CHAPTER 1: SCIENTIFIC PRINCIPLES

Unit of learning code: **CON/CU/PL/CC/03/5/A**

Related unit of competency in occupational standard: Apply Scientific principles.

Introduction to the unit of learning

This unit specifies the competencies required to Apply scientific principles. It involves applying principles of: units of measurements, force, work, energy and power, friction, heat, acoustics, pressure in fluids, mechanical properties of materials and electrical.

1.1. Summary of Learning Outcomes

1. Apply principles of units of measurements
2. Apply principles of Force, work, energy and power
3. Apply principles of Friction
4. Apply principles of heat
5. Apply principles of acoustics
6. Apply principles of pressure in fluids
7. Apply mechanical properties of materials
8. Apply electrical principles

1.2.1 Learning outcome 1: Apply principles of units of measurement

1.2.1.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply principles of units of measurement. It includes definition of terms and concepts, selection of units of measurement and conversion of units

1.2.1.2 Performance Standard

1.1 Units of measurements are identified based on task given
1.2 Units are converted based on standard conventions.

1.2.1.3 Information Sheet

TERMS AND CONCEPTS

- Measurement: It is the process by which one can convert physical parameters into meaningful data.
- Instrument: A device for finding the value, or magnitude of a quantity or variable.
- Accuracy: It is the nearness of the measured value towards the true value. i.e., the measure of conformity to the true value.
- Precision: It refers to the degree of agreement within a group of measurements or instruments. i.e., The measure of repeatability or reproducibility.
- Resolution: It is defined as the smallest change in input that can be detected by an instrument.
- Sensitivity: It is the ratio of response of an instrument to a change in a measured variable.
- True value: It is the average of the infinite no. of measurements when the average deviation tends to become zero.
- Error: The deviation from the true value of the measured variable.
- Measured Value**:** It may be defined as the approximated value of true value.
- Physical quantity: A characteristic or property of an object that can be measured or calculated from other measurements
- Units: A standard used for expressing and comparing measurements
- SI units: The international system of units that scientists in most countries have agreed to use; includes units such as meters, liters, and grams
- Derived units: Units that can be calculated using algebraic combinations of the fundamental units
- Order of magnitude: Refers to the size of a quantity as it relates to a power of 10
- Conversion factor: A ratio expressing how many of one unit are equal to another unit

SELECTION OF UNITS OF MEASUREMENT

In order to measure we need to know or define the quantity to be measured and the units for measuring it. In 1971 a system known as the International System of Units (Systeme' Internationale) and seven basic units were agreed upon as follows. Other quantities can be obtained from these basic quantities and are referred to as derived quantities.

S/no	Basic quantity	SI Units	Symbols
1.	Length	Metre	m
2.	Mass	Kilogram	kg
3.	Time	Second	s
4.	Electric current	Ampere	A
5.	Thermodynamic temperature	Kelvin	K
6.	Luminous intensity	Candela	Cd
7.	Amount of substance	Mole	mol

Fig 1: Basic quantities

Criteria for a selection of unit:

The selection of a unit depends on the magnitude of a quantity under consideration. When the magnitude of the measurement increases, then the unit used for the measurement should be larger.

The unit should neither be too small nor too big in comparison with the physical quantity to be measured. The accuracy of measurement also influences the selection of the unit.

In the case of construction of a room, accuracy is not major criteria hence units used are meters or feet. But when constructing a rocket, accuracy is important hence millimeter or micrometer may be used.

Thus when the accuracy is important, then the unit used for the measurement should be smaller.

Characteristics of a Standard Unit:

- It should be well defined without any doubt or ambiguity.
- It should be of suitable size i.e. neither too long nor too small in comparison with the quantity to be measured.
- It should be easily available.
- It should be non-destructible.
- It should not change with time.
- It should not change with place.
- It should be reproducible.

UNIT CONVERSION

Units of length

The SI unit of length is a meter (m). There are many other units of length which are given below with their relation:

10 millimeter = 1 centimeter
10 centimeter = 1 decimeter
10 decimeter = 1 decameter
10 decameter = 1 hectometer
10 hectometer = 1 kilometer

Measurement of mass

There are many other units of mass which are given below with their relation:
1000 milligram = 1 gram
1000 gram = 1 kilogram
100 kilogram = 1 quintal
10 quintal = 1 metric ton

It is often necessary to convert from one unit to another. We write the units we have and then multiply them by the conversion factor so the units cancel out, as shown:

$$80\ \cancel{m} \times \frac{1\ km}{1000\ \cancel{m}} = 0.080\ km.$$

Note that the unwanted meter unit cancels, leaving only the desired kilometer unit. You can use this method to convert between any type of unit.

Now, the conversion of 80 m to kilometers is simply the use of a metric prefix, as we saw in the preceding section, so we can get the same answer just as easily by noting that

$$80\ m = 8.0 \times 10^{1}\ m = 8.0 \times 10^{-2}\ km = 0.080\ km,$$

However, using conversion factors is handy when converting between units that are not metric or when converting between derived units.

Examples:

1. Convert the grams below into kilograms.
   i. 4000 g = 4000 ÷ 1000 kg = 4 kg
   ii. 6000 g = 6000 ÷ 1000 kg = 6 kg
   iii. 50000 g = 50000 ÷ 1000 kg = 50 kg

1.2.1.4 Learning Activities

Activity

1. Collect the following items, measure their weight in kilograms then convert the weight to grams.
   - A plank of wood
   - A piece of stone

2. Find the following, find their volume in liters and convert it into milliliters
   - Milk
   - Water

1.2.1.5 Self-Assessment

1. What is the appropriate unit of measure used to describe the width of a computer monitor? (2 marks)

2. Which is the best metric unit for measuring the weight of a person? (2 marks)

3. Which is the most precise device for measuring length: (1 marks)
   a. Vernier calipers with 20 divisions on the sliding scale?
   b. A screw gauge of pitch 1 mm and 100 divisions on the circular scale?
   c. An optical instrument that can measure length to within a wavelength of light?
   d. A 30 cm straight ruler

4. What is the correct conversion of $0.02m^2$ to cm^2? (1 marks)
   a. 200 cm^2
   b. 20 cm^2
   c. 2 cm^2
   d. 0.002 cm^2

5. The weight of a lamb is 45 kg. What is its weight in grams? (2 marks)

   I Kg = 1000g
   45 x1000 = 45000 kg

6. Shelly bought 2355 g of apples for the fruit cream. What is the weight of apples in kilograms? (2 marks)

   I Kg = 1000g
   2355 ÷ 1000 = 2.355

1.2.1.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Pins

1.2.1.7 References

Math-only-math.com., learn math step-by-step

Model Answers

1. What is the appropriate unit of measure used to describe the width of a computer monitor? (2 marks)

   The width of computer monitor is usually between 10 inches and 20 inches.

   Hence; 1 inch = 2.54 centimeters.

   So, when these values are converted to centimeters, it is about 25 and 50

   Therefore, the appropriate unit of measure to describe the width of a computer monitor is inches or centimeters.

2. Which is the best metric unit for measuring the weight of a person? (2 marks)

   Some of the metric units of measurement for weight are milligram, gram, kilogram and so on.

   The best metric unit for measuring the weight of a person is kilogram

3. Which is the most precise device for measuring length: (1 marks)
   a. Vernier calipers with 20 divisions on the sliding scale?
   b. A screw gauge of pitch 1 mm and 100 divisions on the circular scale?
   c. An optical instrument that can measure length to within a wavelength of light?
   d. A 30 cm straight ruler

4. What is the correct conversion of $0.02m^2$ to cm^2? (1 marks)
   a. 200 cm^2
   b. 20 cm^2
   c. 2 cm^2
   d. 0.002 cm^2

5. The weight of a lamb is 45 kg. What is its weight in grams? (2 marks)

6. Shelly bought 2355 g of apples for the fruit cream. What is the weight of apples in kilograms? (2 marks)

1.2.2 Learning Outcome 2: Apply principles of Force, work, energy and power

1.2.2.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply principles of Force, work, energy and power. It includes, definition of terms and concepts, laws, Force, Energy, basic calculations of force, work, energy and power and application of force, work, energy and power.

1.2.2.2 Performance Standard

2.1 Force, work, energy and power are defined based on standard conventions
2.2 Forms of energy are described based on the state of the matter
2.3 Energy is converted according to scientific principles
2.4 Simple calculations on work, energy and power are solved based on the task requirements

1.2.2.3 Information Sheet

FORCE

Force is a push or a pull. Force is therefore that which changes a body's state of motion or shape. The SI unit for force is Newton (N). It is a vector quantity. It is represented by the following symbol.

Types of forces

1. Gravitational force: this is the force of attraction between two bodies of given masses.
   : Earth's gravitational force is the force which pulls a body towards its center. This pull of gravity is called weight.
2. Force of friction : this is a force which opposes the relative motion of two surfaces in contact with each other. Friction in fluids is known as viscosity.
3. Tension force: this is the pull or compression of a string or spring at both its ends.
4. Upthrust force: this is the upward force acting on an object immersed in a fluid.
5. Cohesive and adhesive forces: cohesive is the force of attraction of molecules of the same kind while adhesive is the force of attraction of molecules of different kinds.
6. Magnetic force: this is a force which causes attraction or repulsion in a magnet.
7. Electrostatic force: this is the force of attraction or repulsion of static charges.
8. Centripetal force: this is a force which constrains a body to move in a circular orbit or path.
9. Surface tension: this is the force which causes the surface of a liquid to behave like a stretched skin. This force is cohesive.

Factors affecting surface tension

a) Impurities – they reduce the surface tension of a liquid i.e. addition of detergent
b) Temperature – rise in temperature reduces tension by weakening inter-molecular forces.

WORK

Work is done when a force acts on a body and the body moves in the direction of the force.

In Physics, work requires a force to move. For instance: pushing a car to 'bump start' it involves work. Work always involves an applied force moving a certain distance and is measured by the product of the force and the distance it moves along its line of action. If the force is perpendicular to the direction of motion, no work is done.

Work = force x distance (in the direction of the force)

- Work done equals energy gained.
- It is a scalar.
- It is measured in joules (J).

NB

Total Work Done	=	Applied Force x Distance
Kinetic Energy	=	Resultant Force x Distance
Potential Energy	=	Weight x Distance
Energy Dissipated	=	Frictional Force x Distance

Distance must always be in the direction of the force

Examples

1. Calculate the work done by a stone mason lifting a stone of mass 15 kg through a height of 2.0 m. (take g=10N/kg)

   Solution
   Work done = force × distance
   $= (15\times 10) \times 2 = 300$ Nm or 300 J

2. A girl of mass 50 kg walks up a flight of 12 steps. If each step is 30 cm high, calculate the work done by the girl climbing the stairs.

   Solution

Work done = force × distance

= (50× 10) × (12 ×30) ÷ 100 = 500 × 3.6 = 1,800 J

3. A force of 7.5 N stretches a certain spring by 5 cm. How much work is done in stretching this spring by 8.0 cm?

Solution:

A force of 7.5 produces an extension of 5.0 cm.

Hence 8.0 cm = (7.5 ×8)/ 5 = 12.0 N

Work done = ½ × force × extension

= ½ × 12.0 × 0.08 = 0.48 J

ENERGY

The energy forms most commonly used are:

- Chemical energy
- Potential energy (E_P)
- Kinetic energy (E_K)
- Heat energy
- Magnetic energy
- Electrical energy
- Nuclear energy
- Sound energy
- Electromagnetic wave energy.

Energy is always measured in joules (J) no matter what form it is in.

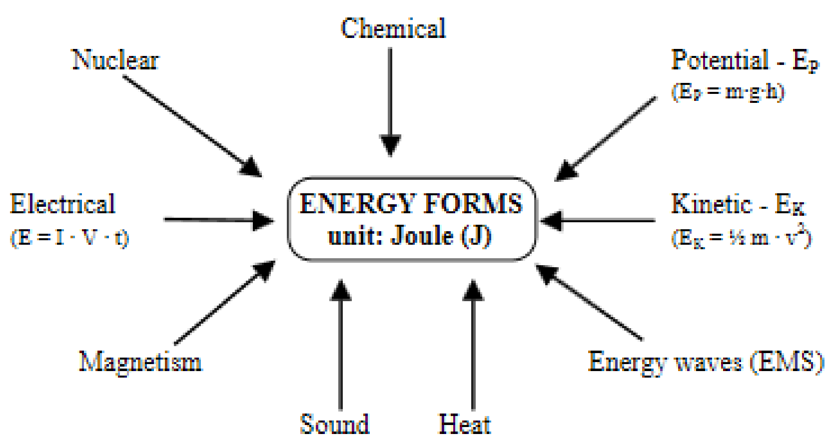


Fig 1.2: Energy forms

Chemical energy

Chemicals such as food, oil, coal and gas would be included in this list. They can all be burnt to provide heat. The chemicals inside a battery will react together to provide electricity. Chemicals are stores of energy that can be released at a convenient time.

Potential energy (E_p)

Potential means hidden or stored. A battery, a spring or a stretched elastic band are examples of stored energy. Anything that is high up will have the potential to be pulled down by gravity, e.g., water behind a dam. This is sometimes called gravitational energy.

Kinetic energy (E_k)

This is the energy of movement. The k.e. of a moving object increases with mass (kg) and/or velocity (m/s). The equation used to calculate the k.e. of a moving object is:

$$\text{Kinetic energy} = \tfrac{1}{2} \,.\text{Mass} \,.\, \text{Velocity}^2 = \tfrac{1}{2}.\, m.v^2$$

Electromagnetic waves (EMS)

Any wave form, such as light, X-rays, ultraviolet or gamma waves, belongs to a set known as the electromagnetic spectrum (EMS). They are sometimes called waves, rays or even radiations. They all transfer energy from place to place. Infrared radiation is a good example and is responsible for the warming effect of a sunny day.

Heat energy

Ice melts when it is heated, an iron bar will expand when heated, etc.

Sound energy

This is an energy form because sound is the movement of air molecules.

Magnetic energy

Magnetism is an energy form and can make things happen (attraction/repulsion).

Electrical energy

The most easily converted energy form. A bulb will give out light (and heat) when provided with electrical energy. The amount of electrical energy passing through a device depends on: the current flow (in amperes), the potential difference (in volts) and the time (in seconds) for which the circuit is switched on.

Increase any of these and the total energy will increase.

The equation used to find electrical energy is:

$$\text{Energy} = \text{Current x Potential Difference x Time} = I \times V \times t$$

Nuclear energy

As atomic nuclei break up they have a heating effect on their surroundings. In nuclear power plants nuclear energy is converted into heat, which is used to provide steam to drive a turbine in order to generate electricity.

Energy changes

Energy arrows (see figure below) can be used to show the changes that take place when energy is used. It is quite usual for energy to be wasted (in the form of heat) when one form of energy is changed into another.

The major energy changes that take place in a torch light

Fig 1.3: Energy changes

Transformation and conservation of energy

Any device that facilitates energy transformations is called transducer. Energy can be transformed from one form to another i.e. mechanical – electrical – heat energy. The law of conservation of energy states that “energy cannot be created or destroyed; it can only be transformed from one form to another”.

POWER

Power is the rate at which energy is used or transformed.

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \quad \text{OR} \quad \text{Power} = \frac{\text{Work}}{\text{Time}}$$

- It is a scalar.
- It is measured in watts (W)

Power (P) = work done / time

P = W / t

The SI unit for power is the **watt (W)** or **joules per second (J/s)**.

Example

1. A person weighing 500 N takes 4 seconds to climb upstairs to a height of 3.0 m. what is the average power in climbing up the height?

   Solution

   Power = work done / time = (force × distance) / time

   = (500 ×3) / 4 = 375 W

1.2.2.4 Learning Activities

Perform the Activity below

Procedure:

1. Prepare a bottle/dowel apparatuses.
2. Fill the water bottle and cap tightly.
3. Tie a 1 m long string to the top of the bottle, and the other end to the middle of the dowel.
4. Hold the dowel horizontally with a hand on either side of the string and with the string and bottle hanging down.

Conclusion

- If you have two objects at different heights, which one has greater potential energy? (The higher one).
- When we do work on the bottle by pulling it up with the string, what is happening to the potential energy of the bottle?
  (Work on an object means transferring energy to that object. Work can also change the kinetic energy of an object, which would be observable as a change of motion or temperature of the object.)

1.2.2.5 Self-Assessment

1. Which of the following is not a type of force? (1 mark)
   a. Kinetic force
   b. Gravitational force
   c. Electrostatic force
   d. Magnetic force
2. Energy can be created or destroyed and it cannot be transformed from one form to another. (1 mark)
   a. True
   b. False

3. An example of Kinetic Energy would be: (1 mark)
    a. a moving car
    b. a stretched rubber band that was just released
    c. a charge particle in an electric field
    d. all of the above
4. Which of the statements below is not true about work? (1 mark)
    a. Work done equals energy gained.
    b. It is a scalar.
    c. Distance is not in the direction of the force
    d. It is measured in joules.

5. What are the factors that affect surface tension? (2 mark)

6. A 2kg mass is accelerated horizontally from rest at 1 m/s^2 for 20 m.
   Find: (4 mark)
    i. The force required
    ii. The work done
7. A mass of 10 kg is raised from rest to a height of 20 m using a cable with a tension of 140 N. (3 mark)
   Find the total work done

8. A car travelling at a speed of 72 km/h is uniformly retarded by an application of brakes and comes to rest after 8 seconds. If the car with its occupants has a mass of 1,250 kg. Calculate; (8 mark)
   a) The breaking force
   b) The work done in bringing it to rest

9. A spring constant k = 100 Nm is stretched to a distance of 20 cm. calculate the work done by the spring. (3 mark)

10. A box of mass 500 kg is dragged along a level ground at a speed of 12 m/s. If the force of friction between the box and floor is 1200 N. Calculate the power developed. (3 mark)

1.2.2.6 Tools, Equipment, Supplies and Materials

Functional Plumbing Workshop with the following:

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins

Personal protective equipment (PPEs)

- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.2.7 References

Joseph W Connolly., 2016. Work–energy–power
Secondary Physics 4th Edition Students book Three KLB

Model Answers

1. Which of the following is not a type of force? (1 mark)
   - **a. Kinetic force**
   - b. Gravitational force
   - c. Electrostatic force
   - d. Magnetic force
2. Energy can be created or destroyed and it cannot be transformed from one form to another. (1 mark)
   - a. True
   - **b. False**

3. An example of Kinetic Energy would be: (1 mark)
   - **a. a moving car**
   - b. a stretched rubber band that was just released
   - c. a charge particle in an electric field
   - d. all of the above

4. Which of the statements below is not true about work? (1 mark)
   - a. Work done equals energy gained.
   - b. It is a scalar.
   - **c. Distance is not in the direction of the force**
   - d. It is measured in joules.

5. What are the factors that affect surface tension? (2 mark)
   Impurities – they reduce the surface tension of a liquid i.e. addition of detergent
   Temperature – rise in temperature reduces tension by weakening inter-molecular forces.

