown in Figure 11.

Liquid	Per °F	Per °C
Alcohol	0.000 62	0.001 12
Gasoline	0.0006	0.001 08
Mercury	0.0001	0.000 18
Water	0.000 11	0.0002

Figure 11 — Coefficients of volume expansion (liquids)

The equation for finding the change in volume due to thermal expansion is similar to that of linear expansion. However, the volume expansion coefficient is represented by the letter "b."

Volume expansion = V

$V = bV_oT$

Where:

- V = change of volume
- b = coefficient of volume expansion
- V_o = original volume
- T = change in temperature

When storing liquids, you must take into account the possibility of the liquid expanding beyond the confines of its container. Tightly sealed full containers can burst if they are stored too close to a heat source.

Expansion space

Large buildings, roadways, bridges, and other constructions need to have expansion joints built into their design. Otherwise, seasonal temperature changes can cause cracks, squeaks, breakage, and distortions in the structure.

The pressures created by thermal expansion are astounding. Liquids can blow apart their containers if space is not left for thermal expansion. The force exerted by a steel girder experiencing a linear expansion of 2 mm is the same as the force that would be needed to stretch it by 2 mm. The force is about 1 million newtons! No wonder expansion joints are needed.

Heat transfer

There are three ways in which heat flows: conduction, convection, and radiation (Figure 12).

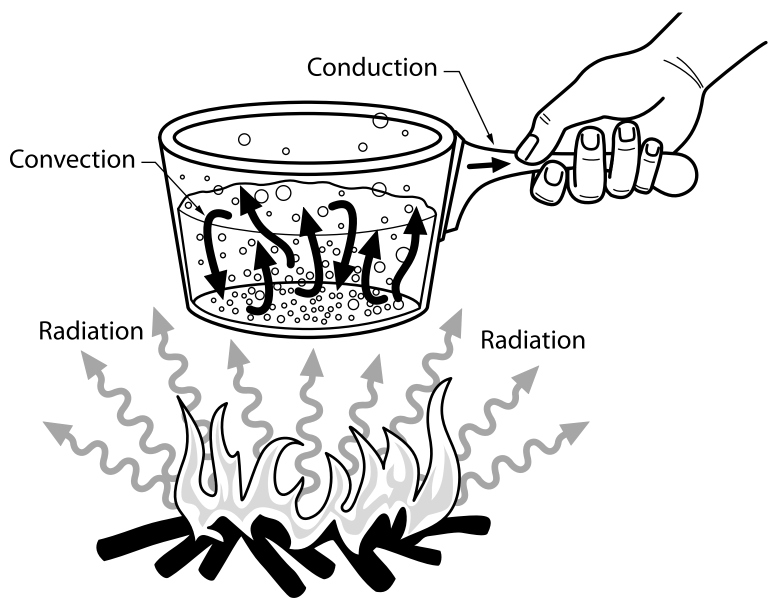


Figure 12 — Heat transfer methods

The most common example of heat transfer by conduction is when a pot is placed on a stove element to cook food. The heat of the element is conducted to the food being cooked by way of the metal pot.

Convection transfer is the most common way a house is heated. A furnace or heater outlet is placed near a wall and the heat rising from the outlet is carried throughout the room by natural air currents produced by the warm air from the furnace mixing with the cool air near the walls.

Radiant heat is similar to light, and the transfer of heat by radiation is very much like the way in which light travels from the sun to Earth.

Conduction

Heat transferred by conduction means that the heat has travelled through a solid, liquid, or gas.

There are several factors that determine how fast heat can travel by conduction:

- Heat transfer by conduction means the heat travels through a body. In order for heat to be conducted through a body, the ends or sides of the object must be at different temperatures.
- The distance through the material (or thickness) that the heat must travel influences the speed of travel. The thicker the material, the slower the heat transfer. All this is saying is that a thick brick wall is a better insulator than is a thin one.
- If the heat to be transferred can influence a large surface area, more heat can be transferred. An example is a large picture window that lets in more heat on a bright sunny day than a smaller window does. Conversely, a large window allows more heat to escape on a cool dull day.
- All solid materials conduct heat; some conduct much better than others. A material's ability to conduct heat depends on the material's thermal conductivity.

