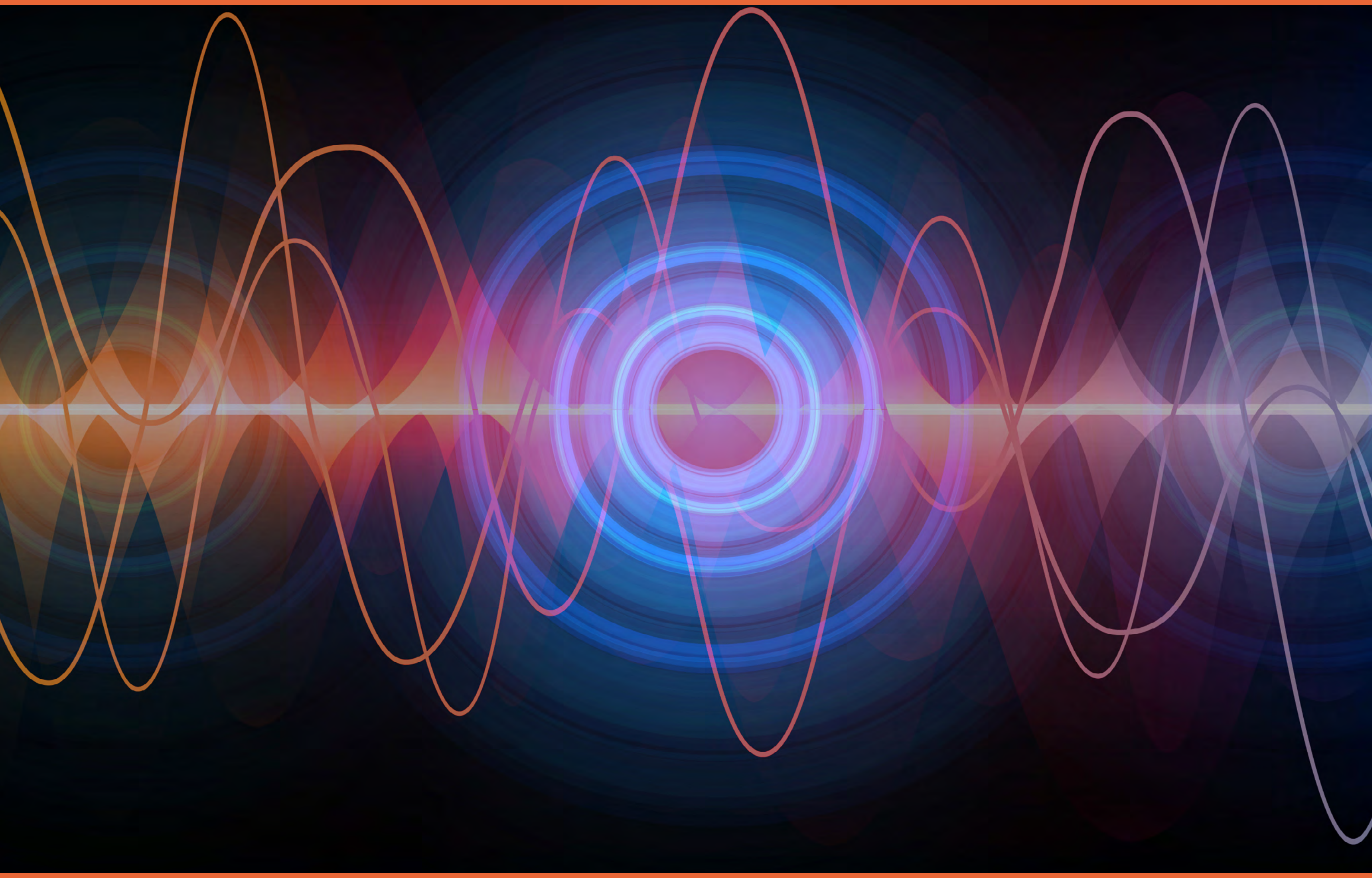
MINISTRY OF EDUCATION
GHANA ASSOCATION OF
SCIENCE TEACHERS

Physics

for Senior High Schools

Year 2



• Baba Issah • Henry Benyah
• Sylvester Affram • Yange Kwabena Clifford

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PHYSICS

For Senior High Schools

2

Baba Issah
Henry Benyah
Sylvester Affram
Yange Kwabena Clifford

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FOREWORD

Ghana's new Senior High School Curriculum aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, knowledge, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, progress to further studies and enter the world of work. This is the first time that Ghana has developed a Senior High School Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

The Ministry of Education is proud to have overseen the production of these Learner Materials which can be used in class and for self-study and revision. These materials have been developed through a partnership between the Ghana Education Service, teacher unions (Ghana National Association of Teachers-GNAT, National Association of Graduate Teacher -NAGRAT and the Coalition of Concerned Teachers- CCT) and National Subject Associations. These materials are informative and of high quality because they have been written by teachers for teachers with the expert backing of each subject association.

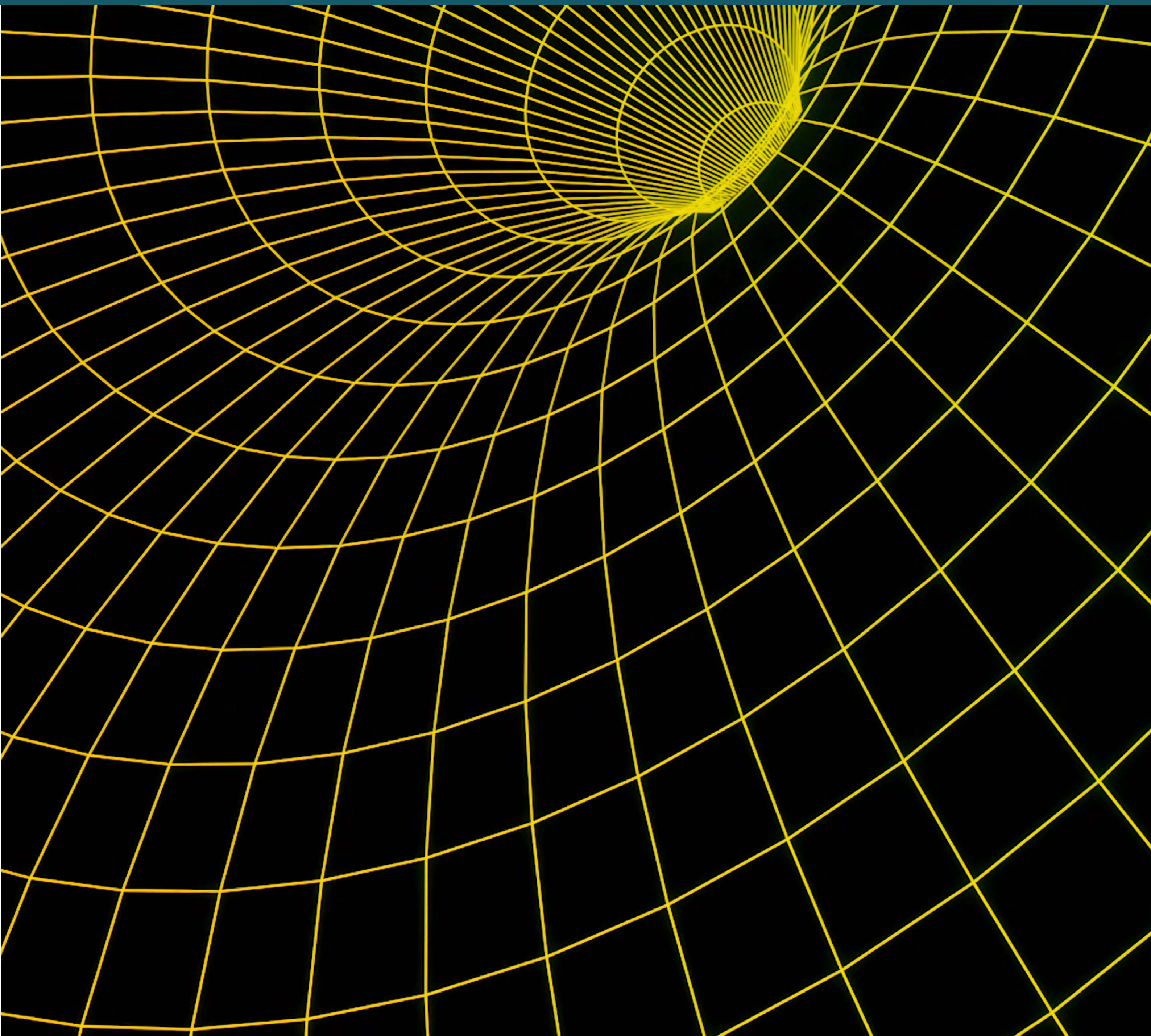
I believe that, if used appropriately, these materials will go a long way to transforming our Senior High Schools and developing Ghana so that we become a proud, prosperous and values-driven nation where our people are our greatest national asset.