6. A 2kg mass is accelerated horizontally from rest at 1 m/s^2 for 20 m.
   Find: (4 mark)

   iii. The force required

   Since there is only one force acting on the mass, this force is the resultant force.

   F = m. a
   = 2kg. 1m/s^2
   = **<u>2 N</u>**

   iv. The work done

   Work = force x distance
   2N x20m
   = **<u>40J</u>**

7. A mass of 10 kg is raised from rest to a height of 20 m using a cable with a tension of 140 N. (3 mark)

Find the total work done

Work = force x distance

140N x 20m

= **<u>2800 J</u>**

8. A car travelling at a speed of 72 km/h is uniformly retarded by an application of brakes and comes to rest after 8 seconds. If the car with its occupants has a mass of 1,250 kg. Calculate; (8 mark)

c) The breaking force

d) The work done in bringing it to rest

Solution

a) F = ma and a = v – u/t

But 72 km/h = 20m/s

a = 0 -20/8 = - 2.5 m/s

Retardation = 2.5 m/s

Braking force F = 1,250 × 2.5

= 3,125 N

b) Work done = kinetic energy lost by the car

$= ½ mv^2 – ½ mu^2$

$= ½ × 1250 × 0^2 – ½ × 1250 × 20^2$

$= - 2.5 × 10^5$ J

9. A spring constant k = 100 Nm is stretched to a distance of 20 cm. calculate the work done by the spring. (3 mark)

Solution

$\text{Work} = ½ ks^2$

$= ½ × 100 × 0.2^2$

= 2 J

10. A box of mass 500 kg is dragged along a level ground at a speed of 12 m/s. If the force of friction between the box and floor is 1200 N. Calculate the power developed. (3 mark)

Solution

Power = F v

= 2,000 × 12

= 24,000 W = 24 kW.

1.2.3 Learning Outcome 3: Apply principles of friction

1.2.3.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply principles of friction. It includes, terms and concepts, types of friction, laws of friction, causes of friction, advantages and disadvantages of friction and application of friction

1.2.3.2 Performance Standard

3.1 Friction is defined and interpreted based on standard conventions

3.2 The advantages and disadvantages of friction are identified based on scientific principles

3.3 Simple problems on friction are solved based on task requirements

1.2.3.3 Information Sheet

APPLY PRINCIPLES OF FRICTION

Terms and concepts

- Kinetic energy: The energy possessed by an object because of its motion, equal to one half the mass of the body times the square of its velocity.
- Friction: The force that resists relative motion between two surfaces sliding across each other. Friction converts kinetic energy into heat.
- Drag force: The force that resists motion of an object traveling through a fluid such as air or water. Drag force is proportional to the velocity of the object traveling.
- Deformation forces: Are forces caused by stretching or compressing a material. Some examples would be springs or elastics.
- Viscosity: It is the measure of the resistance of the air to flow and it differs from one density another.

TYPES OF FRICTION

Friction is defined as the resistance offered by the surfaces that are in contact with each other when they move over each other.

Friction works in the opposite direction in which the body is moving making the body slows down. Friction is useful in most of the cases.

Friction is also dependent on external factors. Different types of motion of the object give rise to different types of friction.

Generally, there are 4 types of friction.

Static Friction

Static friction exists between a stationary object and the surface on which it is resting. It prevents an object from moving against the surface.

Example:

Static friction prevents an object like a book from falling of the desk, even if the desk is slightly tilted. It helps us pick up an object without it slipping through our fingers.

When we want to move an object first we must overcome the static friction acting between the object and the surface on which the object is resting.

Fig 1.4: Static force

Static friction causes these two surfaces to stick together slightly, making that first push a bugger.

Examples of static friction include:

- Book resting on your end table
- Plant resting on a counter

Sliding Friction

Sliding friction occurs between objects as they slide against each other.

When sliding friction is acting there must be another force existing to keep the body moving.

Example:

When a man is pushing an object on a rough surface the force acting is called "sliding friction".

Several factors can affect sliding friction including the flatness and roughness of the surface, size of the object, and speed.

Examples of sliding friction include:

- Puck moving across the ice in hockey
- Kicking a book across a floor
- Dragging a sled up a hill
- Writing your name on paper
- Pushing a chair across the floor

Rolling Friction

Rolling friction is the resistive force that slows down the motion of a rolling ball or wheel. It is also called rolling resistance.

When a force or torque is applied to a stationary wheel, there is a small static rolling friction force holding back the rolling motion. However, resistance from static sliding friction is what really causes the wheel to start rolling.

Rolling friction hinders the motion of an object rolling on a surface, that means it slows down the motion of an object rolling on a surface.

Examples:

It slows down a ball rolling on a surface and it slows down the motion of tire rolling on the surface.

Like sliding friction here also another force is required to keep the object in motion, in case of pedaling bicycle the bicyclist provides the force which is required for the bicycle to be in motion.

Fig 1.4: A ball rolling on a surface

To define it, rolling friction is resistance happening between moving surfaces when one rolls. This concept has several examples:

- Throwing a Skee-Ball
- Rollerblading down the street

Fluid Friction

When you hear fluid friction, friction in water might come to mind. However, fluid friction isn't just water or what you might consider "fluid" like coffee or tea.

Fluid means something without a clear shape such as gas and liquid. For example, gases and honey are also subject to fluid friction.

Now that fluid is all cleared up, it's time to look at fluid friction. In simple terms, fluid friction is the resistance occurring when something tries to move on or through the gas or liquid. It has two types, external and internal friction.

- External friction is the friction force when solid moves through it.
- Internal friction is the friction of the molecules themselves in the fluid.

Explore a few examples to see fluid friction in action.

- Air pushing against your hand when you stick it out the window of a car (external)

LAWS OF FRICTION

To stop an object in motion, a force must act on it in the opposite direction of motion. The force that opposes the motion of the object is called the frictional force.
The following are the laws of friction:

1. Friction depends on the hardness or roughness of the contacting surfaces. Fluid friction depends on the viscosity (the thickness) of the fluid.
2. Friction is directly proportion to the normal force pressing the contacting forces together.
3. Friction does not depend on the area of the contacting surfaces.
4. In the case of sliding, friction is reduced at very high relative speeds. However, in the case of fluid friction, friction increases with increase in relative speed of movement.
5. The sliding friction is usually less than the starting friction.

CAUSES OF FRICTION

Friction is a force that resists the relative motion between two objects or materials. The causes of this resistive force are molecular adhesion, surface roughness, and deformations.

Molecular adhesion

Friction can be caused by molecular adhesion or attraction. Ultra-smooth materials and "sticky" materials fall in this category.

Ultra-smooth

If both surfaces are ultra-smooth and flat, the friction from surface roughness becomes negligible, but then friction from molecular attraction comes into play. This can often become greater than friction if the surfaces where relatively rough.

Sticky materials

Rubber is an example of a material that can have friction caused by molecular attraction. Discounting resistance due to deformations with rubber, it is its stickiness factor that causes it to grip so well and have so much friction.

Fluids

Fluids often exhibit molecular adhesion, increasing the friction. This adhesion force is often seen in the capillary effect. This is where water will be pulled up a glass tube by the forces of molecular adhesion. That same force can slow down fluid motion.

One example is how a coin will easily slide down a ramp. But if you wet the coin, it will stay in place. That is because of the molecular friction of the fluid on the hard surfaces.
The motion of two fluids or two sections of a fluid against each other is also slowed down by the molecular attraction factor.

Surface roughness

Most friction results because the surfaces of materials being rubbed together are not completely smooth. Of course, the rougher the surface, the more the friction.
But surface roughness is a factor when the materials are rough enough to cause serious abrasion. This is called the sandpaper effect.

Deformations

Soft materials will deform when under pressure. This also increased the resistance to motion. For example, when you stand on a rug, you sink in slightly, which causes resistance when you try to drag your feet along the rug's surface.
Another example is how rubber tires flatten out at the area on contact with the road.
When materials deform, you must "plow" through to move, thus creating a resistive force.
When the deformation becomes large, such that one object sinks into the other, streamlining can affect the friction, similar to what happens in fluid friction.
When one or both of the materials is relatively soft, much of the resistance to movement is caused by deformations of the objects or by a plowing effect.

In conclusion:
Friction is a force resisting motion of an object when in contact with another. It is caused by the surface roughness of the contact area of the materials, deformations or the molecular attraction. The standard friction equation holds for hard objects being held back by surface roughness.

ADVANTAGES AND DISADVANTAGES OF FRICTION

Advantages of friction:

- Friction enables us to walk freely.
- It helps to support ladder against wall.
- It becomes possible to transfer one form of energy to another.
- Objects can be piled up without slipping.
- Breaks of vehicles work due to friction.
- Friction is responsible for many types of motion
- We can write on objects due to friction between the paper and the pencil. The friction causes few atoms from the graphite to break and stick onto the paper.
- We can sharpen objects. The friction between two sliding objects allows us to grind or sharpen objects
- Asteroids entering Earth’s surface are burned due to the friction with the Earth’s atmosphere.

Disadvantages of friction:

- It always resists the motion, so extra energy is required to overcome it.
- It causes wear and tear of machines.
- It decreases the life expectancy of moving parts of vehicles.
- Friction produces unnecessary heat leading to the wastage of energy.
- The force of friction acts in the opposite direction of motion, so friction slows down the motion of moving objects.
- Forest fires are caused due to the friction between tree branches.
- It is difficult to clean surfaces. The friction between the dust particles and surfaces can be very strong in some cases. It requires special cleaning liquids to clean such surfaces.
- Friction reduces speed. That is why maglev trains are designed with an elevated concept to reduce friction. You can read this article on how to reduce friction.
- Due to friction, noise is also produced in machines.

Methods of reducing friction

There are a number of methods to reduce friction:

- Use of lubricants: the parts of machines which are moving over one another must be properly lubricated by using oils and lubricants of suitable viscosity.
- Use of grease: proper greasing between the sliding parts of machine reduces the friction.
- Use of ball bearing: in machines where possible, sliding friction can be replaced by rolling friction by using ball bearings.
- Design modification: friction can be reduced by changing the design of fast-moving objects. The front of vehicles and airplanes made oblong to minimize friction.

Application of friction

- Friction finds application when matchsticks are ignited.
- Motion of pistons in a cylinder is an application of friction.
- It is possible to write on books and board as there is friction between pen and the board.
- Friction allows the brakes in a car to dissipate your kinetic energy
- String instruments use friction to grip the strings with the bow
- Friction allows you to hold onto objects without dropping them.
- Clamps use friction to hold other objects together.

1.2.3.4 Learning Activities

Perform the Activity below

Predict what will happen in the following situations and observe each event before attempting to explain the observation made.

- A book is at rest on a flat piece of wood that is inclined at a small angle to a table. Gradually the angle between the wood and the table is increased.
- Two similar blocks of dry soap are pushed across a smooth table top. For one block of soap the table is dry and for the other block the table has been wet with a water detergent mix. Compare the size of the pushing force required to make the bars move.

1.2.3.5 Self-Assessment

1. Frictional force always opposes (1 mark)
    a. The state of rest
    b. The state of motion
    c. None of the above
    d. Both the states

2. How does lubrication help minimize friction? (2 marks)

3. Why is synthetic rubber preferred in making of tyres. (2 marks)

4. What happens when a moving body is suddenly stopped? (1 mark)
    a. The friction increases.
    b. Friction force remains same as it was while the car was moving.
    c. Friction force reduces but has a non-zero value.
    d. Frictional force reduces to zero as it as self-adjusting force.

5. Why is it easier to pull a lawn roller than to push it? (1 mark)
    a. Pulling involves sliding friction
    b. Pulling involves rolling friction
    c. Pulling increases the effective weight
    d. Pulling decreases normal reaction

6. What are some disadvantages of friction? (5 marks)

7. Frictional force in a ceiling fan is reduced by… (1 mark)
    a. Reduced air resistance
    b. Ball bearings
    c. Pressure
    d. Both A and B

8. Correct air pressure in our vehicle tyres helps to reduce: (1 mark)
    a. Static friction
    b. Sliding friction
    c. Rolling friction

d. All of the above

9. Which are the laws of friction? (6 marks)

10. Define the following terms (8 marks)
    - Friction
    - Drag force
    - Deformation forces
    - Viscosity

1.2.3.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins

Personal protective equipment (PPEs)

- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.3.7 References

Archard, J. F., 1957. Elastic deformation and the laws of friction. Proceedings of the Royal Society of London; Series A: Mathematical and Physical Sciences

Gao, J., Luedtke, W. D., Gourdon, D. R., & Israelachvili, J. N.,2004. Frictional forces and Amontons' law: from the molecular to the macroscopic scale.

Otsuki, M., & Matsukawa, H.,2013. Systematic breakdown of Amontons' law of friction for an elastic object locally obeying Amontons' law.

Model Answers

1. Frictional force always opposes (1 mark)

    a. The state of rest
    b. The state of motion
    c. None of the above
    d. Both the states

2. How does lubrication help minimize friction? (2 marks)

    The lubricant forms a thin layer between the two surfaces in contact. Thus sliding friction is replaced by fluid friction which is much smaller.

3. Why is synthetic rubber preferred in making of tyres. (2 marks)

    The coefficient of friction between road and synthetic rubber is large.

4. What happens when a moving body is suddenly stopped? (1 mark)
    a. The friction increases.
    b. Friction force remains same as it was while the car was moving.
    c. Friction force reduces but has a non-zero value.
    d. Frictional force reduces to zero as it as self-adjusting force.

5. Why is it easier to pull a lawn roller than to push it? (1 mark)
    a. Pulling involves sliding friction
    b. Pulling involves rolling friction
    c. Pulling increases the effective weight
    d. Pulling decreases normal reaction

6. What are some disadvantages of friction? (5 marks)
    - It always resists the motion, so extra energy is required to overcome it.
    - It causes wear and tear of machines.
    - It decreases the life expectancy of moving parts of vehicles.
    - Friction produces unnecessary heat leading to the wastage of energy.
    - The force of friction acts in the opposite direction of motion, so friction slows down the motion of moving objects.
    - It is difficult to clean surfaces. The friction between the dust particles and surfaces can be very strong in some cases. It requires special cleaning liquids to clean such surfaces.
    - Friction reduces speed. That is why maglev trains are designed with an elevated concept to reduce friction. You can read this article on how to reduce friction.

7. Frictional force in a ceiling fan is reduced by… (1 mark)
    a. Reduced air resistance
    b. Ball bearings
    c. Pressure
    d. Both A and B

8. Correct air pressure in our vehicle tyres helps to reduce: (1 mark)
    a. Static friction
    b. Sliding friction
    c. Rolling friction
    d. All of the above

9. Which are the laws of friction? (6 marks)
    - Friction depends on the hardness or roughness of the contacting surfaces. Fluid friction depends on the viscosity (the thickness) of the fluid.
    - Friction is directly proportion to the normal force pressing the contacting forces together.
    - Friction does not depend on the area of the contacting surfaces.
    - In the case of sliding, friction is reduced at very high relative speeds. However, in the case of fluid friction, friction increases with increase in relative speed of movement.
    - The sliding friction is usually less than the starting friction.

10. Define the following terms (8 marks)
    - Friction: The force that resists relative motion between two surfaces sliding across each other. Friction converts kinetic energy into heat.
    - Drag force: The force that resists motion of an object traveling through a fluid such as air or water. Drag force is proportional to the velocity of the object traveling.
    - Deformation forces: Are forces caused by stretching or compressing a material. Some examples would be springs or elastics.
    - Viscosity: It is the measure of the resistance of the air to flow and it differs from one density another.

1.2.4 Learning Outcome 4: Apply principles of heat

1.2.4.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply principles of heat. It includes, testing plumbing systems, sources of heat, effects of heat on matter, change of matter as heat varies and methods of heat transfer.

1.2.4.2 Performance Standard

4.1 Sources of heat are identified based on scientific principles
4.2 Effects of heat on matter is identified based on scientific principles
4.3 Methods of heat transfer are identified and interpreted based on scientific principles

1.2.4.3 Information Sheet

SOURCES OF HEAT

Solar

The sun is Earth's major external source of heat energy. The sun's energy travels to Earth as electromagnetic radiation. The amount of radiation we receive depends on the time of day and season, but it is constantly enough heat energy to support life.

Biomass

Animal and plant products give us natural heat energy. When we burn types of plant products, such as trees, heat energy is created. Heat energy from biomass-plant and animal products-is originally from the sun. Plants use heat energy directly from the sun to grow through the process of photosynthesis. Animals eat the plants to get energy. Humans eat plants as well as animals for energy.

Geothermal

Geothermal energy comes from within the Earth. The heat is produced within Earth's core, which is made of solid iron surrounded by molten lava. The core is hotter than the surface of the sun. The energy is produced by the radioactive decay of particles of rocks, creating the magma. People use geothermal heat by utilizing hot springs or underground water to heat homes and buildings.

Fuel

Solid fuel, such as coal, and gaseous fuel, such as petroleum, are natural sources of heat energy. These fuels are created over millions of years from the remains of plants and animals. We find them in deposits beneath the surface of the earth. When humans ignite fossil fuels, the fuels combust, creating heat energy.

Electric

Electricity, simply put, is the flow of electric current along a conductor. This electric current takes the form of free electrons that transfer from one atom to the next. Thus, the more free electrons a material has, the better it conducts.

EFFECTS OF HEAT ON MATTER

There are three states of matter... Solid, liquid, and gas

The amount of heat can be estimated by the change in temperature.

The higher the temperature the more heat a body has. The effect of heat in matter can be looked at from two points, when heat is absorbed or when heat is released by the matter.

When a substance is heated, it can cause.

- Interconversion of states of matter.
- Thermal expansion of the substance.
- Chemical change.

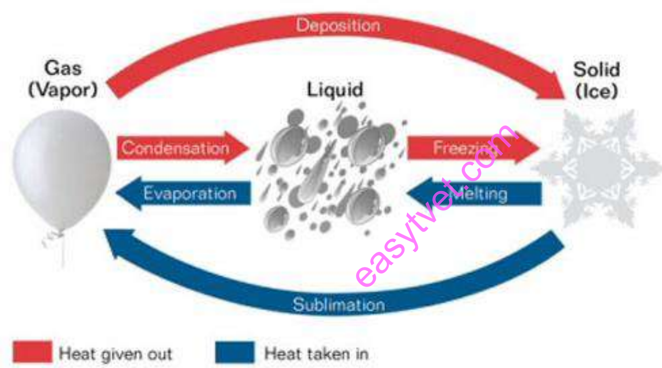


Fig 1.5: Effects of heat on smatter

Effects of heat on solids

Solid expands when heated as they gain heat. Because of this Railway tracks has gaps for expansion.