Thermal resistance

There are no perfect thermal conductors; every one offers some resistance to the transfer of heat. Thermal conductors that have low conductivity values are used as insulating materials.

The insulating value of the material is found by taking the reciprocal of its conductivity value and multiplying by the thickness of the material. The result is referred to as the R value of the material.

$$\text{R value} = \text{thermal resistance} = \frac{\text{thickness}}{\text{thermal conductivity}}$$

Materials such as cork, down, and glass fibre have low conductivity values and so are good insulation materials. Down is used in insulating clothing and sleeping bags. Cork can be used as a thermal insulator in construction, but glass fibre (either blown or in batts) is a more common industrial insulating material.

If you have two or more materials formed into a layered insulating product, the total R value is the sum of the individual R values.

Convection

When a fluid (that is, a gas or liquid) is heated, it expands and so becomes less dense. Cooler fluid, being denser, moves downward and pushes the less dense warmer fluid upward. This upward movement of a less dense fluid, coupled with the downward movement of a denser fluid, is the principle behind heating by convection.

One application of convection heating is the commercial hot water tank. The heating coils in hot water tanks are at the bottom of the tank. The water at the bottom of the tank is warmed and rises to the top. The warmed water displaces cool water at the top of the tank. The cooler water is displaced to the bottom of the tank where it, too, can be warmed by the coils. The water constantly circulates in the tank until all the water is at the desired temperature. This circulatory movement is an example of heat transfer by natural convection. Baseboard heaters employ natural convection as well. The heated surface of the baseboard raises the temperature of the air around it, causing the air to rise and drawing the cooler air into the baseboard, creating convection currents.

Heat can also be transferred by forced convection. For example, the engine cooling system in an automobile employs a pump to circulate the cooling medium, often water and radiator fluid, as seen in Figure 13.

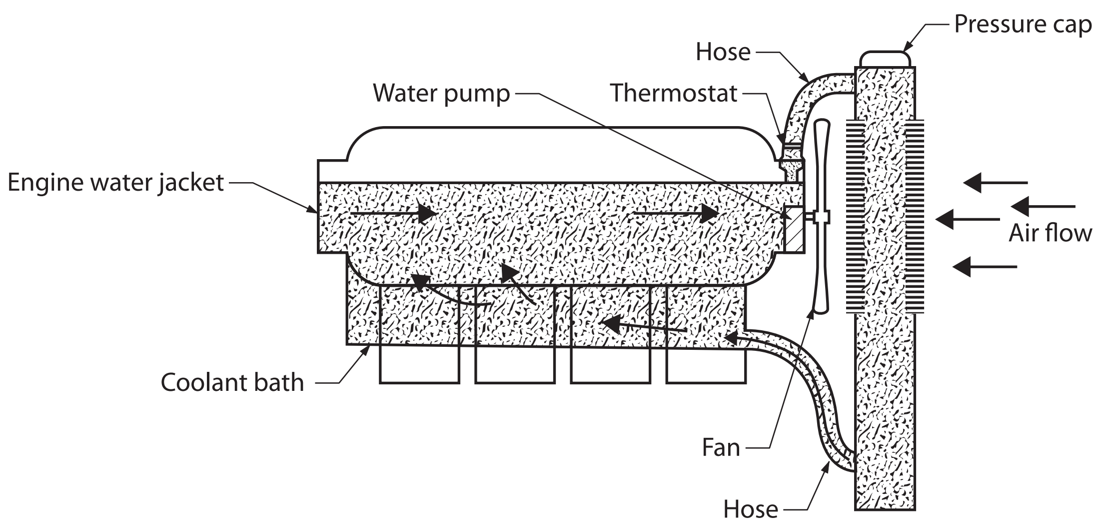


Figure 13 — Radiator cooling system

The cool water absorbs heat from the engine and returns to the radiator through the upper radiator hose. The heated water passes through the radiator, where it is cooled by air rushing between the copper tubes and fins of the radiator. The now cooled water is again pumped through the engine.

Convection heating also explains why basements are cool and upstairs rooms are hot on warm summer evenings. Warm air rises throughout the day and then collects in the lower levels of the house. The house is being heated from the top down. During the evening, as outside temperatures drop, the house cools from the bottom up because cooled air settles under the less dense trapped hot air. The first rooms heated in the day are the upstairs ones; the last rooms cooled at night are the upstairs ones.