Haruna Iddrisu MP

Minister for Education

SECTION 1

DIMENSION, VECTORS, FLOTATION AND DEFORMATION



MECHANICS AND MATTER

Basic Physics

INTRODUCTION

In this section, you will learn how dimensional analysis helps us create and verify equations, deepening your understanding of the relationships between physical quantities and enhancing your problem-solving skills.

You will also apply basic mathematical concepts, such as trigonometric ratios and the Pythagorean Theorem, to find resultants and break down vectors into components, making it easier to determine the overall effect of multiple forces on systems or structures.

We will explore the concept of floating force (buoyancy) and density to understand why some objects float while others sink. Additionally, you will study how materials behave, focusing on their ability to return to their original shape after being stretched, compressed, or deformed (elasticity), how stiff or resistant they are to stretching (Young's modulus), and the maximum force or stress they can handle before breaking (breaking stress). These concepts are essential for understanding how materials respond to forces in engineering and everyday applications.

KEY IDEAS

- Dimensional analysis is essential for validating and deriving the relationships between different quantities in physics.
- The understanding of vectors is essential for determining the components of forces as well as determining the overall effect of multiple forces on objects and systems.
- **Archimedes' Principle**: When a body is wholly or partially immersed in a fluid, it experiences an upward force (upthrust) which is equal to the weight of fluid displaced.
- **Principle of flotation**: A floating body displaces its own weight in the fluid in which it floats.

- Elastic deformation is a type of deformation in which the body regains its shape and size after the applied force is removed, while plastic deformation is a type of deformation in which the body does not regain its shape and size after the applied force is removed.
- **Hooke's law:** Provided the elastic limit is not exceeded, the extension in an elastic material is proportional to the load or applied force.
- Whilst the stiffness constant of a spring or piece of wire is dependent on its physical dimensions, the **Young's Modulus** is not. It is the ratio of the stress (force per unit area) on a material to the stress (extension per unit length) on that material.

DIMENSIONAL ANALYSIS

Dimensional analysis is the study of the relationship between physical quantities by consideration of their dimensions. In Year One, the concept of dimensions was introduced, focusing on how to determine the dimensions of various physical quantities and how to derive their units based on these dimensions.

Understanding the dimensions of quantities is crucial not only for identifying their respective units but also for validating equations in physics. By using dimensional analysis, it becomes possible to check whether an equation is dimensionally consistent (the dimensions are the same on both sides of the equation), which serves as a preliminary verification step before delving into more complex mathematical proofs.

Additionally, dimensional analysis can aid in deriving relationships between different physical quantities. For instance, if it is assumed that the acceleration of an object is the only factor which determines the resultant force acting on it, we find that the dimensions do not match:

$F \propto a$

$F = ka$

$[MLT^{-2}] \neq [LT^{-2}]$

Furthermore, by analysing the difference between the dimensions on each side of the equation, we can see that resultant force must also be dependent on mass. Therefore,

$F \propto ma$

F = kma

We can find experimentally that k=1, and so,

F = ma

Activity 1.1 Recalling the Dimensions

List the 7 fundamental quantities, including their symbols, which you met in Year One

1.

2.

3.

4.

5.

6.

7.

Activity 1.2 Checking Validity Using Dimensions

1. First, you should read through the worked example given below. If you are unclear about any of the steps in the solution, ensure that you ask your teacher or discuss with a peer!
2. Next, try the practice questions which follow independently.

Worked example

The initial and final velocities of a moving object are u and v, respectively. If the acceleration of the object is a and the time of motion is t, check whether the expression, $v = u + at$ is dimensionally correct.

Solution

Step 1: Identify the Physical Quantities and Their Dimensions

a. Final velocity (v): LT^{-1}
b. Initial velocity (u): LT^{-1}

c. Acceleration (a): LT^{-2}

d. Time (t): T

Step 2: Write the Equation in Dimensional Form

[v] = [u] + [a] × [t]

Step 3: Substitute the Dimensions and Simplify

a. Left-hand side:
$[v] = LT^{-1}$

b. Right-hand side: $[u] = LT^{-1}$, and $[a \times t]$
$= LT^{-2} \times T = LT^{-1}$
Thus, the right-hand side becomes:
$[u] + [a \times t]$
$= LT^{-1} + LT^{-1} = 2LT^{-1}$
But figures are dimensionless constant, therefore $[u] + [a \times t] = LT^{-1}$

Step 4: Compare Both Sides and Conclude

Both sides of the equation have the same dimensions: LT^{-1}

Since both sides of the equation have the same dimensions, the equation is dimensionally consistent.

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

Consider the equation of motion given by $s = ut + \frac{1}{2}at^2$(where s is the displacement, u is the initial velocity, a is the acceleration, t is the time). Using dimensional analysis, check whether the given equation is dimensionally correct.

Suppose an equation is proposed: $d = v^2 t$ (where d is distance, v is velocity, and t is time). Check if this equation is valid by analysing its dimensions.

Activity 1.3 Checking Validity and Establishing Quantities Using Dimensions

1. First, you should read through the worked example given below. If you are unclear about any of the steps in the solution, ensure that you ask your teacher or discuss with a peer!
2. Next, try the practice questions which follow independently.

Worked example

It is known that the time period depends only on the length l of the pendulum and the acceleration due to gravity g. Using dimensional analysis, derive the formula for the time period T.

Solution

Step 1: Assume a relation between the physical quantities (T, L, and g)

Assume that the time period T is related to L and g as:

$$T \propto l^a g^b$$

then introduce a constant of proportionality k

$$T = k l^a g^b$$

where k is a dimensionless constant, and a and b are unknown powers we need to find using dimensional analysis.