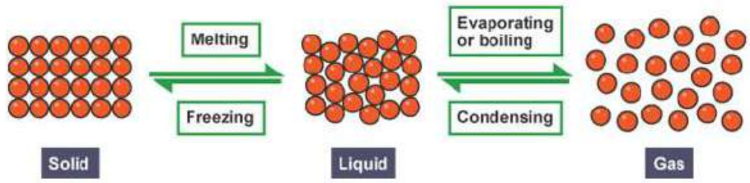


Fig 1.6: Effects of heat on solids

Effects of heat on liquids

Liquids can either change to solids or gas when exposed to heat

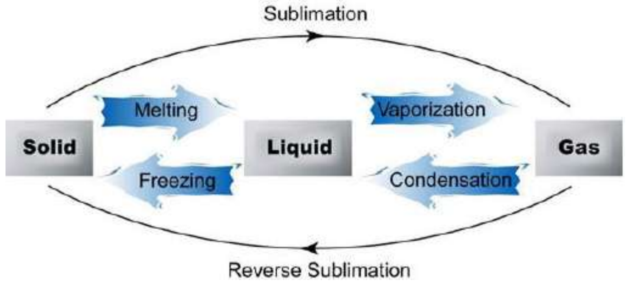


Fig 1.7: Effects of heat on liquids

- Liquids increase in size when heated they are said to have **expanded**.
  Pipes carrying water or steam are looped at intervals to allow for expansion. If not, the pipes will burst
- When cooled, liquids decrease in size they are said to have **contracted**.
- When liquids are heated to a certain temperature, they change to gas they evaporate or vaporize.
- When liquids are exposed to very low temperatures the liquid freezes and become solid. When water freezes it expands.

Effects of heat on gases

- When heated gases expand.
  A hot balloon uses the expansion of gases. Filled with heated air. As the volume of air increases (expansion), the density of air decreases.
  Warm air less dense this it rises and carries the balloon upwards.

Fig 1.8: Hot balloon

- When cooled gases contract.
- Gas condenses to become liquid when cooled to very low temperatures.

CHANGE OF MATTER AS HEAT VARIES

Physical Change

Physical changes are changes in which no bonds are broken or formed. This means that the same types of compounds or elements that were there at the beginning of the change are there at the end of the change.

Because the ending materials are the same as the beginning materials, the properties (such as color, boiling point, etc.) will also be the same.

Physical changes involve moving molecules around, but not changing them. Some types of physical changes include:

- Changes of state (changes from a solid to a liquid or a gas and vice versa)
- Separation of a mixture
- Physical deformation (cutting, denting, stretching)
- Making solutions (special kinds of mixtures)

As an ice cube melts, its shape changes as it acquires the ability to flow. However, its composition does not change. Melting is an example of a physical change. When we heat the liquid water, it changes to water vapor.

But even though the physical properties have changed, the molecules are exactly the same as before. We still have each water molecule containing two hydrogen atoms and one oxygen atom covalently bonded.

<u>Classification of physical change</u>

Physical changes can further be classified as Reversible or Irreversible.

The melted ice cube may be refrozen, so melting is a reversible physical change. Physical changes that involve a change of state are all reversible. Other changes of state include **vaporization** (liquid to gas), **freezing** (liquid to solid), and **condensation** (gas to liquid).

Dissolving is also a reversible physical change. When salt is dissolved into water, the salt is said to have entered the aqueous state. The salt may be regained by boiling off the water, leaving the salt behind.

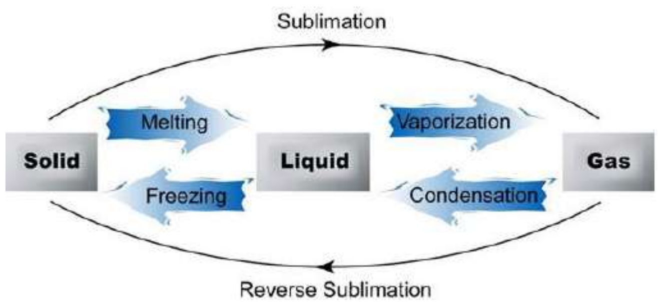


Fig 1.9: physical change

Chemical Change

Chemical changes occur when bonds are broken and/or formed between molecules or atoms. This means that one substance with a certain set of properties (such as melting point, color, taste, etc) is turned into a different substance with different properties. Chemical changes are frequently harder to reverse than physical changes.

One good example of a chemical change is burning a candle. The act of burning paper actually results in the formation of new chemicals (carbon dioxide and water) from the burning of the wax.

Another example of a chemical change is what occurs when natural gas is burned in your furnace. In this case, not only has the appearance changed, but the structure of the molecules has also changed. The new substances do not have the same chemical properties as the original ones. Therefore, this is a chemical change.

Observations that help to indicate chemical change include:

- Temperature changes (either the temperature increases or decreases).
- Light given off.
- Unexpected color changes (a substance with a different color is made, rather than just mixing the original colors together).
- Bubbles are formed (but the substance is not boiling - you made a substance that is a gas at the temperature of the beginning materials, instead of a liquid).
- Different smell or taste (do not taste your chemistry experiments, though!).
- A solid forms, if two clear liquids are mixed (look for a precipitate).

METHODS OF HEAT TRANSFER

Heat can travel from one place to another in three ways:

i. Conduction
ii. Convection
iii. Radiation.

Both conduction and convection require matter to transfer heat.

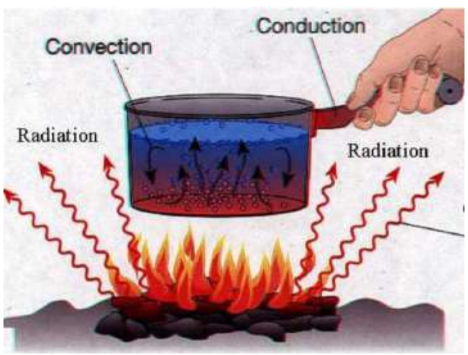


Fig 1.10: Heat transfer

If there is a temperature difference between two systems heat will always find a way to transfer from the higher to lower system.

When particles of matter are in direct contact, heat transfers by means of conduction. The adjacent atoms of higher energy vibrate against one another, which transfers the higher energy to the lower energy, or higher temperature to lower temperature.
That is, atoms of higher intensity and higher heat will vibrate, thereby moving the electrons to areas of lower intensity and lower heat. Fluids and gases are less conductive than solids (metals are the best conductors) due to the fact that they are less dense, meaning that there is a larger distance between atoms.

Conduction

Conduction is the transfer of heat between substances that are in direct contact with each other. The better the conductor, the more rapidly heat will be transferred. Metal is a good conduction of heat. Conduction occurs when a substance is heated, particles will gain more energy, and vibrate more. These molecules then bump into nearby particles and transfer some of their energy to them. This then continues and passes the energy from the hot end down to the colder end of the substance.

Convection

Thermal energy is transferred from hot places to cold places by convection. Convection occurs when warmer areas of a liquid or gas rise to cooler areas in the liquid or gas. Cooler liquid or gas then takes the place of the warmer areas which have risen higher.

This results in a continuous circulation pattern. Water boiling in a pan is a good example of these convection currents. Another good example of convection is in the atmosphere. The earth's surface is warmed by the sun, the warm air rises and cool air moves in.

Radiation

Radiation is a method of heat transfer that does not rely upon any contact between the heat source and the heated object as is the case with conduction and convection. Heat can be transmitted through empty space by thermal radiation often called infrared radiation.
This is a type electromagnetic radiation. No mass is exchanged and no medium is required in the process of radiation. Examples of radiation is the heat from the sun, or heat released from the filament of a light bulb.

Radiation (not to be confused with thermal radiation) refers to the transfer of heat through empty space. This form of heat transfer occurs without an intervening medium; radiation works even in and through a perfect vacuum. For instance, energy from the sun travels through the vacuum of space before the transfer of heat warms the Earth.

1.2.4.4 Learning Activities

Find a partner. Then, try to change solid ice to liquid water by adding heat. For this activity, you will need:

- 3 - 5 Ice cubes
- 3 Plastic cups
- 1 Spoon
- 1 Cup warm water
- Stopwatch/time

Procedure

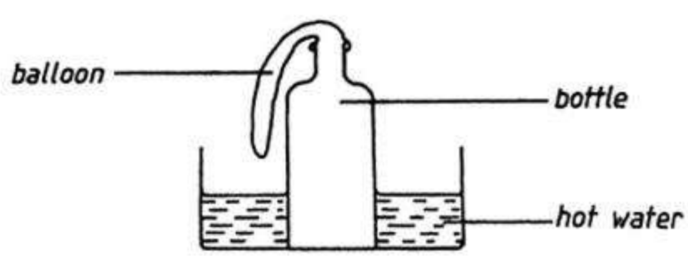
1. Fill a cup with warm water, about ¾ full.
2. Place one ice cube in the water. Start the timer.
3. One partner stirs the ice water with the spoon. The other partner times how long it takes the ice to melt. Write down the time.
4. Next, put an ice cube in an empty cup. Set it outside in the sunlight.
5. Time how long it takes the ice cube to melt. Write down how long it takes.
6. Have one partner hold an ice cube in their hands. The other partner times how long it takes to melt. Write down the time.
7. Compare how long it took each ice cube to melt.

Conclusion:

- Which way melted the ice cube the fastest?
- Why do you think this way worked best?
- Suggest another way that you could change ice into water.

1.2.4.5 Self-Assessment

1. A balloon was fastened to the neck of a bottle and the bottle was then placed in hot water as shown in the diagram below (1 mark)

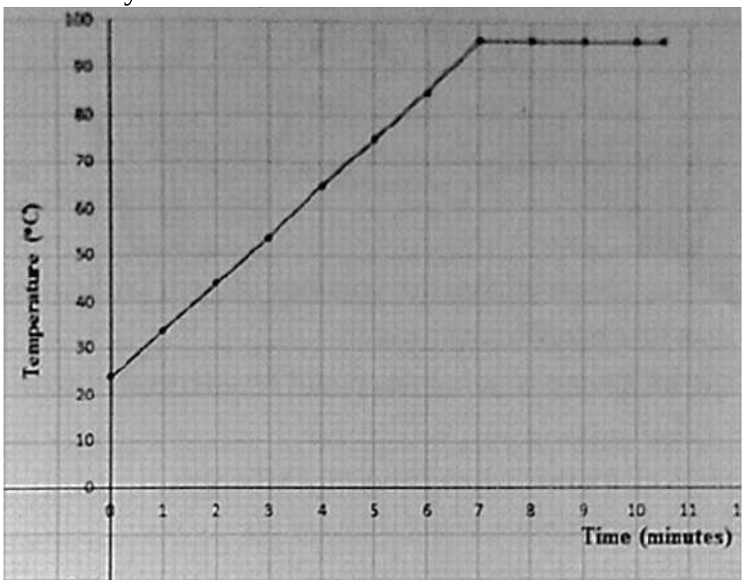


Which one of the following statements describes what happened to the balloon?

a. The balloon expanded
b. Remained the same size

c. Melted
d. Shrunk

2. The graph below shows the results obtained when students heated water and recorded its temperature every minute. (1 mark)

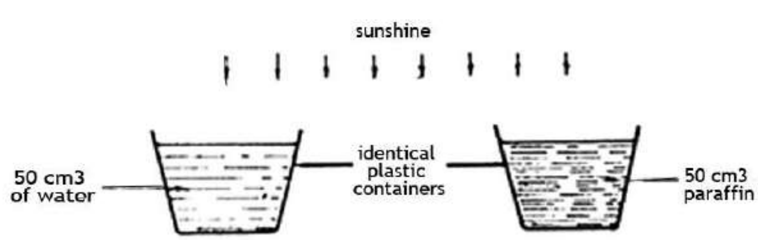


Which of the following statement is **NOT** correct about the students results as shown in the graph?

a. The water had all evaporated
b. The temperature of the water after 3.5 minutes was 60^0 C
c. The water boiled at 96^0 C
d. The temperature of the water before heating was 24^0 C

3. Malwa was roasting meat in the house and his sister smelt the roasting meat as she approached the house. By which of the following processes had the smell reached her nose? (1 mark)
   a. Conduction
   b. Evaporation
   c. Diffusion
   d. Radiation

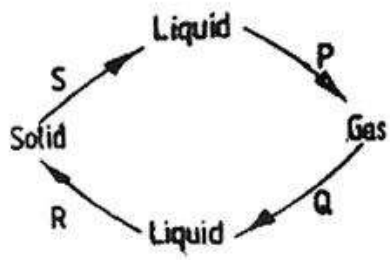
4. Some students set an experiment as shown in the diagram below. (1 mark)



After two hours they observed that the volumes of both liquids had decreased and that there was less paraffin than water. Which one of the following conclusions could be **correctly** made from their observations?

a. All liquids evaporate when exposed to the sun
b. Some liquids evaporate faster than others
c. Paraffin becomes hotter than water
d. Liquids only evaporate on sunny days.

5. The diagram below shows how matter changes from one state to another due to heating and cooling. (1 mark)



The processes marked **P, Q** and **S** are

	P	**Q**	**S**
a.	Condensation	Melting	Evaporation
b.	Evaporation	Melting	Condensation
c.	Evaporation	Condensation	Melting
d.	Melting	Evaporation	Condensation

6. Which one of the following changes when a piece of candle wax is heated until it all melts?

a. Volume
b. Weight
c. Shape
d. Mass

7. Which of the following properties of a gas changes when it is heated and then cooled?
a. Volume
b. Mass
c. Weight
d. Color

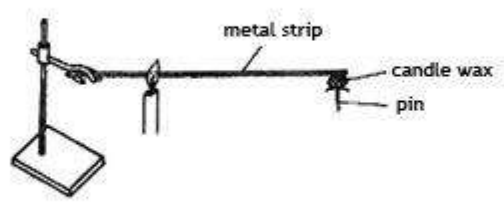
8. Four groups of students **P, Q, R,** and **S** wanted to compare rates of evaporation of different liquids. The materials set up by each group were as follows:

P Identical containers with different amounts of liquid
Q Identical containers with equal amounts of liquid

R Different sizes of containers with equal amounts of liquid
S Different sizes of containers with different amounts of liquid

Which one of the groups of pupils set up materials correctly?
a. P
b. Q
c. R
d. S

9. A pin was fixed to one end of a metal strip using candle wax. The metal strip was heated as shown in the diagram below.

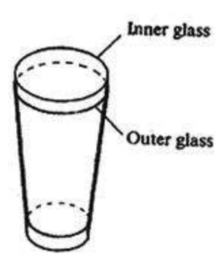


After a few minutes, the pin dropped. The **CORRECT** conclusion which can be drawn from this experiment is that.
a. Metals expand when heated.
b. The pin was near the source of heat.
c. Metals conduct heat.
d. The pin was too heavy.

10. The process by which water vapor changes to liquid is called
a. Condensation
b. Freezing
c. Melting
d. Evaporation

11. Which one of the following shows the correct order of the processes that take place when ice is heated until steam is formed and the steam cooled to form water?
a. Vaporization, melting, condensation.
b. Melting, condensation, vaporization.
c. Vaporization, condensation, melting.
d. Melting, vaporization, condensation.

12. A drinking glass was placed inside another drinking glass as shown in the diagram below.



The glasses got stuck to each other. Which one of the following methods could be used to separate them?

a. Placing cold water in the inner glass and dipping the outer glass in warm water.
b. Placing warm water in the inner glass and dipping the outer glass in cold water.
c. Placing cold water in the inner glass and dipping the outer glass in cold water.
d. Placing warm water in the inner glass and dipping the outer glass in warm water.

13. Label each of the following changes as a physical or chemical change. Give evidence to support your answer.
    a. Boiling water.
    b. A nail rusting.
    c. A green solution and colorless solution are mixed. The resulting mixture is a solution with a pale green color.
    d. Two colorless solutions are mixed. The resulting mixture has a yellow precipitate.

1.2.4.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins

Personal protective equipment (PPEs)

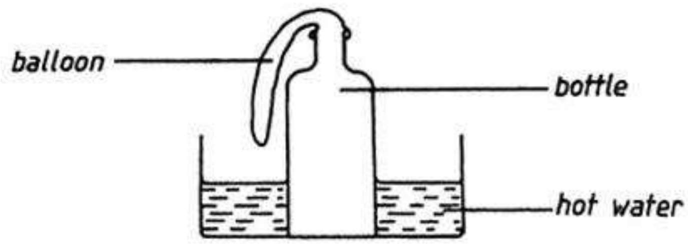
- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.4.7 References

Frank Kreith.,Raj M. Manglik., Mark S. Bohn., Principles of heat transfer., seventh edition
Secondary Physics 4th Edition Students book Three KLB

Model Answers

1. A balloon was fastened to the neck of a bottle and the bottle was then placed in hot water as shown in the diagram below (1 mark)



Which one of the following statements describes what happened to the balloon?

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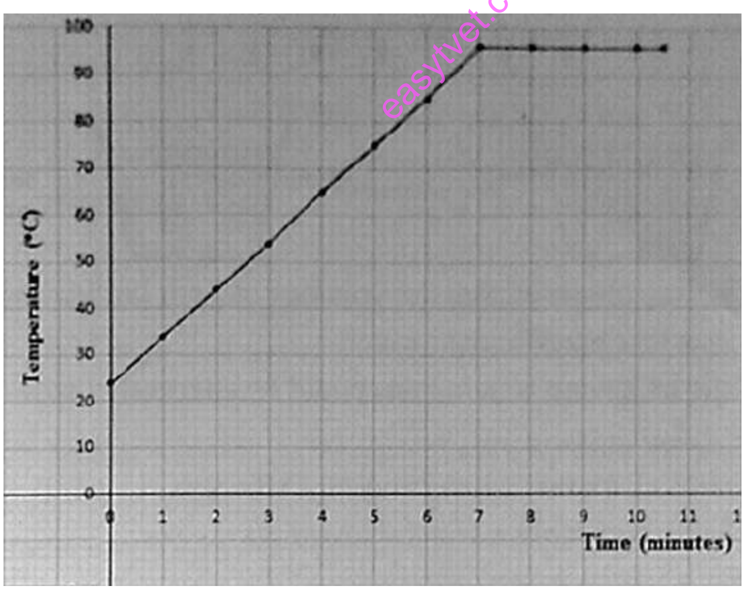
2. The graph below shows the results obtained when students heated water and recorded its temperature every minute. (1 mark)



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3. Malwa was roasting meat in the house and his sister smelt the roasting meat as she approached the house. By which of the following processes had the smell reached her nose? (1 mark)
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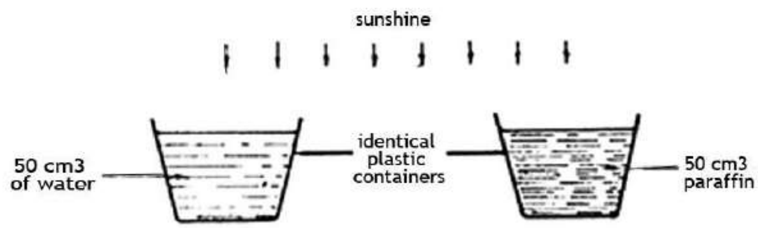
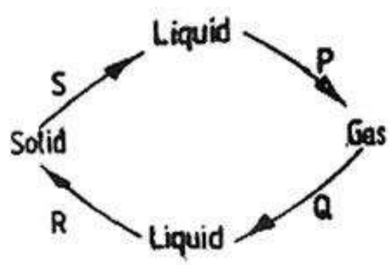
4. Some students set an experiment as shown in the diagram below. (1 mark)



After two hours they observed that the volumes of both liquids had decreased and that there was less paraffin than water. Which one of the following conclusions could be **correctly** made from their observations?

   a. All liquids evaporate when exposed to the sun
   b. Some liquids evaporate faster than others
   c. Paraffin becomes hotter than water
   d. Liquids only evaporate on sunny days.