Radiation

Radiated heat is heat that travels like light. When you are out in the sun on a warm summer day, you are warmed by the radiating heat of the sun. The heat from the sun cannot reach us through conduction or convection, as it travels through millions of miles of empty space in the form of electromagnetic waves.

There are many types of electromagnetic waves, including X-rays, gamma rays, radio waves, and infrared waves. The waves that are produced by thermal radiation are waves emitted by an object (that is, a solid, a liquid, a gas) because of the object's temperature.

At low temperatures, objects emit little thermal radiation. But as an object's temperature increases, so does the level of radiated heat.

The ability to emit heat is closely related to the ability to absorb heat. A dark black surface is a good absorber and radiator of heat. Solar collectors are often painted black so that they absorb heat more efficiently. On the other hand, you probably know from experience that wearing white or light-coloured clothing will keep you cooler on a bright, hot day. A highly polished, light-coloured surface is a poor absorber and radiator of heat.

Emissivity values

The amount of heat a surface can emit or absorb is sometimes compared to an ideal object called a blackbody that is assumed to emit and absorb all heat. In scientific applications, the blackbody is used to provide a baseline for comparison purposes, and objects have an emissivity ("e") value in comparison to a blackbody's "e" value of 1.0, and, at the other end of the scale, a perfectly reflective body's "e" value of 0.0.

Highly polished silver has an "e" value of 0.05, indicating it would reflect, not absorb, heat, whereas thick matte black paint on a surface could have an "e" value of 0.95, very close to the ideal "e" value of a blackbody.

Boiler, steam, and hot water pipes are painted white to reduce radiated heat loss. Conversely, an electric portable or baseboard heater should be a dark colour so that the unit can better radiate heat.

Summary of concepts and relationships

You should be able to recall and use the following concepts and relationships:

British thermal unit (Btu): the amount of heat needed to change the temperature of one pound of water by one degree Fahrenheit

calorie: the amount of heat needed to change the temperature of one gram of water by one degree Celsius

conduction: the transfer of heat through a body of material (solid, liquid, gas)

convection: the transfer of heat by the movement of fluids (liquid, gas)

heat: internal energy being transferred from one object to another as a result of a temperature difference between the objects

heat transfer: heat loss of hot item = heat gain of cooler item

kilocalorie: the amount of heat needed to change the temperature of one kilogram of water by one degree Celsius

latent heat of fusion (Lf): the quantity of heat needed to change a solid to a liquid or a liquid to a solid

latent heat of vaporization (Lv): the quantity of heat needed to change a liquid to a gas or a gas to a liquid

linear expansion: the expansion of the length of a material due to its absorption of thermal energy: $L = aL_oT$

radiation: the transfer of heat by electromagnetic waves (thermal radiation)

specific heat capacity: the amount of heat that must be added to or taken from 1 kg (or 1 lb.) of material to change the material's temperature by 1°C (or 1°F).

temperature: a measure of the intensity of the internal energy of an object

thermal resistance: the inability of a material (solid, liquid, gas) to transfer heat, and the ability of a material to insulate, measured in R values

volume expansion: the expansion of the volume of a material due to its absorption of thermal energy: $V = bV_oT$

Now complete the Learning Task 3 Self-Test 2: Thermal expansion and heat transfer.

Self-Test 2: Thermal expansion and heat transfer

1. Which of the following best describes how matter typically behaves when heated?
    a. Matter will soften when heated.
    b. Matter will harden when heated.
    c. Matter will expand when heated.
    d. Matter will contract when heated.

2. Which term best describes the predictable change in length due to temperature change in a solid?
    a. Linear expansion
    b. Fusion heat of a solid
    c. Latent heat of a solid
    d. Sensible heat of a solid

3. Which of the following describes the three ways in which heat moves?
    a. Lineal, diagonal, invisible
    b. Chemical, mechanical, electrical
    c. Conduction, convection, radiation
    d. Thermal transfer, thermal flow, thermal mechanics

4. Which of the following describes heat transferred by touch?
    a. Radiation
    b. Conduction
    c. Convection
    d. Thermal flow

5. Which of the following describes heat transferred by electromagnetic waves?
    a. Radiation
    b. Conduction
    c. Convection
    d. Thermal flow

6. Which of the following describes heat transferred using the changing density of a fluid as a medium?
   a. Radiation
   b. Conduction
   c. Convection
   d. Thermal flow

7. Which of the following statements best describes the effect that heat absorption and heat emitting-properties have on surface conditions?
   a. Dark surfaces are poor heat emitters and absorbers.
   b. Dark surfaces are good heat emitters and absorbers.
   c. Light surfaces are good heat emitters and absorbers.
   d. Surface conditions do not have an effect on objects' heat absorption and emitting properties.