Step 2: Identify the dimensions of physical quantities

- **a.** Period (T): T
- **b.** Length (l): L
- **c.** Gravitational acceleration (g): LT^{-2}

Step 3: Write dimensions for both sides of the equation and apply your knowledge in indices

Using the assumed relation, write down the dimensions of both sides of the equation.

$$T = L^a (LT^{-2})^b$$

$$T = L^a L^b T^{-2b}$$

$$T = L^{a+b} T^{-2b}$$

Step 4: Equate the dimensions of both sides

Now, compare the dimensions of both sides of the equation.

- **a.** Left-hand side is $[T] = T$.
- **b.** Right-hand side is $L^{\{a+b\}} T^{\{-2b\}}$.

For dimensional consistency, the dimensions of both sides must be the same.

Equate the powers of L on both sides of the equation (note: L does not appear on the left-hand side of the equation, and so the power of
L = 0 on this side): a + b = 0

Equate the powers of T on both sides of the equation: -2b = 1

Step 5: Solve the system of equations

From -2b = 1, we get:
$b = -\frac{1}{2}$

Substituting $b = -\frac{1}{2}$ into a + b = 0:
$a - \frac{1}{2} = 0 => a = \frac{1}{2}.$

Step 6: Write the final equation

Now substitute $a = \frac{1}{2}$ and $b = -\frac{1}{2}$ into the assumed relation:
$T = k\,L^{\{\frac{1}{2}\}}\,g^{\{-\frac{1}{2}\}}.$
This simplifies to:
$T = k\,\sqrt{\frac{L}{g}}$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

Derive the equation for the time taken t for an object to fall from a height h under gravity g using dimensional analysis. Assume that no other factors exist after that time.

For further information and details about the application of dimensional analysis, visit the video link below:

https://www.youtube.com/watch?v=sk9BUMBK6hU

Activity 1.4 Discussion on the importance of Dimensions

Objective: To understand the importance of dimensional analysis in everyday life.

Materials needed

1. Textbook or reference material
2. Internet
3. Worksheet

What to do

1. Identify a friend or friends to form a small learner group.
2. Work in groups or pairs to research and discuss real-world examples where dimensional analysis is used.
3. Engage in group discussions with the following discussion prompts:
   a. Can you think of a time when you have used dimensional analysis in your everyday life, even without realising it?
   b. How can dimensional analysis help prevent errors in calculations and measurements?
   c. What are the potential consequences of using incorrect units or formulas?
   d. Can dimensional analysis be applied to other areas of life besides science and engineering? If so, how?
4. Each group should appoint one member to summarise and record the answers from the discussions.
5. After the discussions, each group should share one key point from their discussion with the class or peers.

See Annex A for the solutions to some activities on dimensional analysis

VECTORS

Vectors are a class of physical quantities that, if we look carefully, we can identify numerous examples of in our day-to-day lives. What makes them special is that they have both **magnitude and direction**, unlike their counterparts (scalars), which have only **magnitude**.

For example, when a mango fruit falls from the tree, it travels downward due to its weight.

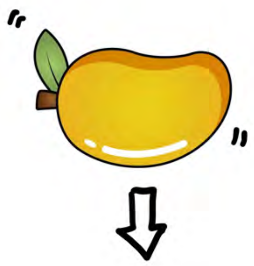
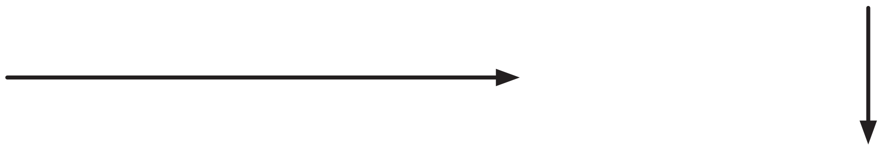


Figure 1.1: A mango falling under gravity

Weight, a type of force, is therefore an example of a vector as it has both a magnitude and a direction (in this case, downward). Other examples of vectors are momentum, velocity, acceleration, etc.

A vector is typically represented with a straight line bearing and an arrow. The length of the line signifies the magnitude of the vector, while the arrow indicates the direction of the vector. If the two vector arrows shown in **Figure 1.2** represent the same quantity (e.g. both represent velocities), vector (**A**) is a larger velocity than vector (**B**).



(A). A vector acting in a horizontal direction   (B). A vector acting in a vertical direction

Figure 1.2: Vectors acting in horizontal and vertical directions

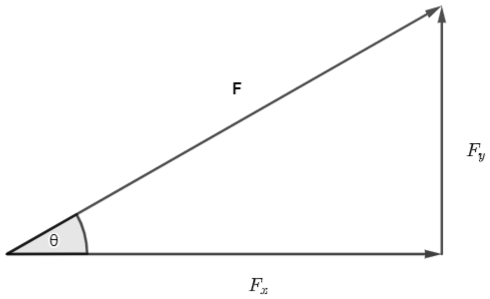
Activity 1.5 Drawing vectors using scale diagrams

Using a scale of 1N = 1cm, draw the following force vectors:

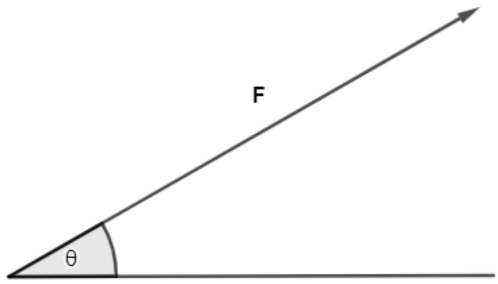
1. 5N acting horizontally to the left
2. 7.5N acting horizontally to the right
3. 4N acting at an angle of 35 degrees clockwise from vertically upwards.

Resolving Vectors

Vectors do not always act in the horizontal or vertical directions. When a vector acts at an angle less than 90° to the horizontal, it is said to be inclined. For example, when you kick a football over a wall, the force exerted by your foot on the ball acts in a line inclined to the ground. An inclined vector has both horizontal and vertical **components** (i.e. a component which acts to move the ball horizontally and a component which lifts the ball into the air vertically).



(A) An inclined vector



(B) an inclined vector with both horizontal and vector components shown

Figure 1.3: Inclined vectors

Resolving an inclined vector into two components

Simple trigonometric functions can be used to find the two components of a vector acting at an angle to the horizontal or at an angle to an inclined plane.

Consider the diagrams in **Figure 1.3 (B).** If the magnitude of the vector F is 20 N and the angle of incline is 30 degrees, then we can use the sin and cos functions on the calculator to find Fx and Fy :

Hypothenuse = F = 20 N

Opposite = Fy

Adjacent = Fx

$\theta = 30$ degrees

$\sin\theta = \frac{opp}{hyp}$

Therefore:

$$\begin{aligned} \text{opposite} &= \text{hypothenuse} \times \sin\theta \\ &= 20 \sin 30 \\ &= 10 \text{ N} \end{aligned}$$

$\cos\theta = \frac{adj}{hyp}$

Therefore:

$$\begin{aligned} \text{adjacent} &= \text{hypothenuse} \times \cos\theta \\ &= 20 \cos 30 \\ &= 17.3 \text{ N} \end{aligned}$$

Hence, the vertical component of F, Fy, is 10 N and the horizontal component of F, Fx is 17.3 N.

Finding the resultant of two perpendicular vectors

When two vectors act perpendicular to each other at a point, we might want to know the direction and magnitude of the single vector resulting from their action. For example, if you walk 100 m due East and 50 m due north, what would be the single displacement joining your origin and destination? That is your resultant displacement.