5. The diagram below shows how matter changes from one state to another due to heating and cooling. (1 mark)



The processes marked **P, Q** and **S** are

	P	Q	S
a.	Condensation	Melting	Evaporation
b.	Evaporation	Melting	Condensation
c.	**Evaporation**	**Condensation**	**Melting**
d.	Melting	Evaporation	Condensation

6. Which one of the following changes when a piece of candle wax is heated until it all melts?

   a. Volume
   b. Weight
   c. Shape
   d. Mass

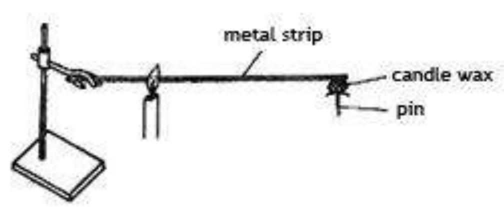
7. Which of the following properties of a gas changes when it is heated and then cooled?
   a. Volume
   b. Mass
   c. Weight
   d. Color

8. Four groups of students **P, Q, R,** and **S** wanted to compare rates of evaporation of different liquids. The materials set up by each group were as follows:

   P Identical containers with different amounts of liquid
   Q Identical containers with equal amounts of liquid
   R Different sizes of containers with equal amounts of liquid
   S Different sizes of containers with different amounts of liquid

   Which one of the groups of pupils set up materials correctly?
   a. P
   b. Q
   c. R
   d. S

9. A pin was fixed to one end of a metal strip using candle wax. The metal strip was heated as shown in the diagram below.



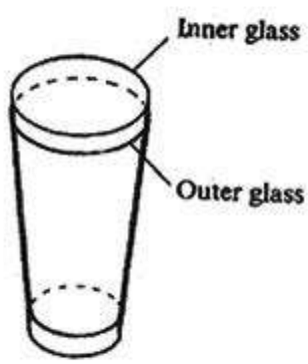
   After a few minutes, the pin dropped. The **CORRECT** conclusion which can be drawn from this experiment is that.
   a. Metals expand when heated.
   b. The pin was near the source of heat.
   c. Metals conduct heat.
   d. The pin was too heavy.

10. The process by which water vapor changes to liquid is called
   a. Condensation
   b. Freezing

c. Melting
d. Evaporation

11. Which one of the following shows the correct order of the processes that take place when ice is heated until steam is formed and the steam cooled to form water?
   a. Vaporization, melting, condensation.
   b. **Melting, condensation, vaporization**.
   c. Vaporization, condensation, melting.
   d. Melting, vaporization, condensation.

12. A drinking glass was placed inside another drinking glass as shown in the diagram below.



The glasses got stuck to each other. Which one of the following methods could be used to separate them?
   a. Placing cold water in the inner glass and dipping the outer glass in warm water.
   b. Placing warm water in the inner glass and dipping the outer glass in cold water.
   c. Placing cold water in the inner glass and dipping the outer glass in cold water.
   d. Placing warm water in the inner glass and dipping the outer glass in warm water.

13. Label each of the following changes as a physical or chemical change. Give evidence to support your answer.
   a. Boiling water. – **Physical change**
   b. A nail rusting. – **Chemical change**
   c. A green solution and colorless solution are mixed. The resulting mixture is a solution with a pale green color. – **Physical change**
   d. Two colorless solutions are mixed. The resulting mixture has a yellow precipitate. – **Chemical change**

1.2.5 **Learning Outcome 5:** Apply principles of pressure in fluids

1.2.5.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply principles of acoustics. It includes, terms and concepts, units of measurements of pressure, definition of density, variations of pressure, laws, solving simple problems involving liquids of different densities and application of air pressure in relation to objects in everyday life.

1.2.5.2 Performance Standard

5.1 Density and variation of pressure is defined based on scientific principles
5.2 Laws are identified based on scientific principles
5.3 Simple calculations on pressure in liquids are performed based on scientific principles

1.2.5.3 Information Sheet

Terms and concepts

- Density: The state or quality of being dense; compactness; closely set or crowded condition.
- Pressure: It is the amount of pressing, a measurement of how a force is distributed over a surface.
- Floatation: the tendency of an object to rise up to the upper levels of the fluid or to stay on the surface of the fluid.
- Sinking: the tendency of an object to go to the lower levels of the fluid.

Definition of density

A material's density is defined as its mass per unit volume.
The formula for density is $d = M/V$

Where:
d is density
M is mass
V is volume.

Density is commonly expressed in units of grams per cubic centimeter.

Unit of Density

- Though SI unit of density is kg/m^3, for convenience we use g/cm^3 for solids, g/ml for liquids, and g/L for gases.
- Density can be explained as the relationship between the mass of the substance and the volume it takes up.
- In a qualitative term, it shows how much heavy an object is at constant volume.

- Different substances have different density, which means for the same volume of different substances weigh differently.

Other Density Units

Talking about other density units, metric tons and liter are also used even though they are not part of the SI. Some other units include:

- gram per milliliter (g/mL)
- metric ton per cubic meter (t/m^3)
- kilogram per liter (kg/L)
- megagram (metric ton) per cubic meter (mg/m^3)
- gram per cubic centimeter (g/cm^3)
  $1\ g/cm^3 = 1000\ kg/m^3$
- kilogram per cubic decimeter (kg/dm^3)

Applications of Density in Real Life

Many applications of density are there in our real-life like a few examples are in pipe design, shipbuilding, helium balloons, weight distribution in the airplane, and the fact that ice floats on water.

- The knowledge of the densities of two substances helps you in separation techniques. For example, separation of oil from water. Leakage of an oil tank in the ocean then oil drops start to float on the water due to their less density in the water.
- Another well-known application of density is determining whether an object will float on water or not. The floating of ships and diving of submarines are due to their density difference.

Example

1. Calculate the density of water if it has a mass of 1160 Kg and a volume of 1 m^3?

Solution:

Given;

Mass = 1160 Kg

Volume = 1 m^3

Density is given by the formula:

Density = Mass/Volume

$\rho = 1160/1 = 1160\ kg/m^3$

UNITS OF MEASUREMENTS OF PRESSURE

Pressure is the force per unit area applied in the direction perpendicular to a surface.

To work out pressure we need to know two things; the force or weight applied and the area over which the force or weight works.

The equation for working out pressure is simply;

pressure = force ÷ area

$$\mathbf{P} = \frac{\mathbf{dF}}{\mathbf{dA}}$$

where:
P is pressure
F is the component of force perpendicular to the surface
A is the area of the surface

When a force is constant over an area, the pressure acting on that area is simply

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

It can be given the units of $N.m^{-2}$. Pressure is a scalar quantity; thus, it acts in all directions at any given point. In order for pressure to create a force, the pressure must be integrated over some area.

SI unit of pressure

For pressure, the SI system's basic unit is Pascal (Pa), which is N/m^2 (Newton per square meter, while Newton is Kgm/s^2).

Examples

1. If a weight of fluid of 200 N acts on a surface of 5 m^2, calculate the pressure created.

   pressure = force ÷ area,

   P = F / A = 200 / 5 = **<u>40 Pa</u>**

2. What force must be applied to a surface area of 0.0025 m^2, to create a pressure of 200,000 Pa?

   P = F / A, rearranging gives:

   F = P x A = 200000 x 0.0025 = **<u>500 N</u>**

3. In a hydraulic lift system, what must the surface area of a piston be in cm^2 if a pressure of 300 kPa is used to give a desired upward force of 2000 N?

   P = F / A, rearranging gives:

A = F / P = 2000 / 300000 = 0.00667 m^2

What is the piston surface area in cm^2?

1 m^2 = 100 cm x 100 cm = 10 000 cm^2,

so, the area of the piston = 10 000 x 0.00667 = **<u>66.7 cm²</u>**

PRESSURE IN LIQUID (DENSITY AND DEPTH FACTORS)

You can calculate the pressure at a given depth created by the weight of liquid in the earth's gravitation field using the following formula:

pressure in a liquid = depth of liquid x density of liquid x gravitational field strength

$$P = h\rho g$$

P, pressure in pascals (**Pa**)
h = depth in meters (**m**)
ρ = density (**kg/m³**)

and the gravitational field strength = **g** = **9.8 N/kg** (on the Earth's surface)

Unit connections

Taking the formula P = h x ρ x g in terms of units.
pressure = force per unit area = height of column of material x density of material x gravitational constant

$$N / m^2 = m \times kg/m^3 \times 9.8\ N/kg$$

Unit analysis: on the right the kg cancel out, $m/m^3 = 1/m^2$, you are left with **N/m^2**

<u>Applications of pressure</u>

The area of the edge of a knife's blade is extremely small. This creates a pressure high enough for the blade to cut through a material.
Syringes are used to take blood for blood tests. The pressure of the liquid (blood) forces the liquid to move into the syringe when its plunger is withdrawn.
When air is sucked out of a drinking straw, the air pressure inside if decreases and the atmospheric pressure outside forces the liquid to go inside the straw.

Skis have a large area to reduce the pressure on the snow. This ensures that the skis do not sink into the snow too far.
The pressure under the studs on the soles of football shoes is high enough for them to sink into the ground, which gives extra grip.
A vacuum cleaner has a fan inside that creates a low pressure inside the device. Consequently, air and dirt particles are sucked into the device.

Examples

1. Calculate the pressure created by a 30 m depth of water given the density of water is 1000 kg/m^3 and gravity 9.8 N/kg.

   P = hρg

   P = 30 x 1000 x 9.8 = **294 000 Pa** (2.94 x 10^5 Pa, **294 kPa**)

2. At a depth of 12.5 m of a chemical solvent the pressure at the bottom of the storage tank due to the solvent was 306 kPa
   Calculate density of the solvent.

   P = hρg, rearranging gives

   ρ = P/hg = 306000/ (12.5 x 9.8) = **2498 kg/m^3**

3. At what depth in water is the increased pressure five times greater than atmospheric pressure (101 kPa)?

   5 x 101 = 505 kPa, 505000 Pa, density of water 1000 kg/m^3

   P = hρg, rearranging gives

   h = P/ρg = 505000/ (1000 x 9.8) = **51.5 m**

   Note: The pressure increase in water increases by about the value of atmospheric pressure for every 10 m.

Variations of pressure

One might guess that the deeper you go into a liquid or gas, the greater the pressure from the surrounding fluid will be. The reason for the increased pressure is that the deeper into a fluid, the more the fluid, and thus more weight on top.

Note: Only the density of the fluid and the difference in depth affects the pressure. The shape and size of the container are irrelevant. Thus, the water pressure 6 inches below the surface of the ocean is the same as it is 6 inches below the surface of a glass of salt water.

Idea: Pascal's Principle states that any pressure applied to an enclosed fluid is transmitted undiminished to every point of the fluid.

Pascal’s principle, also called Pascal’s law, in fluid (gas or liquid) mechanics, statement that, in a fluid at rest in a closed container, a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container.

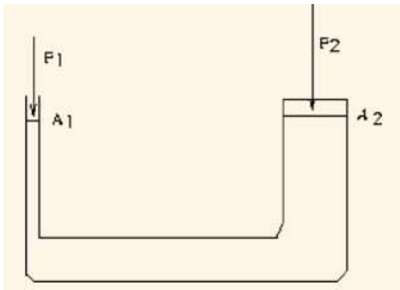


Fig 1.11: pascal’s principle

a pressure of $P_1 = F_1/A_1$ applied downward to the surface on the left of the container gets transmitted as an equal pressure upward of $P_2 = P_1$ on the surface on the other side of the container. The force on the other side is therefore:

$$F_2 = P_2 A_2 = F_1$$

Thus if $A_1 < A_2$, the transmitted force, F_2, is greater than the applied force, F_1. This is the principle behind the hydraulic press. For example, the transmitted force F_2 is used to balance the weight of a car in the hydraulic lift problem at the end of this chapter.

LAWS

Law of floatation

The law of floatation states that, a floating body displaces its own weight of the fluid in which it floats.

This means if a log of 200kg (2000N) floats in water displaces 200kg (2000N) of water, if the same log is placed in other liquid and be able to float it will displace the same 200kg of fluid in which it floats.

<u>Conditions for objects to float</u>

i. The average density of the object should be less than the density of the fluid in which the object has to float.
   Example; a ship is very heavy but it floats because it is hollow inside it contains air, this causes its average density to be lower than that of water.
ii. The upthrust force of the fluid on the object must be equal total weight of the object. (law of floatation)
   Example; a coin will sink to the bottom when placed on the surface of water, this is because the upthrust of water on coin is less than its weight

iii. The volume of object submerged must be large so as to displace large amount of fluid.

Relationship between upthrust and real weight of floating body

Real weight = apparent weight + apparent loss in weight

Apparent loss in weight = weight of fluid displaced = upthrust

Therefore;

Real weight =apparent weight + upthrust

But when an object floats its apparent weight is zero

Apparent weight = 0

Then,

Real weight = 0 + upthrust

Real weight = upthrust.

Therefore, relationship between upthrust and real weight of floating object is such that upthrust is equal to real weight, and since upthrust is equal to weight of fluid displaced then floating body displaces its own weight of the fluid in which it floats (law of floatation)

In order an object to float its real weight must be equal to upthrust.

If an object floats the volume of fluid displaced is equal to the volume of an object submerged and the percentage of the volume of an object submerged is equal to the relative density of an object with respect to the density of fluid in which it floats.

Example

An ice cube of density 0.9g/cm^3 floats in freshwater of density 1.0g/cm^3 what fraction of volume of ice is submerged? If the same ice is floating in sea water of the density 1.3g/cm^3 what is the percentage volume of ice will be submerged?

Solution:

Percentage volume of an object submerged in fresh water,

$$= \frac{\text{density of floating object}}{\text{density of fluid}}$$

$$= \frac{0.9\ g/cm^3}{1.3\ g/cm^3}$$

= 0.9

= 90%

Percentage volume of an object submerged in fresh water,

$$= \frac{\text{density of floating object}}{\text{density of fluid}}$$

$$= \frac{0.9\ g/cm^3}{1 g/cm^3}$$

= 0.69

= 69%

Application of law of floatation in everyday life

- In transportation by water ways
  The law of floatation is applied in all vessels which travel by waterways that include ships, submarines and ferry boats.
- In transportation by air ways
  It is also applied in some vessels which travel by air ways such as hot air balloon and air ship.
- In decoration
  Balloons of different colors and shapes are filled with lighter gas so that will float in air.
- In measurement of specific gravity of liquids
  Hydrometer is an instrument which is used to measure specific gravity of liquids, in its operation it employs the law of floatation.

Archimedes principles

Archimedes' principle referred to as the physical law of buoyancy was discovered by the ancient Greek inventor and mathematician known as Archimedes.

The principle states thus; the exerted upward buoyant force on a body fully or partially immersed in a fluid is equal to the weight of the fluid displaced by that the body acting in the upward direction at the center of mass of the displaced fluid.

This principle explains that the volume of displaced fluid is equivalent to the volume of an object fully immersed in a fluid or to that portion or fraction of the volume immersed for an object partially submerged in a liquid since the density of the fluid is constant.

This can be illustrated mathematically using the equations below:

Weight = Mg;

Where; M implies mass of an object
g is acceleration due to gravity; g is a constant.

Mass = density x volume

Simply put,

Weight = density x volume x g

When a body is immersed partly or wholly in a liquid, there is an apparent loss in the weight of the body which is equal to the weight of liquid displaced by the body.

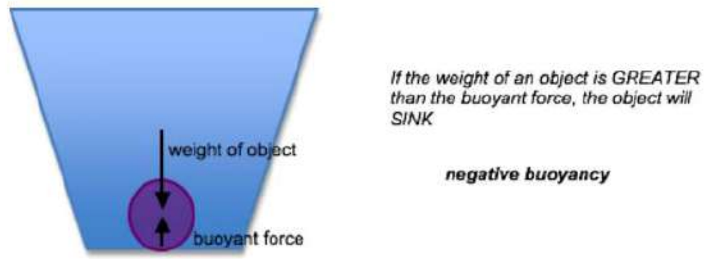


Fig 1.12: Negative buoyancy

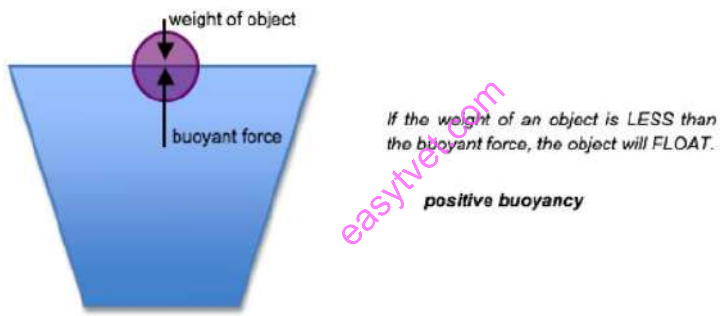


Fig 1.13: Positive buoyancy

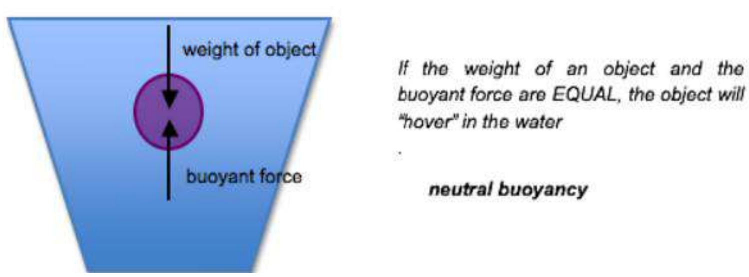


Fig 1.14: Neutral buoyancy

Application of air pressure in relation to objects in everyday life

- We suck out air in the straw so that air pressure within the straw drops and becomes less than the atmospheric air pressure. The liquid rises in the straw reaches our mouth.
- Domestic Vacuum cleaners suck in air and create low pressure area, around the point of suction. The surrounding air is still at the atmospheric air pressure. The atmospheric air pressure pushes in more air to the low-pressure area. But the suction continues. This results in an air current formation. The air current carries dust particles along with. The dust particles are trapped in the trash bags and the air is let out.
- Siphons work because of air pressure.
- The injection syringes utilize atmospheric air pressure. In the first step the piston is drawn in. This creates low pressure within the syringe. The atmospheric air rushes in. The needle is inserted through the cap and the air is pushed in to the bottle. It creates high pressure area in the bottle. The piston is gradually withdrawn it creates low pressure area in the syringe. Medicine in the bottle is at higher pressure so it flows in through the needle into the syringe.
- Automobile servicing - uses air pressure to create strong water current to wash away stubborn sticky dust.
- Air Brakes - Air pressure is used to activate brakes in trains.
- Many industrial applications, processes utilize air pressure.