8. When a material is heated, its length expands but not its volume.
   a. True
   b. False

Appendixes

Appendix A: Science web links

Khan Academy sites

Atoms, molecules, and ions

https://www.khanacademy.org/science/chemistry/atomic-structure-and-properties

Electricity and magnetism

https://www.khanacademy.org/science/physics/electricity-magnetism

Fluids

https://www.khanacademy.org/science/physics/fluids

Forces and Newton's laws of motion

https://www.khanacademy.org/science/physics/forces-newtons-laws

Gas Laws

https://www.khanacademy.org/science/physics/thermodynamics/v/thermodynamics-part-2

Gravitation

https://www.khanacademy.org/science/physics/newton-gravitation

One-dimensional motion: In this tutorial we begin to explore ideas of velocity and acceleration.

https://www.khanacademy.org/science/physics/one-dimensional-motion

Thermodynamics gas pressures

https://www.khanacademy.org/science/physics/thermodynamics/v/thermodynamics-part-1

Work and energy

https://www.khanacademy.org/science/physics/work-and-energy

University of Colorado Simulators

Buoyancy Simulator

http://phet.colorado.edu/en/simulation/buoyancy

Energy Forms and Changes Simulator

http://phet.colorado.edu/en/simulation/energy-forms-and-changes

Fluid Pressure and Flow Simulator

http://phet.colorado.edu/en/simulation/fluid-pressure-and-flow

Gas Properties Simulator
http://phet.colorado.edu/en/simulation/gas-properties

Generator Simulator
http://phet.colorado.edu/en/simulation/generator

Magnets and Electromagnets
http://phet.colorado.edu/en/simulation/magnets-and-electromagnets

Masses and Springs Simulator
http://phet.colorado.edu/en/simulation/mass-spring-lab

Ohm's Law Simulator
http://phet.colorado.edu/en/simulation/ohms-law

States of Matter Simulator
http://phet.colorado.edu/en/simulation/states-of-matter

Appendix B: Metric unit symbols and relationships

Time

seconds	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

Prefixes

mega	M	1 000 000
kilo	k	1000
hecto	h	100
deca	da	10
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	μ	0.000 001

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

square kilometre	km^2	$1\ km^2 = 1\,000\,000\ m^2$
hectare	ha	$1\ ha = 1 hm^2 = 10\,000\ m^2$
square metre	m^2	$1\ ha = 10\,000\ m^2$
square centimetre	cm^2	$1\ m^2 = 10\,000\ cm^2$

Volume

kilolitre	kL	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	$1\ mL = 1\ cm^3$

Mass

tonne	t	1 t = 1000 kg
kilogram	kg	1 kg = 1000 g
gram	g	1 g = 1000 mg
milligram	mg	

Water

1 kL of water = 1 t of water
1 L of water = 1 kg of water
1 mL of water = 1 g of water

Appendix C: Imperial (U.S.) units

Length	**Liquid Measure**	**Weight**
1 foot (ft.) = 12 inches (in.)	1 pint (pt.) = 2 cups	1 pound (lb.) = 16 ounces (oz.)
1 yard (yd.) = 3 feet	1 quart (qt.) = 2 pints	1 ton = 2000 lb.
1 mile (mi.) = 5280 feet	1 gallon (gal.) = 4 quarts	