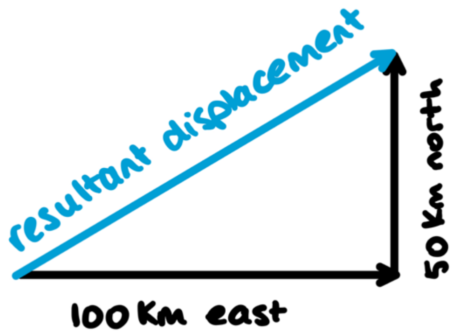
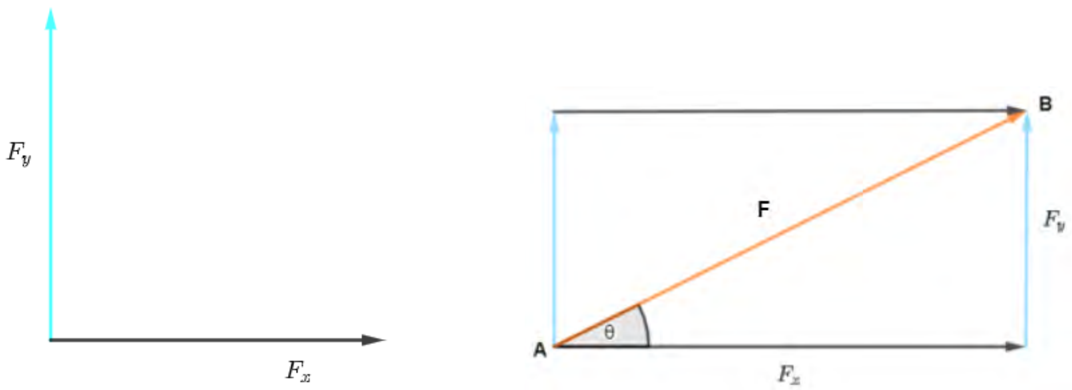


Figure 1.4: The resultant displacement after both horizontal and vertical motion

When two forces act on the same object, which can be treated as a single point, simultaneously, we can draw a free-body diagram as shown in **Figure 1.5 (A)**. The diagram can then be re-drawn, with the vector arrows places top-to-tail, as shown in **Figure 1.5 (B)**.



(A) Two perpendicular vectors F_y and F_x (B) F_x and F_y have a resultant F

Figure 1.5: Perpendicular vectors

To determine the resultant of any two perpendicular vectors, as in **Figure 1.5 (A)**. Re-draw the vector arrows top-to-tail as shown in **Figure 1.5 (B).**

Draw a diagonal from the original meeting point (**A**) of the vectors to the meeting point (**B**) of the duplicate vectors**.**

Applying the Pythagorean theorem, the magnitude of $F = \sqrt{F_x^2 + F_y^2}$

Determine the direction of the vector as $\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$

Activity 1.6 Finding the resultant displacement of an object

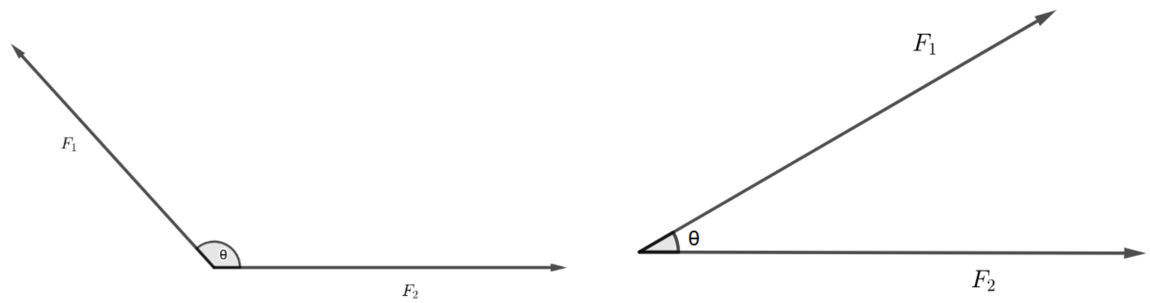
Use the diagram in **Figure 1.4** to determine

1. the resultant displacement
2. the direction of the resultant displacement of the object, which has travelled 100km east and then 50km north.

Finding the resultant of non-perpendicular vectors

Sometimes, vectors act at angles less than or greater than 90° to one another. In such cases, we use different methods to determine the magnitude and direction of their resultants.

Look at the vector diagrams below. Imagine two trucks using tow ropes to pull a boulder in the direction of F_1 and F_2, respectively. For each situation, a and b, we can determine which direction the boulder will move in and with how much resultant force.



a) $\theta < 90°$ *between* F_1 *and* F_2 *b)* $\theta > 90°$ *between* F_1 *and* F_2

Figure 1.6: Two non-perpendicular vectors

To determine the resultant of such vectors

1. Redraw the vector arrows top-to-tail to form a parallelogram (see **Figure 1.7** below).
2. Draw a diagonal from their origin to the other vertex of the parallelogram. This is the resultant vector.

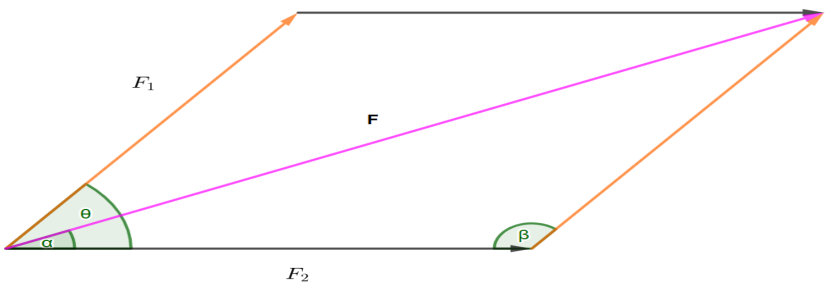


Figure 1.7: Resultant of two non-perpendicular vectors using the parallelogram law of vector addition

F is the resultant, making the angle α with the horizontal

3. To calculate the magnitude of the resultant, apply the cosine rule (see more in **Annex B – Further Information**):

   $F = \sqrt{F_1^2 + F_2^2 + 2(F_1 \times F_2)\cos\theta}$ or

   $F = \sqrt{F_1^2 + F_2^2 - 2(F_1 \times F_2)\cos\beta}$, where $\boldsymbol{\beta = 180 - \theta}$

4. Calculate the angle of the resultant with respect to the horizontal using the following mathematical rule called the sine rule (see more in **Annex B – Further Information**):

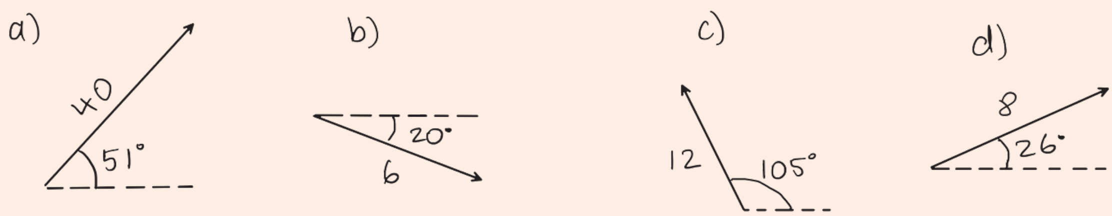
   $$\frac{F}{\sin\beta} = \frac{F_1}{\sin\alpha}$$

5. Make α the subject is as follows

   $$\alpha = \sin^{-1}\left(\frac{F_1 \sin\beta}{F}\right)$$

Activity 1.7 Resolving vectors

1. Find the horizontal and vertical components of the following vectors:



2. A force of 10.0 N is applied to a ball at an angle of 30° to the horizontal. Determine the horizontal and vertical components of this force.
3. Looking at the image below of iron filings showing the shape of the magnetic field around a bar magnet, discuss with your peer where the

magnetic field has only horizontal components and where it has both horizontal and vertical components. If the equipment is available, use a bar magnet and some iron filings to see if you achieve the same pattern as in the image below!