1.2.5.4 Learning Activities

ACTIVITY 1

Procedure:

i. Press your hand with all your strength against a hard surface and note the sensation.
ii. Now press one finger with the same degree of effort against the same surface and note the sensation.

Conclusion:

- In the first case, you will probably feel no pain, but in the second case the pressure exerted on your fingertip may be so much as to be painful.
- Your arm has not become any stronger, obviously, so the difference in your sensations must stem from the fact that the force which you are applying is being applied over a smaller area - the tip of a finger as opposed to the palm of the hand.
- If the surface area is reduced even more, e.g., by applying the fingertip to the end of a pin, the degree of pressure would be so great that the pin would be pressed into the finger, probably causing a great deal of pain.

ACTIVITY 2

Experiment verification of law of floatation

Materials needed:

- Eureka can
- Beaker
- Top pan balance
- Dry wooden block
- Water
- Tripod stand

Process:

1. An overflow can is kept over a top pan balance
2. The can is filled with water up to its spout and an empty beaker is kept below the spout of the can.
3. The weight of water with overflow can (Eureka can) is noted.
4. Now, a dry wooden block is kept in the water of the can.

Conclusion:
The water is displaced into the beaker but the top balance does not show any change. It proves that the weight of the displaced water is equal to the weight of the block. It verifies the law of floatation.

1.2.5.5 Self-Assessment

1. What is the density of a cube of sugar weighing 11.2 grams measuring 2 cm on a side? (6 marks)

2. A solution of water and salt contains 25 grams of salt in 250 mL of water. What is the density of the salt water? (Use density of water = 1 g/mL) (8 marks)

3. The average standard rectangular building brick has a mass of 3.10 kg and dimensions of 225 mm x 112 mm x 75 mm.
   The gravitational field constant g = 9.8 N/kg. (8 marks)

   a. Calculate the pressure the brick creates when standing on its surface of smallest area.
   b. Calculate the pressure the brick creates when standing on its surface of greatest area.

4. If you find a shiny rock, a carbon allotrope with a volume of 0.042 cm^3 and a mass of 0.14 g, is it graphite or diamond? The density of graphite is 2.266 g/cm^3 and the density of diamond is 3.51g/cm^3. (6 marks)

.

5. What does Boyles law state? (1 mark)

a. The pressure of a fixed mass of an ideal gas is inversely proportional to its volume if the temperature is constant within
b. The pressure of a fixed mass of an ideal gas is directly proportional to its volume if the temperature is constant within.
c. The pressure of a mass of an ideal gas is inversely proportional to its volume if the temperature is constant within
d. The pressure of a fixed mass of an ideal gas is inversely proportional to its temperature if the volume is constant within

6. A transparent plastic container was filled with water. Two small holes were then mad, one on the lid and the other at the bottom. It was noticed that when both holes were open, water flowed out through the bottom hole. When the top was closed, the flow of water stopped. The flow of water stopped because (1 mark)
   a. Water in the container is denser than air.
   b. Pressure in water is greatest at the bottom.
   c. Air pressure in the container increased.
   d. The pressure exerted by the water is equal to the air pressure at the bottom hole.

7. A little amount of water in a tin can was heated and the water allowed to boil for some time. The tin was closed firmly and cold water poured on it. The can collapsed suddenly. This happened because (1 mark)
   a. Pressure outside the tin can increased.
   b. Pressure inside the tin can increased.
   c. The contraction of tin can was sudden.
   d. The pressure inside the tin can decreased.

8. Students dropped different objects from the same height and recorded the time taken for each object to reach the ground. Their results were as shown in the table below.

Object	Time taken to reach the ground
Stone	2 seconds
Rubber ball	2 seconds
Sheet of paper	4 seconds
Block of wood	2 seconds

The most likely reason why the paper took longer to reach the ground is (1 mark)
   a. It was not as heavy as the other objects
   b. It had a larger surface area than the other objects
   c. It was affected more by air resistance than the other objects
   d. The force of gravity on the paper was less than on the other objects

1.2.5.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins

Personal protective equipment (PPEs)

- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.5.7 References

Malcolm J. McPherson., Part 1 Basic principles of fluid mechanics and physical thermodynamics.

Secondary Physics 4th Edition Students book Three KLB

Model Answers

1. What is the density of a cube of sugar weighing 11.2 grams measuring 2 cm on a side? (6 marks)

Solution:

Step 1: Find the mass and volume of the sugar cube.

Mass = 11.2 grams
Volume = cube with 2 cm sides.

Volume of a cube = $(\text{length of side})^3$
Volume = $(2 \text{ cm})^3$
Volume = 8 cm^3

Step 2: Plug your variables into the density formula.

density = mass/volume
density = $11.2 \text{ grams}/8 \text{ cm}^3$
density = 1.4 grams/cm^3

Answer: The sugar cube has a density of 1.4 grams/cm^3.

2. A solution of water and salt contains 25 grams of salt in 250 mL of water. What is the density of the salt water? (Use density of water = 1 g/mL) (8 marks)

Step 1: Find the mass and volume of the salt water.

$\text{density}_{water} = \text{mass}_{water}/\text{volume}_{water}$
solve for mass_{water},

$\text{mass}_{water} = \text{density}_{water} \cdot \text{volume}_{water}$
$\text{mass}_{water} = 1 \text{ g/mL} \cdot 250 \text{ mL}$
$\text{mass}_{water} = 250 \text{ grams}$

Now we have enough to find the mass of the salt water.

$\text{mass}_{total} = \text{mass}_{salt} + \text{mass}_{water}$
$\text{mass}_{total} = 25 \text{ g} + 250 \text{ g}$
$\text{mass}_{total} = 275 \text{ g}$

Volume of the salt water is 250 mL.

Step 2: Plug your values into the density formula.

density = mass/volume
density = 275 g/250 mL

density = 1.1 g/mL

Answer: The salt water has a density of 1.1 grams/mL.

3. The average standard rectangular building brick has a mass of 3.10 kg and dimensions of 225 mm x 112 mm x 75 mm.
   The gravitational field constant g = 9.8 N/kg. (8 marks)

   a. Calculate the pressure the brick creates when standing on its surface of smallest area.

      smallest surface area = 112 mm x 75 mm

      area = (112/1000) x (75/1000) = 0.0084 m^2

      downward force (weight) = mass x g = 3.1 x 9.8 = 30.38 N

      pressure = force / area = 30.38 / 0.0084 = 3620 Pa (3 sf)

   b. Calculate the pressure the brick creates when standing on its surface of greatest area.

      largest surface area = 225 mm x 112

      area = (225/1000) x (112/1000) = 0.0252 m^2

      downward force (weight) = mass x g = 3.1 x 9.8 = 30.38 N

      pressure = force / area = 30.38 / 0.0252 = 1210 Pa (3 sf)

4. If you find a shiny rock, a carbon allotrope with a volume of 0.042 cm^3 and a mass of 0.14 g, is it graphite or diamond? The density of graphite is 2.266 g/cm^3 and the density of diamond is 3.51g/cm^3. (6 marks)
   Solution:

   Given;

   Volume of the shiny rock =0.042 cm^3

   Mass of the shiny rock = 0.15 g

   Density of graphite = 2.266 g/cm^3

   Density of diamond = 3.51g/cm^3

   Use the density equation to solve for m, mass of graphite and for the mass of a diamond.

$$\rho = m/V$$

$$m = \rho V$$

$$m = 2.266\ g/cm^3 \times 0.042\ cm^3 = 0.0951g \text{ for graphite}$$

$$m = 3.51 g/cm^3 \times 0.042\ cm^3 = 0.1474\ g \text{ for diamond}$$

The mass of the shiny rock you found is identical with the mass of diamond.

5. What does Boyles law state? (1 mark)
   a. **The pressure of a fixed mass of an ideal gas is inversely proportional to its volume if the temperature is constant within**
   b. The pressure of a fixed mass of an ideal gas is directly proportional to its volume if the temperature is constant within.
   c. The pressure of a mass of an ideal gas is inversely proportional to its volume if the temperature is constant within
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b. It had a larger surface area than the other objects
c. It was affected more by air resistance than the other objects
d. The force of gravity on the paper was less than on the other objects

1.2.6 **Learning Outcome 6:** Apply principles of acoustics

1.2.6.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Test plumbing system. It includes, terms and concepts, sources of sound, measurement of sound, effects of sound on surrounding areas and sound insulation methods.

1.2.6.2 Performance Standard

6.1 Sources of sound are identified based on scientific principles
6.2 Effects of sound on surrounding areas is identified based on scientific principles
6.3 Methods of sound insulation are identified and interpreted based on scientific principles

1.2.6.3 Information Sheet

Terms and concepts

- Amplification: The process of increasing or making stronger.
- Frequency: A measure of the number of vibrations per second.
- Hertz: The metric unit for frequency (1 Hertz (Hz) = 1 vibration per second).
- Longitudinal wave: A wave with particles vibrating in the same direction that the wave is travelling.
- Medium: A material (solid, liquid or gas) that is used or travelled through.
- Molecule: A particle made up of particular atoms.
- Pitch: The quality of the actual note behind a sound, such as G sharp; a subjective definition of sounds as high or low in tone.
- Pressure: Applied force.
- Resonance: The tendency of an object to vibrate at its maximum wave size (amplitude) at a certain frequency.
- Tension: A tightening stress force related to stretching an object.
- Tone: The quality of sound.
- Transverse wave: A wave with particles vibrating perpendicular to the direction that the wave is travelling; this type or wave is not produced in air, like longitudinal sound waves.
- Vibration: Repetitive motion of an object around its resting point; the backbone of sound.

SOUND

Sound energy is a form of energy because of which our ears are able to hear something.

One cannot create sound or destroy it. But one can transform one form of energy into sound energy. For instance, when a cell phone rings, the sound is produced by converting electrical energy into sound energy.

How is a sound produced?

A sound is produced when an object vibrates, that is they move in a 'to-and-fro' motion.

For instance,

- When we strike a tuning fork or a stretched rubber band, it vibrates and produces sound.
- The human voice is produced because of the vibration of the vocal cords.
- String instruments produce sound as their strings vibrate.
- When a bird flaps its wings a sound is produced.
- A flute produces sound because the air column of the flute vibrates as air passes through it.

How does sound travel?

- In order to propagate, sound requires a medium through which it can travel. This medium could be a gas, liquid or solid.
- Sound propagates in a medium as the particles of the medium vibrate from a starting point. This means that sound always has a starting point and an ending point.
- For instance, while you talk to a friend, as you speak, the particles in the air get displaced due to the pressure caused by the sound you produce. They then displace the adjacent particles and so on. In this way, sound travels from your place to your friend's ears.
- Therefore, we can say that the particles of a medium do not travel from one point one another in order to propagate sound. Sound propagates because of the disturbance caused by a source of sound in the medium.

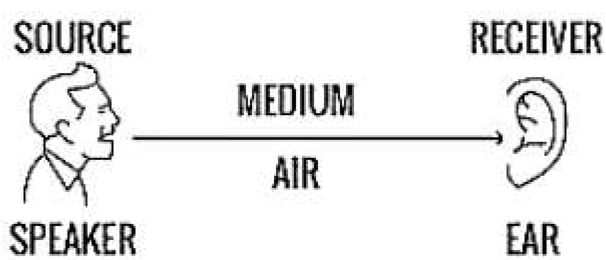


Fig 1.15: Sound travels through a medium

What is a wave?

- A wave is a disturbance produced in a medium as the particles of the medium vibrate.
- The particles produce motion in each other without moving forward or backwards.
- This leads to the propagation of sound.
- Hence sound is often called a Wave.

How can a sound travel through air?

- When an object vibrates in the air or produces a sound, some regions of high pressure are created in front of it. These are called the Regions of Compression. These regions of compression move forward in the medium as particles exert pressure on their adjacent particles.
- WIth alternate regions of compression, there are also regions of low pressure that are in its front. Thes are called Regions of Rarefaction.
- As the object would move forwards and backwards consecutively producing sound, the series of compressions and rarefactions will be created. This will allow sound to move through air or any other medium as well.
- If the medium is dense the pressure exerted on the particles will be more in order to propagate the sound and vice versa.
- Therefore, we can also say that propagation of sound is all about change in the pressure of the medium.

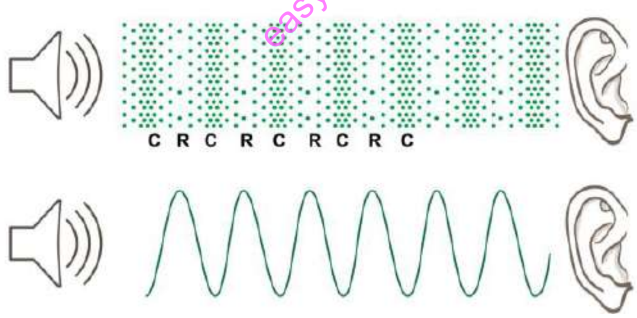


Fig 1.16: Sound wave causing compression (C) and refraction (R)

The loudness of a sound

- The loudness of a sound depends upon the amplitude of the sound.
- The higher the amplitude, the higher is the displacement of the particles and the higher is the loudness of the sound.
- The loudness of the sound is directly proportional to the square of its amplitude.
- The SI unit for measuring the loudness of a sound in decibels (dB).

Pitch of the sound

- Every person has a different sound quality.
- Also, every musical instrument vibrates to produce a different kind of sound. This quality of sound is characterized by its Different quality of sounds may have same pitch and loudness.
- The pitch of a sound depends upon the frequency of the sound wave.
- The pitch would be higher if the frequency of the sound is high.

Difference between pitch and sound

Pitch

- It depends upon the frequency of the sound.
- Pitch of a sound is how our ears react to the frequency of a sound.
- Pitch of the sound helps in recognizing whether the sound is shriller or flatter.

Loudness

- The loudness of a sound depends upon the amplitude of the sound wave.
- The loudness of sound also depends upon the energy of the sound wave.
- The loudness of a sound helps in recognizing whether a sound is loud or feeble.

What are mechanical waves?

A wave that is produced when objects of the medium oscillate is called Mechanical Wave. The sound waves are therefore, mechanical waves.

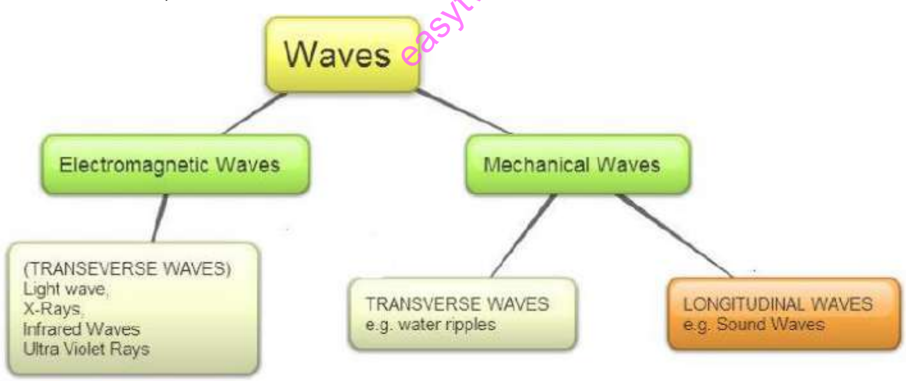


Fig 1.17: Types of Waves

- Sound cannot travel through the vacuum as it always needs a medium to propagate. The vacuum contains no air hence no particles can propagate sound.

Longitudinal waves - Any wave that vibrates in the direction of the motion is called a Longitudinal Wave. Sound waves are longitudinal because the particles of the medium vibrate in the direction which is parallel to the direction of the propagation of the sound waves. The particles in the medium oscillate to and from in the case of longitudinal waves.

Transverse Waves - A transverse wave is produced when the particles of the medium oscillate in a direction which is perpendicular to the direction of the propagation of the wave. The particles in a transverse wave oscillate in an up and down motion. For Example, light waves are transverse in nature.

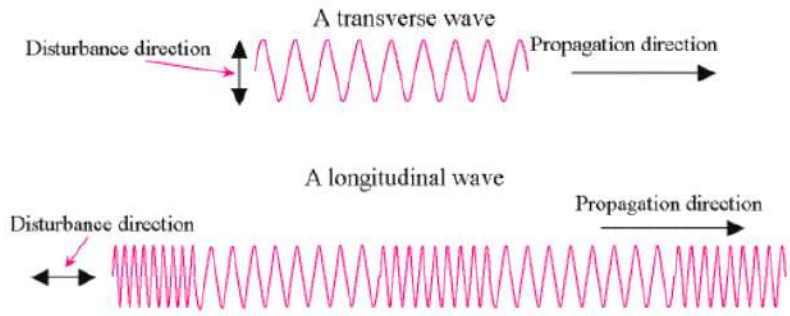


Fig 1.18: Longitudinal vs. Transverse Waves

A sound wave is characterized by three factors:

- Amplitude
- Frequency
- Speed

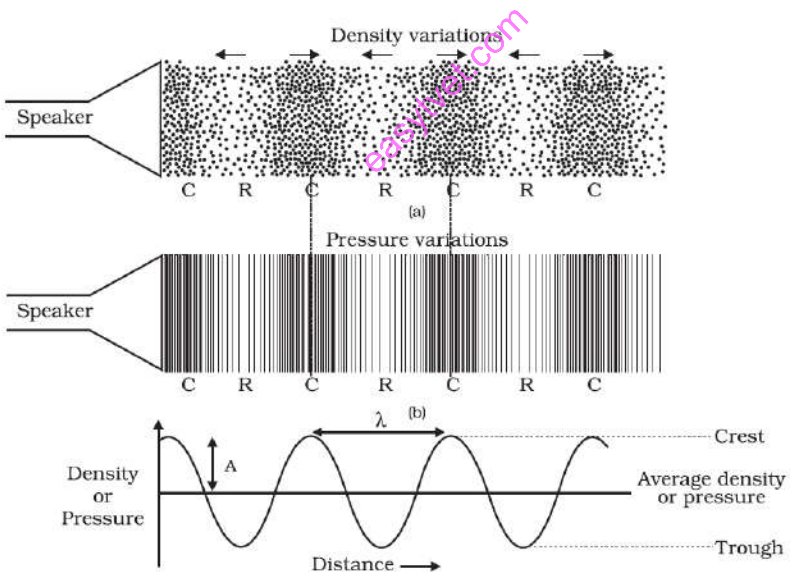


Fig 1.19: Characteristics of sound

Sound cannot travel at the same speed in different mediums.
The speed of sound in a medium is affected by three things:

- The density of the medium. For instance, speed of sound is the maximum through solids
- The temperature of the medium. As the temperature increases, the sound propagates easily.

- Humidity in the air also affects the travel of sound. As the humidity increases, so does the propagation of sound.