Metric/Imperial (U.S.) Conversions

Metric to Imperial (U.S.)	Imperial (U.S.) to Metric
Length	
1 cm = 0.394 inches	1 inch = 2.54 cm
1 m = 39.4 inches	1 yard = 0.914 m
1 km = 0.621 miles	1 mile = 1.61 km
Area	
1 hectare = 2.47 acres	1 acre = 0.405 ha
1 km^2 = 0.386 square miles	1 sq. mi. = 2.59 km^2
Liquid Measure	
1 L = 0.26 gallons	1 gallon = 3.79 L
1 L = 4.23 cups	1 cup = 0.24 L
Mass/Weight	
1 g = 0.0353 ounces	1 ounce = 28.4 g
1 kg = 2.20 pounds	1 pound = 0.454 kg

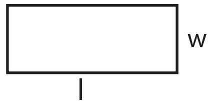
Appendix D: Perimeter, Area, and Volume Formulae

Square

$P = 4s$

$A = s^2$

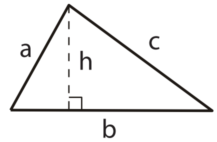
Rectangle



$P = 2l + 2w$

$A = lw$

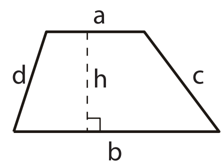
Triangle



$P = a + b + c$

$A = \frac{1}{2}bh$

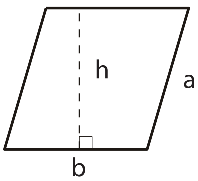
Trapezoid



$P = a + b + c + d$

$A = \frac{1}{2}h(a + b)$

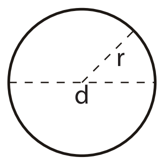
Parallelogram



$P = 2(a + b)$

$A = bh$

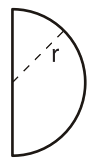
Circle



$P = \pi d$ or $P = 2\pi r$

$A = \pi r^2$

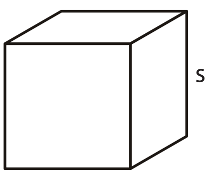
Semicircle



$P = \frac{1}{2}\pi d + d$

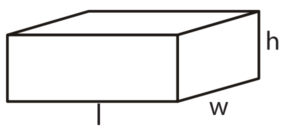
$A = \frac{1}{2}\pi r^2$

Cube



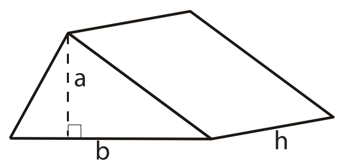
$V = s^3$

Rectangular prism



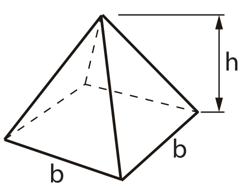
$V = lwh$

Triangular prism



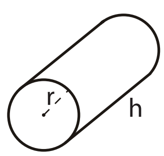
$V = \frac{1}{2}bah$

Pyramid



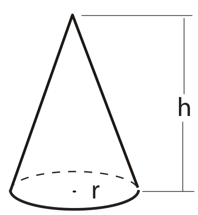
$V = \frac{1}{3}b^2h$ or $V = b^2h \div 3$

Cylinder



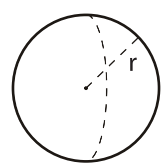
$V = \pi r^2h$

Cone



$V = \frac{1}{3}\pi r^2h$ or $V = \pi r^2h \div 3$

Sphere



$V = \frac{4}{3}\pi r^2$ or $V = \pi r^2h \div 3$

Answer Key

Learning Task 1: Identify the properties of matter

Self-Test 1: Structure of matter

1. a. The atom
2. b. Solid, liquid, and gas
3. b. Adhesive forces
4. b. Newton
5. c. Kilogram
6. c. 9.8 metres per second^2
7. d. The amount of space an object occupies or a container holds
8. a. The ratio of a mass or weight to a volume
9. b. kg/m^3
10. c. SD = >1
11. b. 72%
12. d. A ratio of a substance's density compared to fresh water
13. a. Salt water has a higher specific gravity than fresh water.
14. b. False
15. b. False

Self-Test 2: Describe the basic properties of solids

1. d. The solid's resistance to physical forces acting upon it
2. c. Tension
3. d. Compression
4. a. Shear
5. b. Torque
6. a. Strain
7. b. Elasticity
8. c. Ultimate strength
9. d. A piece of equipment can carry a load five times heavier than its rating.