Note: *If you try this for yourself, ensure that the bar magnet is placed under a piece of paper and the iron filings are sprinkled on top of the piece of paper (to stop them from just sticking to the magnet).*

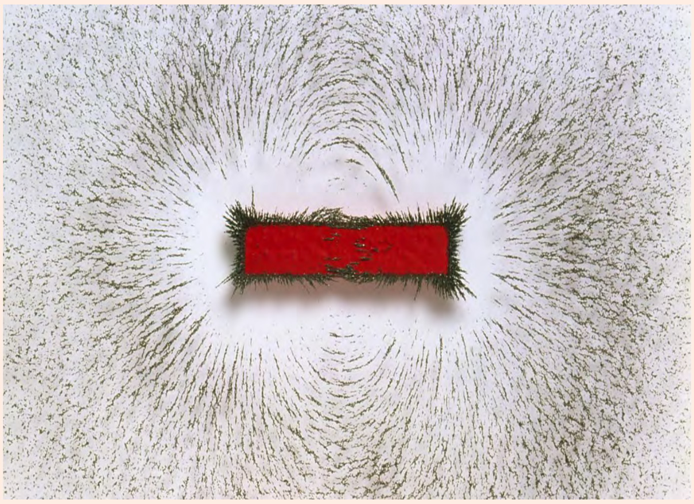


Figure 1.8: Iron filings surrounding a bar magnet

Activity 1.8 Determining the resultant of two vectors

1. A tennis player kicks a ball at an angle to the ground. If the ball travelled 10 m up and 8 m to the right at the same time, calculate

a. the inclined distance it travelled before beginning to fall.

b. the angle at which the ball was kicked.

2. Two forces are pulling a boulder; assume $F_1 = 20$ N is directed between north and east and $F_2 = 15$ N is directed eastward. If the angle between them is 60^0, determine the

a. magnitude of the resultant force on the boulder and

b. direction (angle) of its motion with respect to the east.

See Annex A for solutions to activities on vectors. See Annex B for further information on vectors.

DENSITY

Imagine you have two boxes of the same size. One box is filled with feathers, and the other is filled with bricks. Even though the boxes are the same size, they feel very different. The box with the bricks is much heavier, right?

That's because this volume of bricks contains a much greater mass (more particles) than this volume of feathers. Thus, we say the bricks have a higher density.

Density measures how much stuff is packed into a certain space. It's like how crowded a room is. If there are a lot of people in a small room, it's very dense. If there are only a few people in a big room, it's less dense.

Equal volumes of different substances have different masses. This is due to differences in their densities. Density helps us to understand why some objects float while others sink, and why certain materials feel heavier than others, even if they are the same size.

The density of water is 1000 kgm^{-3}. This means that a metre cubed of water has a mass of 1000 kg. In a similar way, an object (e.g. gold) of density 19300 kgm^{-3} means that a metre cubed of gold has a mass of 19300 kg.

Density is defined as the mass per unit volume of a substance.

Mathematically, Density $= \frac{Mass}{Volume}$

The S. I. Unit of density is kgm^{-3}.

Activity 1.9 Discussion on why ships float but metal sinks

1. Identify a friend or friends to form a small learner group
2. Engage in group discussions by asking your friends "*why do they think a heavy piece of metal sinks in water, but a large metal ship loaded with goods can float?*"

Figure 1.11: Diagram showing a Ship floating

Figure 1.12: Diagram showing Stones Sinking

3. Let your friends think individually for two minutes and write down their thoughts.
4. Share your ideas with your friends to identify similarities and differences.
5. Discuss the similarities and the differences and come out with your conclusions on why you think a heavy piece of metal sinks in water, but a large metal ship loaded with goods can float.
6. Engage your colleagues in a brief discussion about what they think could cause a boat, designed to float, to start sinking. Try to include all of the following key terms in your explanation: density, buoyant force, surface area, and displacement.

Figure 1.13: Diagram of a Ship Sinking

Activity 1.10 Calculating density

Read the two worked examples below before attempting the questions that follow.

Worked examples

1. A block of aluminium has a mass of 540 grams and a volume of 200 cm^3. What is the density of the aluminium in gcm^{-3}?
2. A piece of gold has a density of 19.3 gcm^{-3} and a volume of 10 cm^3. What is its mass in grams?

Step-by-Step Solution for Question 1

1. **Write the formula for density**

   $\text{Density} = \frac{Mass}{Volume}$

2. **Substitute the given values**

   $\text{Density} = \frac{540\, g}{200\, cm^3}$

3. **Perform the division:**

   $\text{Density} = 2.7\, gcm^{-3}$

Step-by-Step Solution for Question 2

1. **Rearrange the density formula to solve for mass**

   $Mass = Density \times Volume$

2. **Substitute the given values**

   $M = 19.3\, gcm^{-3} \times 10\, cm^3$

3. **Perform the multiplication**

   $M = 193\, g$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A metal block has a mass of 1.5 kg and a volume of 0.0003 m^3. Calculate the density of the metal.
2. A gold bar has a volume of 0.0005 m^3, and the density of gold is 19,320 kg/m^3. Calculate the mass of the gold bar.

3. A metal object has a mass of 2.4 kg, and its density is 8,000 kg/m^3. Calculate the volume of the object.

Activity 1.11 Determining Density of Objects Experimentally

Objective

1. To experimentally determine the density of various regular and irregular-shaped solid objects and of liquids.
2. To understand the relationship between mass, volume, and density.

Materials

1. Regular-shaped objects (e.g., spherical marble, cuboid piece of wood, cube or cuboid plastic block)
2. Irregular-shaped object (e.g., stone, small plastic toy animal)
3. Liquid (cooking oil, water)
4. Balance or digital scale
5. Measuring cylinder or graduated beaker
6. Vernier callipers or ruler
7. Displacement tank or overflow can

Procedure

1. **Measure mass**
   a. Place each object on the balance or digital scale and record the mass.
   b. Create a table to record the mass of each object.

Table 1.1: Table to record density values of objects

Object	Mass /g	Volume/cm^3	Density/ $g\,cm^{-3}$

2. **Measure volume**

   a. **Regular-shaped objects**

      i. Use vernier callipers or a ruler to measure the length, width, and height of each solid object.

      ii. Calculate the volume of each solid object using the appropriate formula (e.g., for a cube: Volume = length × width × height, for a sphere: volume = 4/3 × pi × radius^3).

   b. **Liquid**

      i. Pour the liquid into the measuring cylinder or graduated beaker.

      ii. Read the volume of the liquid from the markings on the container.

      Note: 1mL = 1cm^3

   c. **Irregular-shaped objects: Displacement method**

      i. Fill the displacement tank or overflow can with water to the brim.

      ii. Carefully submerge the irregular-shaped object into the water.

      iii. Collect the displaced water in a measuring cylinder and record the volume.