Noise pollution

- Noise pollution can be defined as the presence of undesirable and unpleasant sounds in the earth's environment.
- Human beings can bear sounds ranging up to 85 decibels only. Above that, any noise can damage our hearing power.
- Generally, any sound that has a frequency of more than 30 dB is considered noise.
- The unwanted noise causes an adverse effect on the health of the organisms present on the earth.

Causes of noise pollution

1. **Transport noise:** The sound of the traffic on roads, railways and aircraft leads to noise pollution. As the number of vehicles such as cars, motorcycles, buses and trucks is increasing in the cities, especially the Metropolitans, noise pollution is extremely high there.
2. **Industrial noise:** Industries, factories and other commercial businesses cause high-intensity sounds that pollute the environment.
3. **Neighborhood noise**: The noise from the radios, televisions, air conditioners, coolers, kitchen applications and other electrical appliances used in houses lead to noise. Not only this, commercialization around the residential areas often leads to unwanted sounds due to small-scale industries such as printing, car repairing etc.
4. **Construction noise:** Construction of houses, industries and various architectures also lead to sound pollution.
5. **Political activities:** Noise pollution is also created due to the rallies and demonstrations conducted by various political parties in cities and rural areas.
6. **Bursting of crackers and fireworks:** People burst crackers on several occasions such as festivals and ceremonies that lead to sound pollution in the neighborhoods.
7. **Natural sounds:** The environment of the earth also sometimes leads to unpleasant sounds due to lightning, thunderstorms, earthquakes, volcanic eruptions, sounds of various animals etc.

Effects of Noise Pollution

1. Excessive noise in the surroundings can lead to serious health problems such as hypertension, lack of sleep or insomnia, anxiety, lack of memory, stress, irritation and even nervous breakdown.
2. It can lead to temporary or permanent hearing loss in human beings as well as animals.

3. Excessive noise leads to increased blood pressure. It increases cholesterol levels in the blood and therefore increases the chances of cardiovascular diseases in a person.
4. If sound intensity is more than 180 dB it can lead to the death of a person.
5. Noise pollution also leads to a decrease in the production of digestive juices by our body.
6. It can affect animals as well and can lead to their death and loss of habitats. Excessive noise decreases a person's ability to concentrate especially on children and they are unable to concentrate well on their studies due to neighborhood noises.
7. Unwanted sounds in the environment can hinder the animals from finding their prey or their direction of motion.

Prevention of Noise Pollution

1. Factories and other industries should be set up at a distance from residential areas.
2. Silencing devices should be incorporated into heavy vehicles such as aircraft, industrial equipment, machinery and other home appliances.
3. We should always play television, radio and other music systems at a low sound so that it does not harm the neighborhood.
4. Use of horns should be minimized especially near public places such as hospitals, religious places and schools.
5. Soundproofing systems should be installed in industries, party halls and other buildings that produce a high amount of unwanted sounds.
6. Trees should be planted in huge numbers as they can absorb unwanted noise from the environment.
7. People who work in noisy conditions such as industries and mines should be provided earplugs to protect their ears.
8. People should be made aware of noise pollution its adverse effects so that they can take an active involvement in preventing it.

1.2.6.4 Learning Activities

Measuring speed of sound

In measuring the speed of sound, echoes offer a simple way to do it.
You will need:

- A good-sized tape measure
- A stopwatch.

Procedure:

i. Stand about 100m or so from a large wall.
ii. Measure the distance carefully, double it, and write it down.
iii. Now clap 20 times, listen for the echo, clap again as soon as you hear it, and keep doing so.

iv. Measure the total time from the very first clap to the very last echo.

1.2.6.5 Self-Assessment

1. Refraction region always has lower pressure. (1 mark)
   a. True
   b. False

2. What is the distance between two consecutive compressions or refractions called? (1 mark)
   a. Crest
   b. Trough
   c. Frequency
   d. Wavelength.

3. What is your understanding of the following terms? (4 marks)
   i. Frequency
   ii. Resonance
   iii. Tension
   iv. Tone

4. Pitch of a sound depends upon three things. What are they? (3 marks)

5. what is the difference between a tone and noise? (2 marks)

6. How does sound travel in a medium? (5 marks)
7. Of the following factors, which one does not determine the loudness of a sound? (1 marks)
   a. The loudness of a sound depends upon the amplitude of the sound.
   b. The higher the amplitude, the higher is the displacement of the particles and the higher is the loudness of the sound.
   c. The loudness of the sound is inversely proportional to the square of its amplitude.
   d. The SI unit for measuring the loudness of a sound in decibels.

8. How would a manufacturing company prevent their neighborhood from noise pollution? (2 marks)
9. What are the factors that affect the speed of sound in a medium? (3 marks)

10. What is the difference between longitudinal waves and transverse waves? (4 marks)

i. Longitudinal waves
ii. Transverse Waves

1.2.6.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins

Personal protective equipment (PPEs)

- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.6.7 References

F. Alton Everest and Ken Pohlmann. McGraw-Hill Education, 2015. Master Handbook of Acoustics

Thomas D. Rossing, Paul A. Wheeler, and F. Richard Moore. Pearson, 2013. The Science of Sound

Model Answers

1. Refraction region always has lower pressure. (1 mark)
    a. True
    b. False

2. What is the distance between two consecutive compressions or refractions called? (1 mark)
    a. Crest
    b. Trough
    c. Frequency
    d. Wavelength.

3. What is your understanding of the following terms? (4 marks)
    i. Frequency: The number of oscillations per unit time is called the Frequency of a Wave
    ii. Resonance: The tendency of an object to vibrate at its maximum wave size (amplitude) at a certain frequency.
    iii. Tension: A tightening stress force related to stretching an object.
    iv. Tone: The quality of sound.

4. Pitch of a sound depends upon three things. What are they? (3 marks)
    - the frequency of the sound
    - size of the object producing the sound
    - type of the object producing the sound

5. what is the difference between a tone and noise? (2 marks)

Tone is the sound which has single frequency throughout while noise is an unpleasant sound.

6. How does sound travel in a medium? (5 marks)
    - Sound needs some vibration of molecules to travel.
    - Solids, liquids and gases all have molecules present in them which allow the propagation of sound.
    - These molecules or particles in solids, liquids and gases are packed in varied ways.
    - Solids have tightly packed particles in them and hence they allow fast propagation of sound through them as the vibrations can be carried easily from one particle to another.
    - Liquids have slightly loosely packed particles and hence it takes a little time for sound to travel in water or through a liquid.
    - Gases have completely loosely packed particles and hence sound takes the most time in travelling through the air.

7. Of the following factors, which one does not determine the loudness of a sound? (1 marks)
    a. The loudness of a sound depends upon the amplitude of the sound.
    b. The higher the amplitude, the higher is the displacement of the particles and the higher is the loudness of the sound.
    c. The loudness of the sound is inversely proportional to the square of its amplitude.
    d. The SI unit for measuring the loudness of a sound in decibels.

8. How would a manufacturing company prevent their neighborhood from noise pollution? (2 marks)

    Soundproofing systems should be installed in industries, party halls and other buildings that produce a high number of unwanted sounds.

9. What are the factors that affect the speed of sound in a medium? (3 marks)
    - The density of the medium. For instance, speed of sound is the maximum through solids
    - The temperature of the medium. As the temperature increases, the sound propagates easily.
    - Humidity in the air also affects the travel of sound. As the humidity increases, so does the propagation of sound.

10. What is the difference between longitudinal waves and transverse waves? (4 marks)
    Longitudinal waves - Any wave that vibrates in the direction of the motion is called a Longitudinal Wave. Sound waves are longitudinal because the particles of the medium vibrate in the direction which is parallel to the direction of the propagation of the sound waves. The particles in the medium oscillate to and from in the case of longitudinal waves.

    Transverse Waves: A transverse wave is produced when the particles of the medium oscillate in a direction which is perpendicular to the direction of the propagation of the wave. The particles in a transverse wave oscillate in an up and down motion.

1.2.7 **Learning Outcome 7:** Apply mechanical properties of materials

1.2.7.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply mechanical properties of materials. It includes, terms and concepts, properties of materials, tests and advantages and disadvantages of materials

1.2.7.2 Performance Standard

7.1 Mechanical properties are identified and interpreted based on type of material
7.2 Advantages and disadvantages of materials are identified based on use of materials
7.3 Materials are tested based on type of material.

1.2.7.3 Information Sheet

Terms and concepts

- Strength - ability of a material to resist applied forces.
- Ductility - ability of a material to undergo permanent shape change (plastic deformation) without rupturing.
- Toughness - ability of a material to absorb energy.
- Tension test - simultaneously measures strength and ductility. There are several types of tensile machines
- and test specimens.
- Modulus of elasticity (Young's modulus) - the proportionality constant between stress and strain
- Yield Strength - 0.2% offset is normally specified for a tensile test since it is too difficult to accurately measure the elastic limit. Speed of loading affects yield strength but not tensile strength.
- Yield point - the stress in a material at which a marked increase in strain occurs without an increase in stress.
- % reduction of area (RA): is the ratio of the minimum cross-section of a tensile specimen after fracture to its original cross-section.
- Hardness: resistance to deformation or penetration by a much harder indenter.

PROPERTIES OF MATERIALS

The concepts of stress, strain, elasticity, deformation and failure are necessary to understand and interpret mechanical properties.

Strength

Strength means the ability of a material to stand up to forces being applied without it bending, breaking, shattering or deforming.
A strong material is one able to withstand large stresses before either breaking or deforming. Some materials have different strengths according to the nature of the stress applied.

Concrete, for example, is strong under compression but has relatively poor tensile strength.

Tensile strength:
The maximum strength, in tension (pulling), that can be absorbed without fracturing, breaking, or snapping. Low tensile strength can be an indicator of defects in crystal structure.

Flexural strength:
Applied stress at the time of fracture from a test in which the stress is perpendicular to the axis of deformation (bending); generally used to characterize beams.

Toughness
A characteristic of a material that relates to its response to sudden blows or shocks. Toughness can be expressed as the amount of energy required for creating or propagating a crack. Closely related to resilience.

Value of toughness of a material can be determined by stress-strain characteristics of a material. For good toughness, materials should have good strength as well as ductility.

For example: brittle materials, having good strength but limited ductility is not tough enough. Conversely, materials having good ductility but low strength are also not tough enough. Therefore, to be tough, a material should be capable to withstand both high stress and strain.

Hardness
It is the ability of a material to resist to permanent shape change due to external stress. There are various measure of hardness - Scratch Hardness, Indentation Hardness and Rebound Hardness.

i. Scratch Hardness
Scratch Hardness is the ability of materials to the oppose the scratches to outer surface layer due to external force.
ii. Indentation Hardness
It is the ability of materials to oppose the dent due to punch of external hard and sharp objects.
iii. Rebound Hardness
Rebound hardness is also called as dynamic hardness. It is determined by the height of "bounce" of a diamond tipped hammer dropped from a fixed height on the material.

Stiffness
A stiff material is one for which a large stress (force applied per unit of cross-sectional area) is required to produce a small strain (fractional change in length). The ratio of stress to strain is known as the Young's modulus of the material.

Brittleness

Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain. Brittleness is converse to ductility of material. Brittleness of material is temperature dependent. Some metals which are ductile at normal temperature become brittle at low temperature.

Malleability

Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress. Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling. This mechanical property is an aspect of plasticity of material. Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

Ductility

Ductility is a property of a solid material which indicates that how easily a material gets deformed under tensile stress. Ductility is often categorized by the ability of material to get stretched into a wire by pulling or drawing.

This mechanical property is also an aspect of plasticity of material and is temperature dependent. With rise in temperature, the ductility of material increases.

The ability of a material to change shape (deform) usually by stretching along its length; closely related to tensile strength.

Creep and slip

Creep is the property of a material which indicates the tendency of material to move slowly and deform permanently under the influence of external mechanical stress. It results due to long time exposure to large external mechanical stress with in limit of yielding. Creep is more severe in material that are subjected to heat for long time. Slip in material is a plane with high density of atoms.

Resilience

Resilience is the ability of material to absorb the energy when it is deformed elastically by applying stress and release the energy when stress is removed. Proof resilience is defined as the maximum energy that can be absorbed without permanent deformation. The modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without permanent deformation. It can be determined by integrating the stress-strain cure from zero to elastic limit. Its unit is joule/m^3.

Fatigue

Fatigue is the weakening of material caused by the repeated loading of the material. When a material is subjected to cyclic loading, and loading greater than certain threshold value but much below the strength of material (ultimate tensile strength limit or yield stress limit), microscopic cracks begin to form at grain boundaries and interfaces.

Eventually the crack reaches to a critical size. This crack propagates suddenly and the structure gets fractured. The shape of structure affects the fatigue very much. Square holes and sharp corners lead to elevated stresses where the fatigue crack initiates

TESTS

Stress-Strain Relationships

There are three types of static stresses to which materials can be subjected:

1. Tensile - tend to stretch the material
2. Compressive - tend to squeeze it
3. Shear - tend to cause adjacent portions of material to slide against each other

Stress-strain curve is the basic relationship that describes mechanical properties for all three types

1. Tensile Test

Most common test for studying stress-strain relationship, especially metals
In the test, a force pulls the material, elongating it and reducing its diameter

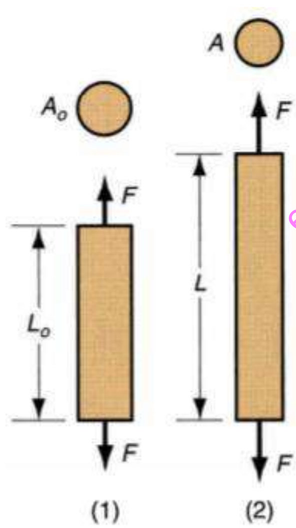


Fig 1.20: Tensile force applied in (1) and (2) resulting elongation of material

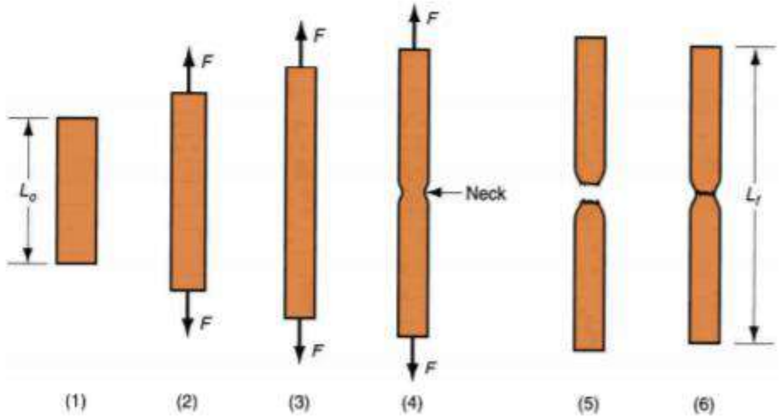


Fig 1.22: Typical progress of a tensile test

1. Beginning of test, no load;
2. Uniform elongation and reduction of cross-sectional area;
3. Continued elongation, maximum load reached;
4. Necking begins, load begins to decrease;
5. Fracture.
6. Final length can be measured

Engineering Stress

Defined as force divided by original area:

$$\sigma_e = \frac{F}{A_0}$$

where σe = engineering stress
F = applied force
A_0 = original area of test specimen

Engineering Strain

Defined at any point in the test as

$$e = \frac{L - L_0}{L_0}$$

where e = engineering strain;
L = length at any point during elongation;
L_0 = original gage length

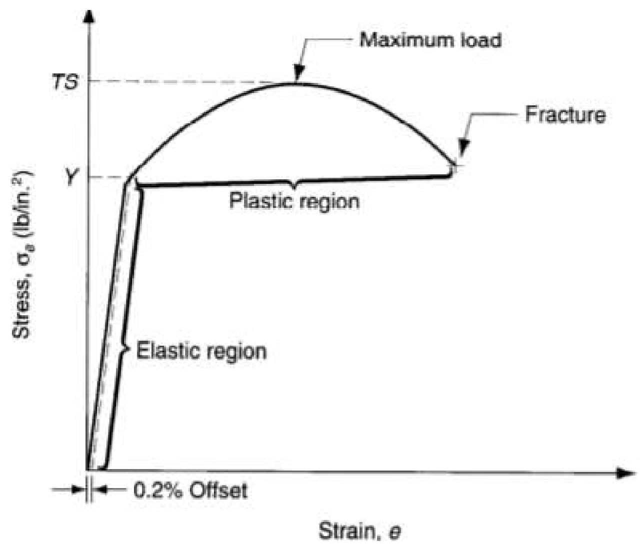


Fig 1.23: Typical engineering stress-strain plot in a tensile test of a metal

Two Regions of Stress-Strain Curve

The two regions indicate two distinct forms of behavior:

i. Elastic region: prior to yielding of the material
ii. Plastic region: after yielding of the material

2. Compression Test

Applies a load that squeezes the ends of a cylindrical specimen between two platens

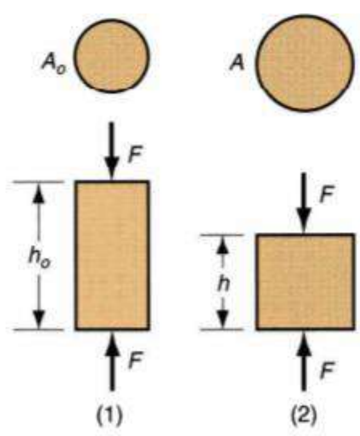


Fig 1.24: Compression test: compression force applied to test piece in (1) and (2) resulting change in height

Engineering Stress

As the specimen is compressed, its height is reduced and cross-sectional area is increased

$$\sigma_e = \frac{F}{A_0}$$

where σe = engineering stress
F = applied force
A_0 = original area of test specimen

Engineering Strain
Defined at any point in the test as

$$e = \frac{h - h_0}{h_0}$$

Since height is reduced during compression, value of e is negative (the negative sign is usually ignored when expressing compression strain)

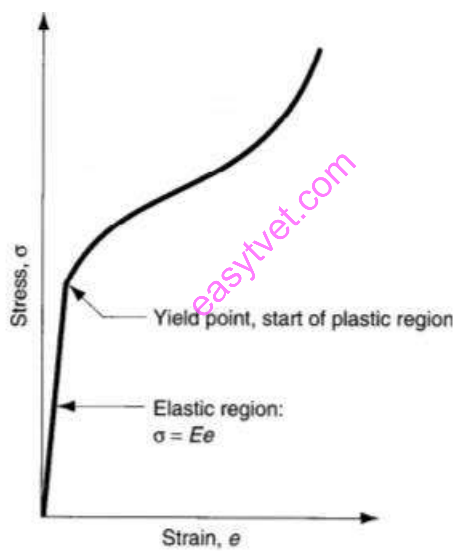


Fig 1.25: Typical engineering stress-strain curve for a compression test

- Shape of plastic region is different from tensile test because cross-section increases
- Calculated value of engineering stress is higher

Tensile Test vs. Compression Test

- Although differences exist between engineering stress-strain curves in tension and compression, the true stress-strain relationships are nearly identical
- Since tensile test results are more common, flow curve values (K and n) from tensile test data can be applied to compression operations
- When using tensile K and n data for compression, ignore necking, which is a phenomenon peculiar to straining induced by tensile stresses

3. Shear Properties

Application of stresses in opposite directions on either side of a thin element

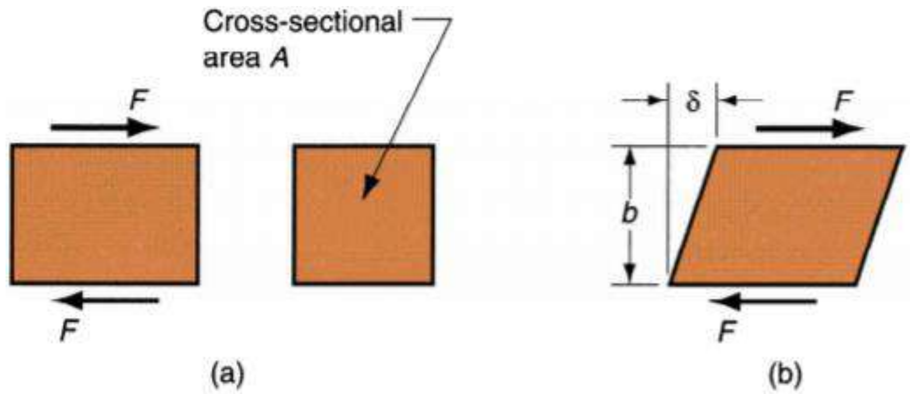


Fig 1.26: Shear (a) stress and (b) strain

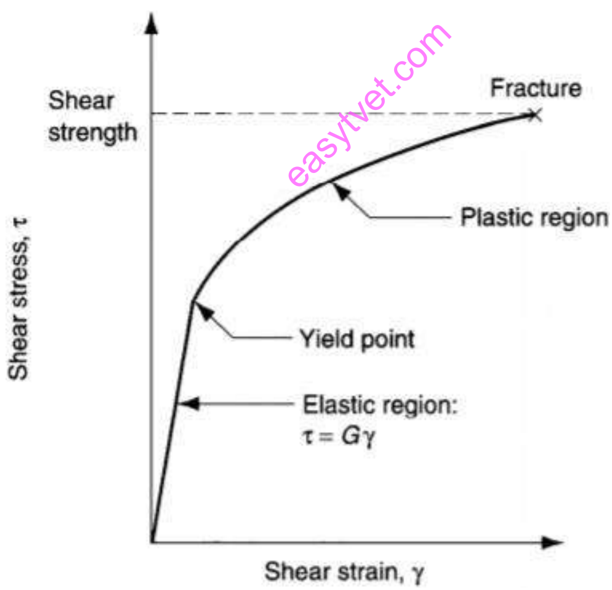


Fig 1.27: Typical shear stress-strain curve from a torsion test

Shear Stress and Strain

Shear stress defined as

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

Where: F = applied force;
A = area over which deflection occurs.