10. b. Hardness
11. d. Brittleness
12. a. Ductility
13. d. Malleability
14. c. Thermal conductivity
15. d. Electrical conductivity
16. b. Thermal expansion
17. b. The greater the difference in the series, the quicker corrosion will occur.
18. a. True

Self-Test 3: Describe the basic properties of liquids

1. c. Adhesive force
2. a. Buoyant force
3. b. A body wholly or partially immersed in water is buoyed up with a force equal to the weight of the fluid displaced by the body.
4. d. The difference between an object's weight in air and its weight in water
5. b. A force over an area
6. b. Newtons over a square metre
7. a. Water pressure increases with depth.
8. b. 29.4 kPa
9. d. 4.33 psi
10. b. The pressure would be uniform throughout the container.
11. b. Viscosity
12. c. Hydraulics
13. c. When velocity is high, pressure is low.
14. c. The longer the tube, the higher the pressure drop.
15. d. The smaller the tube, the greater the pressure drop.
16. a. A water-filled instrument used to measure water pressure
17. a. True

18. a. True
19. a. True
20. a. True
21. a. True

Self-Test 4: Describe the basic properties of gases

1. c. The gas will expand indefinitely.
2. a. Elasticity
3. d. Compressibility
4. c. Absolute, gauge, and atmospheric
5. a. In inches of mercury
6. b. 101.3 kPa
7. d. The gas pressure will be reduced by half.
8. a. The pressure will increase.
9. d. The temperature has been halved.
10. c. As a ratio between the density of the gas and the density of air
11. b. The propane would sink, as it is heavier than air.
12. a. Air
13. c. Absolute zero
14. b. False
15. b. False
16. a. True
17. a. True

Learning Task 2: Describe practical applications of mechanics

Self-Test 1: Motion and force

1. b. Speed
2. a. True
3. a. Work
4. a. True
5. b. False
6. a. True
7. a. True
8. a. True
9. b. False

Self-Test 2: Describe work, power, and energy

1. d. All of the above
2. c. Horsepower
3. c. Energy
4. c. Kinetic energy
5. d. Potential energy
6. d. Potential energy
7. c. Chemical energy
8. c. Chemical energy
9. a. True
10. b. False
11. a. True
12. b. False
13. a. True
14. b. False
15. a. True
16. b. False

17. a. True

18. b. The joule

19. b. Power

Self-Test 3: Basic machines

1. d. Simple machine

2. d. All of the above

3. d. Mechanical advantage

4. c. Ideal mechanical advantage

5. b. MA= 4:1

6. a. Fulcrum

7. b. Increase the MA

8. c. 490 N

9. a. Increase the length of the handles

10. a. 25

11. b. 200 mm

12. b. 1

13. a. 15 cm

14. c. 4

15. a. 10 cm

16. a. Eliminate slippage

17. d. 400 N

18. d. 4

19. b. 125 rpm

20. d. The inclined plane

21. c. 326 N

22. a. MA = ramp length/ ramp height.

23. b. MA = wedge length/ wedge thickness.

24. b. Pitch

25. d. The hydraulic press

26. c. The output pressure

27. d. Area of resistance cylinder/area of effort cylinder

28. a. 62.5 N

Learning Task 3: Describe the basic properties of thermal energy

Self-Test 1: Measurement and effects of heat

1. a. Thermal energy

2. a. Heat

3. d. Temperature

4. a. Bimetallic strip thermometer

5. b. Resistance thermometers

6. b. Thermocouple

7. b. Optical pyrometer

8. a. Joule

9. c. 1.0°C

10. a. Specific heat

11. b. Latent heat

12. c. Latent heat of vaporization

13. a. The volume of the substance increases.

14. d. Refrigerant

15. b. British thermal unit

16. a. True

17. b. False

18. a. True

19. b. False

20. b. False

21. a. True

22. a. True

23. b. False
24. a. True
25. b. False
26. a. True
27. a. True
28. b. False
29. a. True
30. b. False
31. b. False
32. a. True
33. a. True

Self-Test 2: Thermal expansion and heat transfer

1. c. Matter will expand when heated.
2. a. Linear expansion
3. c. Conduction, convection, radiation
4. b. Conduction
5. a. Radiation
6. c. Convection
7. b. Dark surfaces are good heat emitters and absorbers.
8. b. False

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