      Note: 1mL = 1cm^3

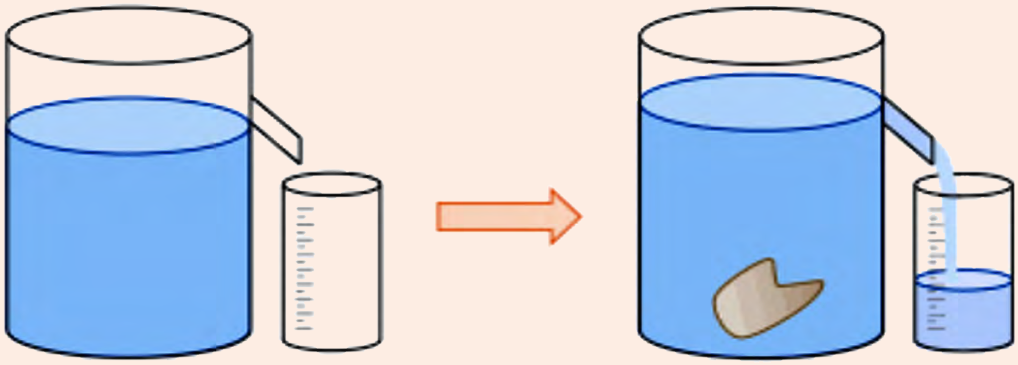


Figure 1.14: Diagram demonstrating the measurement of volume of the irregular objects

3. **Calculate density**

   1. Use the formula: Density = $\frac{Mass}{Volume}$

   2. Calculate the density of each object using the measured mass and volume.

   3. Record the calculated density in the table.

4. **Analyse results**
   1. Compare the densities of the different materials.
   2. Discuss any trends or patterns observed in the densities.
   3. Explain the differences in density based on the properties of the materials.

Note:

1. Ensure accurate measurements of mass and volume.
2. Use consistent units for mass and volume (e.g., grams and cubic centimetres).
3. Handle materials carefully, especially when dealing with liquids.

ARCHIMEDES' PRINCIPLE AND FLOTATION

When a body is immersed in a fluid (liquid or gas), the fluid exerts an upward force on the body. This force, known as upthrust or buoyant force, opposes the weight of the body.

Archimedes' Principle states that, when a body is wholly (fully) or partially immersed in a fluid (liquid or gas), there is an upthrust (upward force) which acts on the body and is equal to the weight of the fluid displaced by the body.

As the weight of an object is equal to its mass, m, multiplied by the gravitational field strength, g, the up thrust, u, on a body is:

$u = mg$ (weight of fluid displaced)

As the mass of the displaced fluid depends on its density, ρ, and volume, v, according to:

$$m = \rho v$$

We can combine the two formulae to give the relationship:

$$u = \rho v g$$

Since the volume of an object with a uniform area of cross-section can be found by multiplying the cross-sectional area of its base by its height, we can say:

$$v = Ah$$

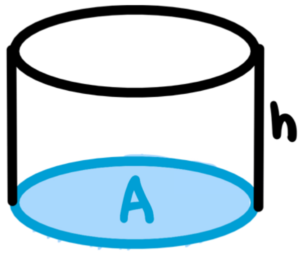


Figure 1.15: The volume of an object of uniform cross-sectional area

Therefore, upthrust on such an object,

$$u = \rho A h g$$

Activity 1.12 Calculating upthrust

An object of volume 4 m^3 is totally immersed in a liquid of density 1080kg/m^3. Calculate the upthrust of the liquid on the object. (g = 10 m/s^2)

Flotation

When the upthrust (buoyant force) is equal to the weight of the body in air (W_a), the apparent weight of the body in the fluid (W_f) becomes zero.

$W_a - u = W_f = 0$

In this case, the body experiences no net downward force, making it appear weightless in the fluid. This results in the body floating.

The principle of floatation states that *"A floating body displaces its own weight of fluid in which it floats"*.

Activity 1.13 Experimental verification of Archimedes Principle

Objective: Verify Archimedes' principle by measuring the buoyant force on a submerged object. *Note: in the absence of practical equipment, use an online simulation to observe Archimedes' Principle*:

ophysics.com/fl1.html

Materials needed

1. Spring balance
2. Beaker of water
3. Metal block capable of sinking
4. Large container with water that can serve as a eureka can by creating a hole at the side
5. Measuring cylinder

What to do

1. Measure the weight of the object in air using a spring balance.
2. Submerge the object completely in water and measure the apparent weight in water.
3. Collect the water displaced with a beaker and determine the weight of the water displaced

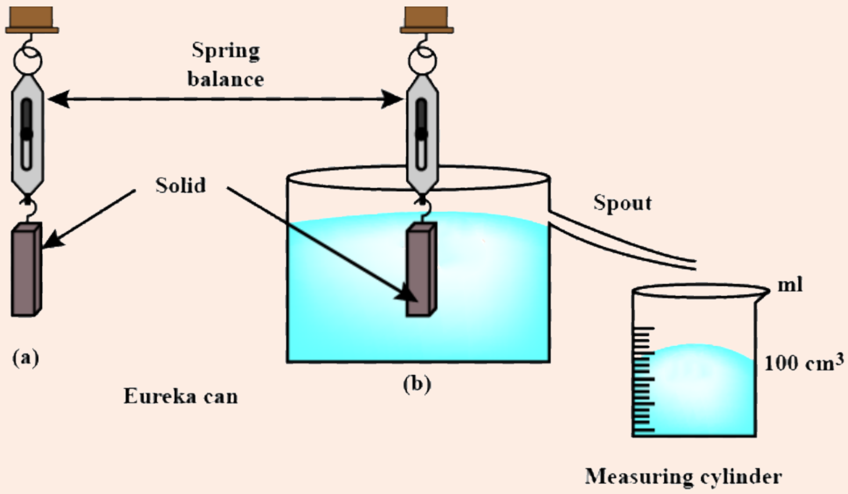


Figure 1.16: Diagram demonstrating experiment to verify Archimedes' principle

4. Calculate the upthrust or Buoyant Force = Weight in Air−Weight in Water
5. Compare the buoyant force to the weight of water displaced by the object and draw your conclusion
6. You can now verify Archimedes' principle.

Activity 1.14 Experimental verification of the principle of flotation

Objective: To verify the principle of flotation

Materials needed

1. Spring balance
2. Beaker of water
3. Wooden block capable of floating
4. Measuring cylinder
5. Large container with water that can serve as a eureka can by creating a hole at the side

What to do

1. Measure and record the weight of the block of wood.
2. Gently drop the block of wood into the large container containing the water.
3. Collect the water displaced with a beaker and determine the weight of the water displaced.
4. Compare the weight of the block of wood to the weight of the fluid displaced and draw your conclusion.
5. You can now verify the principle of flotation.

Extension

Try repeating **Activities 1.13** and **1.14** using fluids other than water (e.g. oil, saltwater). Draw a conclusion as to how the density of the fluid affects the buoyant force on the object, and whether the object sinks or floats as a result.

Activity 1.15 Research on real-life application of density and flotation

Now that you have studied density and flotation, research a real-life application of these concepts (e.g., hot air balloons, life jackets and submarines). Work in groups of no more than 4 learners.

Present your research to another group or to the whole class in the form of a written or oral presentation.