Shear strain defined as

$$\gamma = \frac{\delta}{b}$$

Where δ= deflection element;
b = distance over which deflection occurs

1.2.7.4 Learning Activities

Determining the tensile strength of glues

Procedure:

i. Ceramic specimens are prepared (see figure below) with two holes drilled in each end.
ii. The specimens are broken in half, and then glued back together.
iii. Different types of glues are used, and the specimens are either glued across the entire fracture surface, or just half.
iv. The glues are prepared and allowed to dry according to the standards for the particular glue.

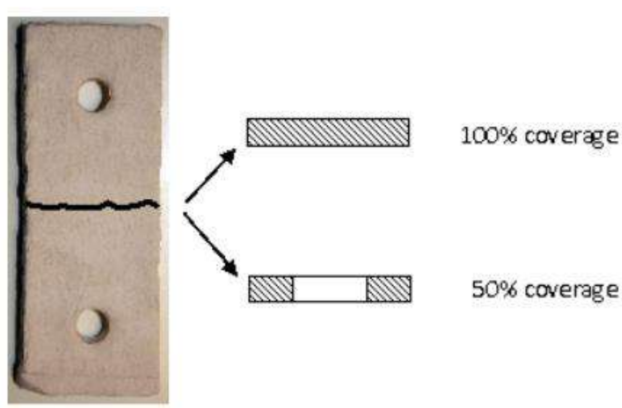


Fig 1.28: specimen

v. For testing, the specimens are hung on hooks going through one of the drilled holes

vi. A large bucket is hung on the specimen using the other hole. Water and various metal weights are slowly and carefully added until the specimen breaks.

1.2.7.5 Self-Assessment

1. The ability of the material to withstand tensile force, without breaking, is known as ______ (1 mark)
   a. Yield strength
   b. Tensile strength
   c. Compressive strength
   d. Creep strength

2. Tensile strength is used as a design criterion for ductile materials. (1 mark)
   a. True
   b. False

3. When a material is pulled in tension, it exhibits the reduction in compressive strength. (1 mark)
   a. True
   b. False

4. Which machine is used to measure compressive strength? (1 mark)
   a. Erichsen machine
   b. Universal testing machine
   c. Impact testing machine
   d. Fatigue testing machine

5. _____ is the maximum stress that can be applied to the material without causing plastic deformation. (1 mark)
   a. Tensile strength
   b. Fatigue strength
   c. Compressive strength
   d. Yield strength

6. As the temperature of a material is lowered, the yield stress _____ and the fracture stress _____ (1 mark)
   a. Increases, increases
   b. Increases, decreases
   c. Decreases, increases
   d. Decreases, decreases

7. Which are the two regions of a Stress-Strain Curve? (2 marks)

8. What is the difference between tensile strength and flexural strength? (3 marks)

9. Draw a sample tension stress – strain curve labeling the different zones. (5 marks)

10. What is your understanding of the following terms? (4 marks)
    i. Plasticity
    ii. Toughness
    iii. Hardness
    iv. Fatigue

1.2.7.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins

Personal protective equipment (PPEs)

- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.7.7 References

J. Pelleg., Mechanical Properties of Materials, Solid Mechanics and its Applications., 2013

Wole Soboyejo., Mechanical Properties of Engineered Materials., 2002.1st Edition

Model Answers

1. The ability of the material to withstand tensile force, without breaking, is known as ______ (1 mark)
    a. Yield strength
    b. Tensile strength
    c. Compressive strength
    d. Creep strength

2. Tensile strength is used as a design criterion for ductile materials. (1 mark)
    a. True
    b. False

3. When a material is pulled in tension, it exhibits the reduction in compressive strength. (1 mark)
    a. True
    b. False

4. Which machine is used to measure compressive strength? (1 mark)
    a. Erichsen machine
    b. Universal testing machine
    c. Impact testing machine
    d. Fatigue testing machine

5. _____ is the maximum stress that can be applied to the material without causing plastic deformation. (1 mark)
    a. Tensile strength
    b. Fatigue strength
    c. Compressive strength
    d. Yield strength

6. As the temperature of a material is lowered, the yield stress _____ and the fracture stress _____ (1 mark)
    a. Increases, increases
    b. Increases, decreases
    c. Decreases, increases
    d. Decreases, decreases

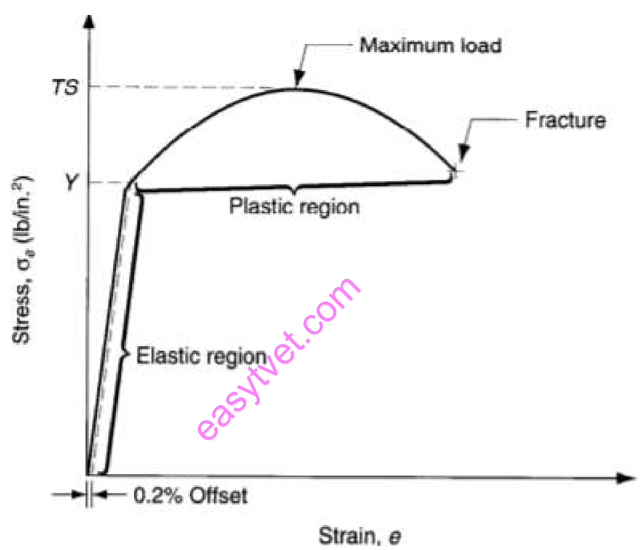
7. Which are the two regions of a Stress-Strain Curve? (2 marks)
    The two regions indicate two distinct forms of behavior:
    Elastic region: prior to yielding of the material
    Plastic region: after yielding of the material

8. What is the difference between tensile strength and flexural strength? (3 marks)

Tensile strength:
The maximum strength, in tension (pulling), that can be absorbed without fracturing, breaking, or snapping. Low tensile strength can be an indicator of defects in crystal structure.

Flexural strength:
Applied stress at the time of fracture from a test in which the stress is perpendicular to the axis of deformation (bending); generally used to characterize beams.

9. Draw a sample tension stress – strain curve labeling the different zones. (5 marks)



10. What is your understanding of the following terms? (4 marks)

i. Plasticity is the property of a material due to which it is permanently deformed due to loading.
ii. Toughness is the ability of a material to absorb energy during deformation, while resilience is its capacity to absorb the energy.
iii. Hardness is the knack of material to defy indentation.
iv. Fatigue is the ability of a material to develop a characteristic behavior under repeated loading

1.2.8 **Learning Outcome 8:** Apply electrical principles

1.2.8.1 Introduction to the learning outcome

This learning outcome specifies the content of competencies required to Apply electrical principles. It includes, terms and Concepts, electrical principles, electrical circuits and electrical safety.

1.2.8.2 Performance Standard

8.1 Electrical principles are identified based on scientific principles
8.2 Electrical standards are interpreted based on international standards
8.3 Occupational safety and health practises are identified based on statutory and sector regulations.
8.4 Simple electrical circuits are identified based on international standards.

1.2.8.3 Information Sheet

Electricity

Electricity, simply put, is the flow of electric current along a conductor. This electric current takes the form of free electrons that transfer from one atom to the next. Thus, the more free electrons a material has, the better it conducts. There are three primary electrical parameters: the volt, the ampere and the ohm.

The Volt

The pressure that is put on free electrons that causes them to flow is known as electromotive force (EMF). The volt is the unit of pressure, i.e., the volt is the amount of electromotive force required to push a current of one ampere through a conductor with a resistance of one ohm.

The Ampere

The ampere defines the flow rate of electric current.

The Ohm

The ohm is the unit of resistance in a conductor. Three things determine the amount of resistance in a conductor: its size, its material, e.g., copper or aluminum, and its temperature. A conductor's resistance increases as its length increases or diameter decreases. The more conductive the materials used, the lower the conductor resistance becomes. Conversely, a rise in temperature will generally increase resistance in a conductor.

Terms and Concepts

- Electric Shock: A stimulation of nerve with a resulting contraction of muscles and feeling of concussion.

- Alternating Current: Current that reverses direction in response to a change in voltage polarity
- Alternator: A rotating machine used to produce electrical energy
- Amp: The unit of electrical current
- Amplification: The process of increasing power, voltage or current of an electrical signal
- Anode: The more positive terminal of a diode or other electronic device
- Attenuation: The reduction in the level of power, current or voltage
- Capacitor: A device capable of storing electrical charge or in AC circuits creating phase shifts
- Cathode: The more negative terminal of a diode or other electronic device
- Circuit Breaker: A protective device that will break the supply to a circuit in the event of excessive current
- Current: The rate of flow of electrons
- Diode: A two terminal electronic device that permits current flow in only one direction
- Phase: The angular displacement of one alternating signal with respect to another
- Power: The rate of energy consumption
- Protection: The equipment necessary in a circuit to prevent overcurrent
- Rectifier: An electronic circuit that converts ac into dc
- Relay: An electromechanical device used to switch signals
- Three phase: A supply consisting of three ac voltages with a phase difference of 120º
- Transistor: A semiconductor device used for amplification or switching
- Volt: The unit of voltage
- Voltage: The amount of energy, or driving force, available to move electrons from one point to another in a circuit path

Electrical physics

All matter is composed of atoms. Each atom comprises of a central nucleus with a number of electrons associated with it. One particular model suggests that this can be considered rather like the sun (the nucleus) surrounded by planets (the electrons). The number of electrons orbiting the nucleus determines the property of the atom. The simplest atom is hydrogen which has only one electron, whilst copper has twenty-nine electrons surrounding it's nucleus.

Each electron carries a negative charge of electricity and this negative charge is balanced by an equal and opposite positive charge on the nucleus. The atom, as a whole is electrically neutral.

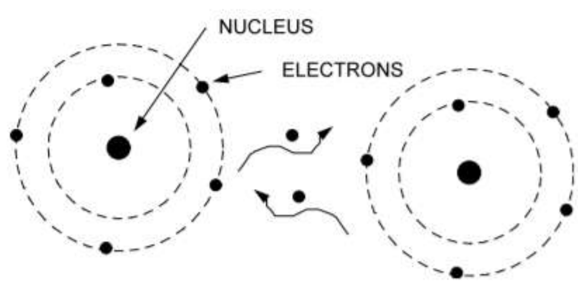


Fig 1.29: Atom

Atoms and Electrons

The electrons are able to move from atom to atom due to energy that they absorb in the form of heat. This movement can be considered as being random.

ELECTRICAL PRINCIPLES

Electrical Units

Voltage

Voltage can be described as the driving force or pressure behind electricity. The physical term electromotive force (emf) is used to describe this quantity although the term is not used generally. Voltage is measured in volts and is often the fixed quantity in an electrical system. The voltage is the supply of energy to a circuit and consequently is supplied from a number of sources. A DC system will have a fixed DC voltage supplied from say a battery or DC Power Supply Unit. An AC system will have its AC supply typically from the mains or on occasions a local generator.

Current

Current is the flow of electrons that arises from applying a voltage to a circuit. Current is measured in amps (amperes). A flow of 1 amp is approximately six million, million, million electrons flowing per second. Current will flow when a voltage is applied and there is a complete circuit (or path). The total current flowing in a circuit will be determined by the resistance.

Power

Power is the rate at which energy is delivered or consumed and is measured in Watts. In most cases the conversion of energy is not 100% efficient and a proportion of the input power appears as wanted output. The total wanted power at the output compared to the input is indicated by the efficiency of the system.

$$\text{Efficiency} = \frac{\text{Power Input}}{\text{Power Output}} \times 100\%$$

Another form of energy is always produced as a byproduct. Most commonly this by product is heat and it is often necessary to find ways of disposing of this heat by providing extra methods of cooling by having fins or fans. Failure to dispose of this heat can cause the equipment to overheat with serious consequences. It is important to understand how a piece of equipment is cooled and any factor that hinders this process can result in damage.

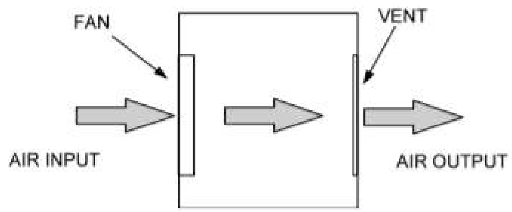


Fig 1.30: Air cooling

Restricting the throughput of air can affect the cooling and result in overheating. Power is lost through resistance as this causes heat. Conductors possess resistance and this generates heat and results in a power loss.
For example, a loud speaker coil possesses resistance. This resistance is not needed in the process of converting electrical power to sound power but will produce heat. This heat will need to be dissipated to protect the speaker from overheating.

Magnetism
An electric current passing through a conductor produces a magnetic field around that conductor. The polarity and intensity of the magnetic field is dependent on the direction and size of current respectively. Motors make use of the magnetic effects to create forces between magnetic fields that in turn create motion.

Resistance
Resistance is determined, amongst other things, by the material where all materials have a property called resistivity. This property depends upon the ability of electrons in that material to be able to leave their orbits around the nucleus and contribute to current flow.
Materials where this can happen easily will be referred to as conductors whereas materials where this cannot happen easily will be referred to as non-conductors or insulators.
Resistivity is measured in Ohms / meter.

Conductors
In a conductor the electrons are not firmly attached to the nucleus and are normally interchanging between atoms in a random manner. They can easily leave their orbit when an external potential is applied and so will cause current to flow. A conductor is classified as a material in which there will easily be current flow i.e., one that possesses a low resistivity.
Examples: silver, copper, aluminum,

Insulators
In an insulator the electrons are firmly attached to the nucleus and will not be moved from their orbit when an external potential is applied. The interchange of electrons will not take place and consequently there will be no current flow. An insulator is defined as material that will not pass current and will have a high value of resistivity. (rubber, PVC, porcelain…)

Energy

Energy is the capacity of an object or a system to do work and is measured in Joules. Energy can neither be created nor destroyed but can be converted from one source to another.

Example:

A lamp converts electrical energy into light energy.
A motor converts electrical energy into mechanical energy
A battery converts chemical energy into electrical energy

The potential energy of water in a highland reservoir is converted into kinetic energy as the water flows down the inlet tube where it is converted into electrical energy by a generator driven from a turbine.

ELECTRICAL CIRCUITS

Series Circuits

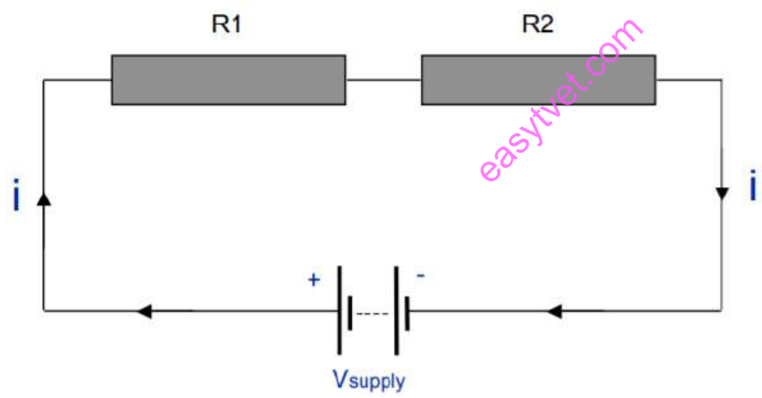


Fig 1.31: Series Circuit

Consider a circuit where two items are connected together in such a way that the current path is through both components. There are two basic features

- the same current will flow through both component
- there will be volt drops across both components

Voltage Law in closed circuit:
The sum of the voltage drops around the circuit will add up to the supply voltage, i.e., there is no voltage lost.

This circuit is a Series Circuit where the total resistance is given by

R(total) = R1 + R2

General expression:

The total resistance in a series circuit is the sum of all the individual resistances

$$R(total) = R1 + R2 + R3 + ...$$

Examples

1. Three resistances of 10Ω, 25Ω and 35Ω are connected in series.

   The total resistance will be

   10Ω + 25Ω + 35Ω = 70Ω

2. A cable of total resistance 0.3Ω is joined to a cable with resistance 0.15Ω.
   The total cable resistance will be

   0.3Ω + 0.15Ω = 0.45Ω

Parallel circuits

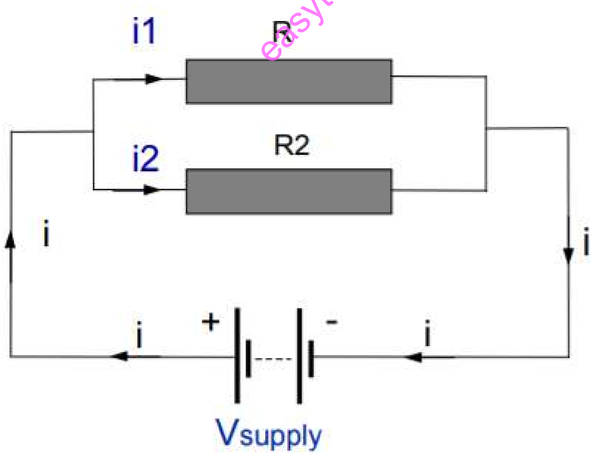


Fig 1.32: Parallel Circuit

Now consider a circuit where two resistances are connected such that they are both connected to the same supply. There are two basic features

- each component will have the same voltage across it
- the current drawn from the supply will split with a proportion of the current flowing through R1 and the remainder flowing through R2.

The current through either resistance can be expressed as

$$I = \frac{\text{Voltage}}{\text{Resistance}}$$

The total current drawn from the supply will be the sum of the currents through the two resistances.

From this it can be appreciated that the current drawn by two resistances connected in parallel would be more that the current drawn by one resistance. If the two resistances were the same value then the current drawn from the supply would be twice the value compared to one resistance.

General expression:

The reciprocal of the total resistance is equal to the sum of the reciprocals of each parallel resistance

$$\frac{1}{R(\text{total})} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \ldots$$

When there are only two resistances, there is an alternative although easier to use formula

$$\text{TOTAL RESISTANCE} = \frac{\text{Product}}{\text{Sum}}$$

$$R\ (\text{total}) = \frac{R1 \times R2}{R1 + R2}$$

Example

1. Two equal resistances of 10Ω are connected in parallel.

   The total resistance will be calculated by

   $$\frac{\text{Product}}{\text{Sum}} = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5\Omega$$

   Note that when the two resistances are equal the resistance is halved.

2. Two resistances of 20Ω and 30Ω are connected in parallel.

The total resistance is given by

$$\frac{\text{Product}}{\text{Sum}} = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12\Omega$$

Series-parallel circuits

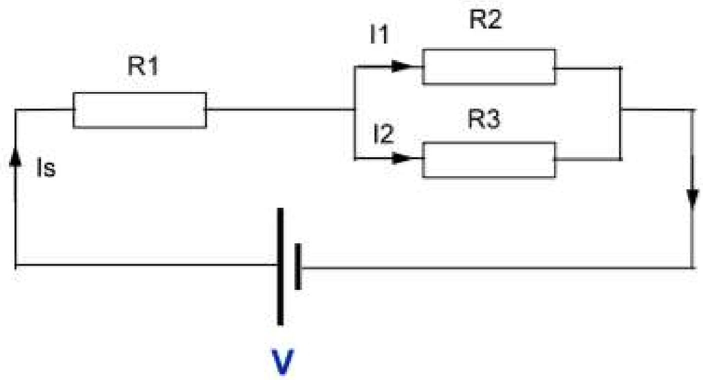
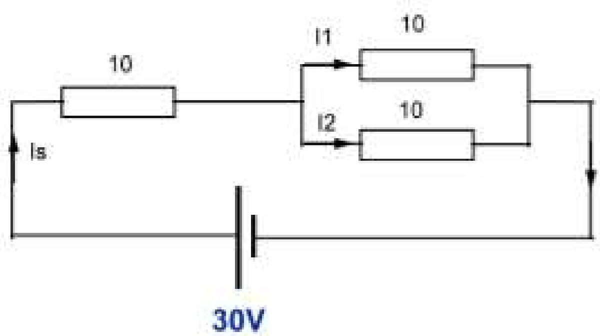


Fig 1.33: Series - Parallel Circuit

A series parallel arrangement consists of a mixture of series and parallel circuits.

It can be seen that the circuit consists of a series resistance in series with a parallel network. This circuit could be analyzed by calculating the parallel resistance first (R2 in parallel with R3) and then considering this in series with the series resistor(R1).

Example:



Total resistance is given by
10 Ω in parallel with 10 Ω

$$\frac{\text{Product}}{\text{Sum}} = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5\Omega$$

This value is in series with 10Ω
Total circuit resistance is therefore 10Ω + 5Ω = 15Ω

Circuit Current $= \frac{30V}{15\Omega} = 2A$

ELECTRICAL SAFETY

The Dangers of Electricity

Most people think of electricity as being dangerous by virtue of its ability to produce electric shock. However, there are many other dangers which include

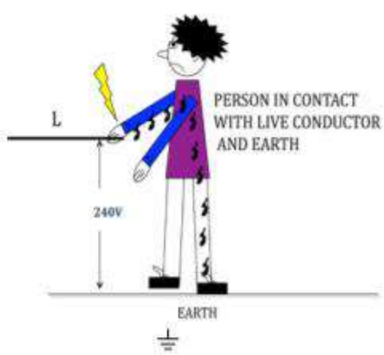
a. Electric shock
b. Electric burn
c. Fires of electrical origin
d. Electric arcing
e. Explosions started or caused by electricity

1. Electric Shock

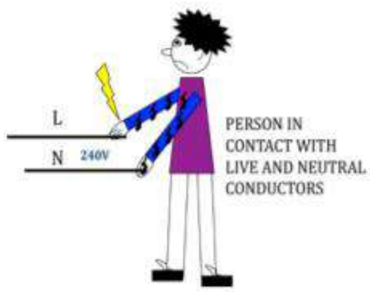
Electric shock is the effect on the nervous system of passing electricity through the human body. The current affects the normal control of the body muscles and the effects of this vary from a mild tingling sensation to death.

Causes of Electric Shock

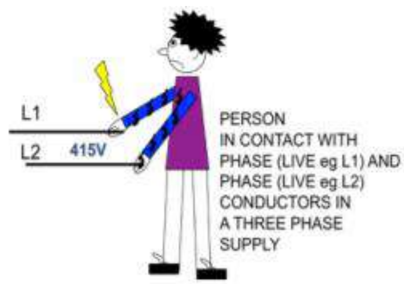
- Contact between the live conductor and earth



- Contact between Live and Neutral in a single or three phase supply



- Contact between Live and Live in a Three Phase Supply



2. Electric Burns

Electricity passing through any resistance liberates heat energy. The element of an electric fire for example has resistance to the flow of current and heats up as a consequence. In the same way, human tissue resists the flow of electric current and the heat liberated causes burns. Such burns are commonly associated with electric shock and often occur at the point of contact with the source of electricity.

In certain circumstances it is possible to suffer electrical burns without being in contact with an electrical source. High powered radio transmitters and microwave ovens, for example, can produce electrical burns due to high frequency electromagnetic waves.

3. Electrical Explosion

This literally means blowing a piece of electrical equipment apart due to electrical overload. A 12V car headlight, for example, will explode if mains voltage is connected across it.

4. Explosion Initiated by Electricity

Certain vapors, gases and fine dusts may explode if triggered by even tiny electric sparks. Examples are petrol, ether, methane, flour dust and talcum powder.

5. Arcing

The air is normally a good insulator, but under certain circumstances this insulation is broken down and sparks jump across air gaps. This is known as arcing. The most spectacular arcing is lightning, but you can see the effect quite clearly when you connect up a car battery. Arcing has its own particular dangers

a. electrical burns
b. ultra violet radiation - this gives symptoms similar to that of sunburn. The radiation from an arc welder can be particularly dangerous to the eyes.
c. infra-red heat or heat radiation - this will burn in the same way as putting your hand close to an electric fire
d. burns due to molten metal particles which often accompany arcing

6. Fire Caused by Electricity

Fires present a number of dangers. The most obvious is burning. But smoke or toxic fume inhalation is at least as dangerous. The main causes of fire are

a. overheating of cables and electrical equipment due to the passage of too much current
b. current leaking due to poor or inadequate insulation
c. overheating of inflammable materials placed too close to electrical equipment
d. the ignition of flammable materials by arcing, sparking or the scattering of hot particles from electrical equipment

Action in the Event of Electric Shock

Break contact with the supply by switching off, removing plug or by wrenching cable free. If this should not be possible, stand on some insulating material, such as dry wood or rubber and break contact by pushing the casualty free. In a place of work a First Aider should be summoned in the event of a person suffering from electric shock.

<u>Treatment for Electric Shock</u>

Reference should be made to an appropriate First Aid manual

- St Johns Ambulance
- St Andrews Ambulance Association
- The British Red Cross Society

Slight Shock

- Reassure the casualty and make them comfortable
- If in doubt refer to a medical practitioner
- Report the accident to the appropriate personnel

Burns

- Cool the tissue with cold water or other non-flammable fluid close to hand
- Remove any smoldering clothing. Clothing that has caught fire but has cooled need not be removed
- Remove anything of a constrictive nature; rings, bangles, belts and boots
- Reassure the casualty

- Dress wounds to prevent infection
- Give sips of fluid to the casualty if conscious
- If the casualty is severely burned arrange for them to be taken to hospital without delay
- Report the accident to the appropriate personnel

Abrasions

- Clean and dress the wound to prevent further infection
- Reassure the casualty
- Arrange for medical help if necessary
- Report the accident to the appropriate personnel

Casualty Unconscious but breathing

- Loosen clothing about the neck, chest, and waist and place casualty in the recovery position
- Keep a constant check on breathing and pulse
- Arrange for medical help if necessary
- Report the accident to the appropriate personnel

Safe Working Practices

Introduction

Death or injury can occur if you work on a piece of electrical equipment and you;

- are not adequately trained in the dangers of working on such equipment
- do not have the necessary knowledge of electricity and the equipment being worked on
- are careless and negligent
- do not observe safety precautions

Remember that you do not only endanger yourself but also others. Causing death or suffering to others can not only be traumatic but could also have severe legal implications as a result of a breach of health and safety law.

Making tests on live equipment

This is a hazardous situation that could result in a fatality. Remember if you can make an equivalent test with the circuit dead that method should be used in preference to a live circuit test.

Before making any tests on a live circuit you must:

- Be aware of all the voltages that you can encounter whilst working on a system.
- Be aware of the voltages that may be generated within a circuit that may be higher then an incoming supply voltage

- At all times you must be fully alert to the parts that you are touching
- Ensure that any tools and equipment that you use are in good working condition and of the correct type and standard for the task being undertaken
- If it is appropriate disconnect power, connect the test instrument in such a way that it can be operated hands free. Power can be reconnected and the instrument read without contact. Before removing the instrument disconnect the power.
- If a circuit is interrupted to make a test ensure that it is reconnected correctly
- Always ensure that earths are connected

Electrical Isolation

The way in which the electrical supply is connected to the equipment will affect the certainty of whether the supply is disconnected. Equipment fed from a connector such as plug can easily be observed as being disconnected and there ought to be little doubt that the equipment being worked on is disconnected from the supply. Switchable isolators can sometimes be difficult to locate or identify. These isolators should be easily accessible and clearly marked indicating the equipment to which it relates.

Isolation

The term isolation is defined here as disconnecting the supply and ensuring that it stays disconnected for the duration of the work being carried out. This is clearly to prevent inadvertent switching on of the supply at a time when the person working on the equipment is not aware.

Precautions should be taken to prevent this reconnection of the supply during this time. Such precautions could include the use of lockable isolators which can be locked in the 'off' position. The person working on the equipment uses a padlock to lock the supply off and they hold the key to that padlock. In some instances where several people are working on equipment, the use of clasps that allow the padlocks of all those working to be fitted is good practice.

Stored Energy

In some cases, electrical energy will be stored within the equipment even when the electrical supply has been isolated.

In the case where energy will be stored within a system there should be

- warning labels indicating this and
- an automatic means for this to be discharged when the power is removed

Working on equipment made dead

Whenever work is to be carried out the requires the assembly or disassembly of electrical equipment that equipment must be disconnected from its source of supply.

The person carrying out the work has to be absolutely sure that the supply has been disconnected and the equipment is dead. Extra tests should be carried out if there can be any doubt which may include

- observing for signs of the equipment being active,
- operating controls on the equipment
- testing with an appropriate test instrument.

If the person carrying out this work has any doubt over the state of the equipment assistance and clarification must be sought.

Replacing faulty items

- Power should always be removed before any part is disconnected
- identify the method of isolating a machine from its supply
- Adequate precautions should be taken to ensure that the supply cannot inadvertently be reconnected
- Be aware of any voltages that will remain in a circuit when the mains power is removed
- Note connections before they are removed
- Note any damage to cables or other components
- When power is reconnected observe for any signs of a problem
    - ✓ Smoking
    - ✓ Sparking
    - ✓ Malfunction of machine

Earthing

The earth connection should be very securely made ensuring that solid contact is made with bare metal. It may well be necessary to ensure that any paint has been removed to enhance this contact. If for any reason this connection is removed it should be replaced before the equipment is turned on.

1.2.8.4 Learning Activities

Activity 1

Given a circuit, use loops to obtain equations which will be solved to determine unknown currents, for example current supplied by generator, current through battery A and B.

Activity 2

Build circuits on breadboard, the electrical quantities should be measured and compared with calculated values using Ohm's and Kirchhoff's laws.

1.2.8.5 Self-Assessment

1. What is current? (1 mark)
    a. flow of electrons

b. amount of energy
c. power in a circuit
d. electrical force

2. Resistance is measured in (1 mark)
    a. amps
    b. volts
    c. watts
    d. ohms

3. which of the following best defines power? (1 mark)
    a. the flow of current
    b. measured in joules
    c. the rate of energy dissipation
    d. the amount of current

4. What is the lowest level of current that could be fatal? (1 mark)
    a. 1A
    b. 10A
    c. 100mA
    d. 0.5A

5. What is electrical Isolation? (1 mark)
    a. turning off an electrical supply
    b. turning off an electrical supply and ensuring that is stays off
    c. unplugging equipment
    d. switching off an isolator

6. When working on an equipment made dead for the purpose of work being carried out which of the following is not appropriate as a safe working practice (1 mark)
    a. ensure that you are earthed
    b. test the supply with a meter
    c. look for signs of the equipment being live
    d. operate controls

7. What is the purpose of earthing? (1 mark)
    a. to provide a safe current path
    b. to trip a circuit breaker
    c. to ensure touchable conducting surfaces cannot become live
    d. to provide a return path for current

8. Electric Shock is current flowing through the body (1 mark)

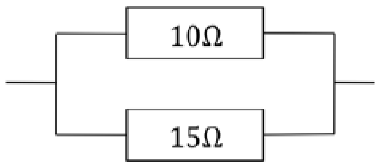
a. True
b. False

9. What are some of the dangers associated with electricity? (5 marks)

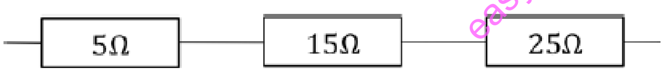
10. What is your understanding of the following terms? (6 marks)
    i. Magnetism
    ii. Resistance
    iii. Conductors

11. How would you take care of an individual suffering from severe burns? (6 marks)

12. Calculate the total resistance of the resistor network (3 mark)



13. Calculate the total resistance of the resistor network below (3 mark)



1.2.8.6 Tools, Equipment, Supplies and Materials

Tools and equipment

- Laboratory testing equipment
- Laboratory apparatus
- Hand tools
- Machine tools

Materials and supplies

- Stationery
- Material samples
- Oils
- Pins
- Electrical cables and accessory

Personal protective equipment (PPEs)

- Safety boots
- Gloves
- Dust coats
- First aid kit
- Ear muffs
- Dust masks
- Overalls
- Helmet
- Goggles

1.2.8.7 References

J.O Bird., Electrical principles & Technology for engineering., 1995., 1st Edition

Brian Tinson.,Basic Electrical Principles., 2011.

Model Answers

1. What is current? (1 mark)
    - **a. flow of electrons**
    - b. amount of energy
    - c. power in a circuit
    - d. electrical force

2. Resistance is measured in (1 mark)
    - a. amps
    - b. volts
    - c. watts
    - **d. ohms**

3. which of the following best defines power? (1 mark)
    - a. the flow of current
    - b. measured in joules
    - **c. the rate of energy dissipation**
    - d. the amount of current

4. What is the lowest level of current that could be fatal? (1 mark)
    - a. 1A
    - b. 10A
    - **c. 100mA**
    - d. 0.5A

5. What is electrical Isolation? (1 mark)
    - a. turning off an electrical supply
    - **b. turning off an electrical supply and ensuring that is stays off**
    - c. unplugging equipment
    - d. switching off an isolator

6. When working on an equipment made dead for the purpose of work being carried out which of the following is not appropriate as a safe working practice (1 mark)
    - **a. ensure that you are earthed**
    - b. test the supply with a meter
    - c. look for signs of the equipment being live
    - d. operate controls

7. What is the purpose of earthing? (1 mark)
    - a. to provide a safe current path
    - b. to trip a circuit breaker
    - **c. to ensure touchable conducting surfaces cannot become live**

d. to provide a return path for current

8. Electric Shock is current flowing through the body (1 mark)
   a. True
   b. False
9. What are some of the dangers associated with electricity? (5 marks)
   - Electric shock
   - Electric burn
   - Fires of electrical origin
   - Electric arcing
   - Explosions started or caused by electricity

10. What is your understanding of the following terms? (6 marks)

e. Magnetism

An electric current passing through a conductor produces a magnetic field around that conductor. The polarity and intensity of the magnetic field is dependent on the direction and size of current respectively. Motors make use of the magnetic effects to create forces between magnetic fields that in turn create motion.

ii. Resistance

Resistance is determined, amongst other things, by the material where all materials have a property called resistivity. This property depends upon the ability of electrons in that material to be able to leave their orbits around the nucleus and contribute to current flow. Materials where this can happen easily will be referred to as conductors whereas materials where this cannot happen easily will be referred to as non-conductors or insulators.

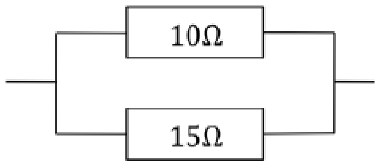
iii. Conductors

In a conductor the electrons are not firmly attached to the nucleus and are normally interchanging between atoms in a random manner. They can easily leave their orbit when an external potential is applied and so will cause current to flow. A conductor is classified as a material in which there will easily be current flow i.e., one that possesses a low resistivity.

11. How would you take care of an individual suffering from severe burns? (6 marks)
    - Cool the tissue with cold water or other non-flammable fluid close to hand
    - Remove any smoldering clothing. Clothing that has caught fire but has cooled need not be removed
    - Remove anything of a constrictive nature; rings, bangles, belts and boots
    - Reassure the casualty
    - Dress wounds to prevent infection

- Give sips of fluid to the casualty if conscious
- If the casualty is severely burned arrange for them to be taken to hospital without delay
- Report the accident to the appropriate personnel

12. Calculate the total resistance of the resistor network (3 mark)



Answer is 6 Ω

13. Calculate the total resistance of the resistor network below (3 mark)

Answer is 45Ω