ELASTIC AND PLASTIC DEFORMATION

Deformation is the change in the shape, size, or structure of a material when a force is applied to it. This could include stretching, compressing, bending, twisting, or any other type of change. After the force is removed, the material may either return to its original shape (**elastic** deformation) or remain permanently changed (**plastic** deformation).

Different materials react differently to the same force. For example, a 1000 N force might stretch one material, while the change in another material may be impossible to perceive under the same force. This is why, before building a bridge, materials that might be used are sent to a research laboratory for testing. These tests help engineers figure out if the materials can handle the forces they will experience.

Figure 1.17: Image showing elastic deformation

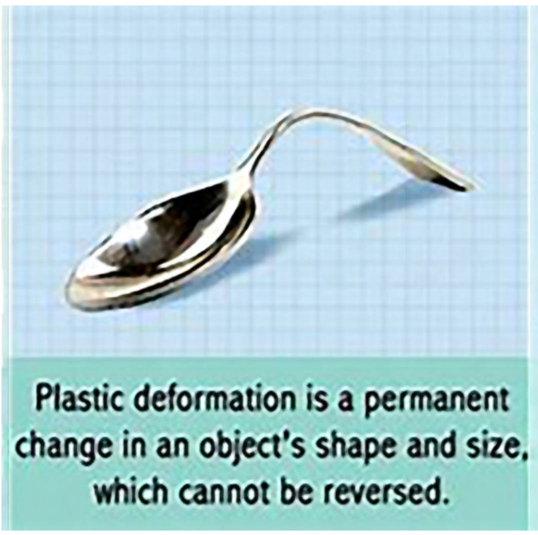


Figure 1.18: Image showing plastic deformation

Activity 1.16 Online Video Analysis of Elastic and Plastic Deformation

Objective

1. To independently research and analyse examples of elastic and plastic deformation through online videos.
2. To apply the concepts of elastic and plastic deformation to real-world scenarios.

Materials needed

1. Computer or device with internet access
2. Notebook or worksheet for recording observations

What to do

1. **Research online videos**
   - **a.** Use a search engine to find videos related to elastic and plastic deformation.
   - **b.** Look for videos that show clear examples of materials being deformed under stress.
   - **c.** Consider using keywords in your search such as "elastic deformation," "plastic deformation," " properties of materials," and "stress-strain relationship."
2. **Watch and analyse**
   - **a**. Select at least three videos that you find interesting or informative.
   - b. Watch each video carefully and take note of the materials being deformed and the nature of the deformation.
   - c. Identify whether the deformation is elastic or plastic based on your observations.
3. **Complete the worksheet or notebook**
   - **a.** Record your observations in a worksheet or notebook.
   - **b.** Answer the following questions for each video:
     - **i.** What is the material being deformed?
     - **ii.** Does the material return to its original shape after the stress is removed?
     - **iii.** Is the deformation elastic or plastic?
     - **iv.** Can you explain using ideas about particles and intermolecular forces why the material behaves in this way?

Note

1. Look for videos that provide clear explanations and visual demonstrations.
2. Consider using educational websites or platforms that offer reliable content.
3. Take notes while watching the videos to help you remember key points.
4. Feel free to search for additional videos if you need more examples.

Activity 1.17 Exploring Deformation

Materials Needed

1. Spring or rubber band
2. Retort stand or hook
3. Small weights (50 g, 100 g, 150 g, 200 g masses)
4. Aluminium foil
5. Mould clay
6. Notebook or worksheet for recording observations

What to do

1. Observe and record your observations of the behaviour of each of the following objects when they experience and force and then that force is removed; do they exhibit elastic or plastic behaviour? How can you tell?
   a. A spring suspended from a retort stand, stretch using small weight on a hanger
   b. A piece of aluminium foil, crumpled by hand
   c. A piece of mould clay, compressed or twisted by hand

Review

1. Use your observations recorded to differentiate between elastic and plastic deformations.
2. Give examples of materials that show elastic behaviour.
3. Give examples of materials that show plastic behaviour.
4. Discuss what is likely to cause elastic materials to undergo plastic deformation.

Activity 1.18 Categorising Scenarios into elastic and plastic deformation

Objective

1. To differentiate between elastic and plastic deformation.
2. To categorise various scenarios into either elastic or plastic deformation.

Materials needed

1. Scenarios or case studies describing different deformations
2. Sticky notes or index cards (for grouping)
3. Markers or pens

What to do

1. **Group the scenarios**
   a. Identify a friend or friends to form a small learner group
   b. Work individually or in small groups to analyse each scenario.
   c. Decide whether the deformation described is elastic or plastic.
   d. Use sticky notes or index cards to label each scenario as "Elastic" or "Plastic."
2. **Discuss and justify**
   a. Discuss your groupings with your classmates and explain your reasoning.
   b. Provide evidence or examples to support your choices.
   c. Address any misconceptions or disagreements that may arise.

Scenarios

1. Stretching a rubber band
2. Bending a paperclip
3. Bouncing a ball
4. Moulding clay
5. Spring compression
6. Car crash impact
7. Bending a fishing rod
8. Tennis ball on a racket
9. Wind blowing a tree branch

10. Pressing a foam cushion
11. Dent in a car door
12. Squeezing aluminium foil
13. Stretching a metal wire beyond its elastic limit
14. Forging metal

HOOKE'S LAW AND ENERGY STORED IN AN ELASTIC MATERIAL

Hooke's law is a helpful rule that explains how springs and other stretchy things behave.

Imagine a spring like a rubber band. When you pull on a rubber band, it gets longer. The more you pull, the longer it becomes. Hooke's law says that the amount a spring stretches depends on how hard you pull it.

We can use a diagram to help us understand this better:

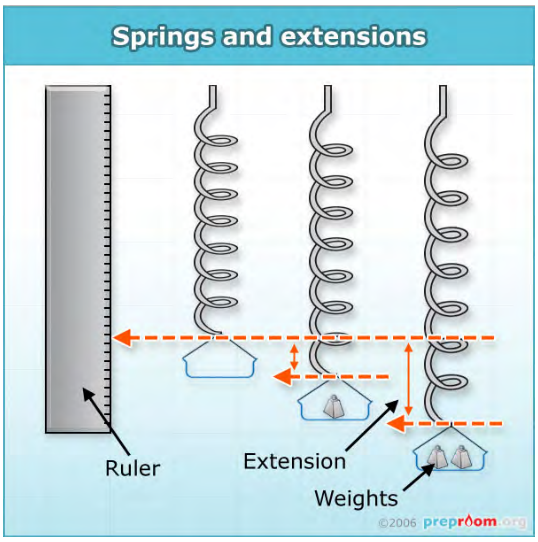


Figure 1.19: diagram showing a spring with different forces applied to it, resulting in different amounts of stretch

In the diagram, the first spring is not being pulled by a force and so is unextended. The second spring is being pulled with a small force, so it stretches only a little. The third spring is being pulled with a larger force, so it stretches more.

Hooke's law is a very important rule in science. It helps us understand how things like bridges, cars, and even our bodies work. It's like a puzzle piece that fits into the bigger picture of how the world around us works.

Hooke's law states that, provided the elastic limit is not exceeded, the extension in an elastic material is proportional to the load or applied force.

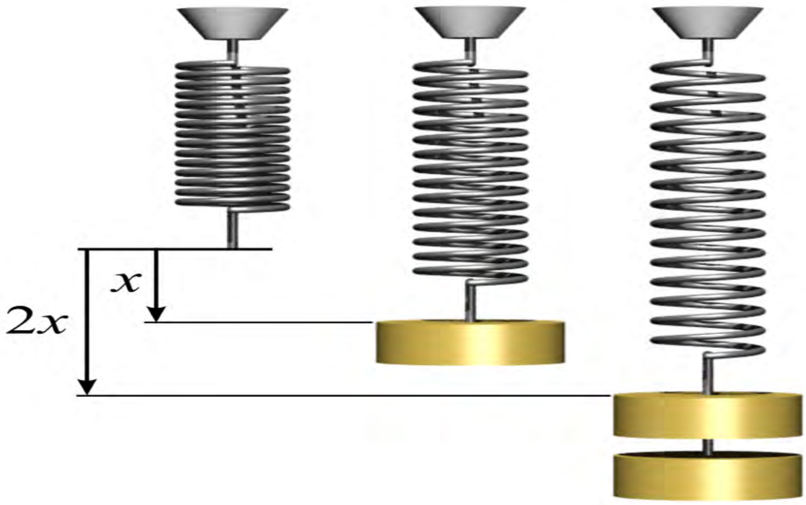


Figure 1.20: Diagram to demonstrate Hooke's law

Mathematically,

F = ke

where:

- F is the force exerted on the spring
- k is the spring constant (a measure of the stiffness of the spring)
- e is the displacement of the spring from its equilibrium position

Activity 1.19 Experimental verification of Hooke's Law

Objective

To verify Hooke's Law and investigate the relationship between the force applied to a spring and its extension. *Note: in the absence of practical equipment an online simulation can be used:*

HTTPS://phet.colorado.edu/en/simulations/hookes-law

Materials Needed

1. Spring
2. Ruler
3. Weights or masses (of varying sizes)
4. Stand
5. Clamp
6. Graph paper

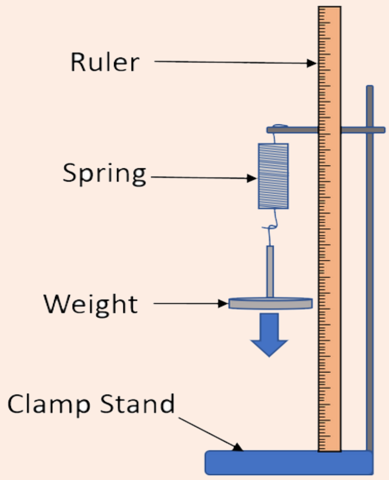


Figure 1.21: A diagram of the apparatus used to investigate Hooke's Law.

What to do:

1. **Set up the experiment**
   - **a.** Attach one end of the spring to a fixed point on the stand using the clamp.
   - **b.** Ensure the spring hangs vertically.
   - **c.** Measure the initial length of the spring when it is unstretched.
2. **Apply weights and measure extensions**
   - **a.** Add weights to the other end of the spring one at a time.
   - **b.** After each weight is added, measure the new length of the spring.
   - **c.** Calculate the extension of the spring by subtracting the initial length from the new length.
   - **d.** Record the force applied (weight = mass × acceleration due to gravity) and the corresponding extension in a table.
3. **Repeat with different weights**
   - **a.** Continue adding weights and measuring extensions until you have a sufficient number of data points.

b. Ensure that you do not stretch the spring beyond its elastic limit, as this will invalidate Hooke's Law.

4. **Graph the data**

   a. Plot a graph of force (on the y-axis) against extension (on the x-axis).

   b. Draw a line of best fit onto the graph (a single straight line, using a ruler, which is centred through as many of the point as possible)

   c. Note that if the spring has exceeded its elastic limit, the graph will become shallower at the end. You could ignore this part of the graph when drawing the line of best fit.

5. **Observe the graph**

   a. If the graph is a straight line passing through the origin, this indicates a linear relationship between force and extension.

   b. This confirms Hooke's Law, which states that the force exerted by a spring is directly proportional to its extension.

   c. The slope of the line represents the spring constant.

6. **Calculate the spring constant**

   The spring constant (k) can be calculated using the formula:

   k = force / extension

   Use values of force and extension taken from a single point on the line of best fit.

7. **Extension:**If you finish this task quickly, try repeating the experiment but using two springs in a) series and b) parallel. How does the effective spring constant compare the spring constant of just one spring?

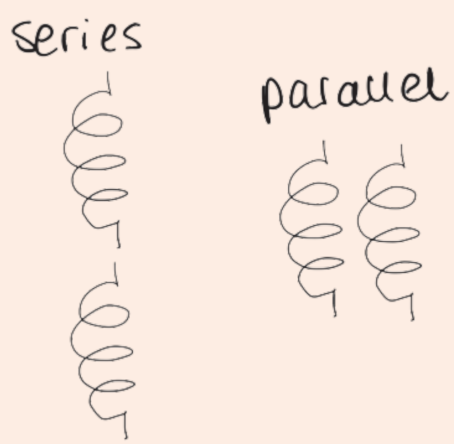


Figure 1.22: Springs in Series and Parallel

Energy stored in an elastic material

Think of an elastic band. When you stretch it, you're creating tension within the material. The application of this tension increases the material's store of elastic potential energy.

The more you stretch the elastic band, the more potential energy you store in it. This is because you're increasing the tension within the material, making it want to return to its original shape.

When you let go of the stretched elastic band, the tension causes it to snap back to its original shape. This movement is powered by the released potential energy, which is converted into kinetic energy (the energy of motion).

This principle applies to many other elastic materials as well, such as rubber, bungee cords, and even certain types of metal. They can all store potential energy when stretched or deformed and release it as kinetic energy when allowed to return to their original shape.

Mathematically,

$$U = \frac{1}{2}Fe = \frac{1}{2}ke^2$$

where:

- U is the potential energy stored in the elastic material
- k is the spring constant
- e is the displacement of the elastic material from its equilibrium position

Activity 1.20 Calculating the Spring Constant and Energy Stored in a Spring

Read the worked example below before attempting the example questions that follow.

1. A spring with an unstretched length of 20 cm is stretched to a length of 30 cm when a 500-gram mass is hung from it.

a. Calculate the spring constant.

b. Calculate the elastic potential energy stored in the spring when it is stretched to its maximum length. ($g = 9.81\ ms^{-2}$)

Step-by-Step Solution

1. **Calculating the Spring Constant**

   a. Convert the mass to kilograms

   500 grams = 0.5 kg

   b. Calculate the force exerted by the mass

   i. Force = Mass × acceleration due to gravity

   ii. Force = 0.5 kg × 9.81 ms^{-2}= 4.905 N

   c. Calculate the extension of the spring and convert to metres

   i. Extension = Final length - Initial length

   ii. Extension = 30 cm - 20 cm = 10 cm = 0.1 m

   d. Use Hooke's Law to calculate the spring constant

   i. Hooke's Law: Force = Spring constant × Extension

   ii. $Spring\ constant = \frac{Force}{Extension}$

   ii. Spring constant = $\frac{4.905\ N}{0.1\ m}$ = 49.05 Nm^{-1}

   Therefore, the spring constant is 49.05 Nm^{-1}.

2. **Calculating the Elastic Potential Energy**

   a. Use the formula for elastic potential energy

   Elastic potential energy = $(\frac{1}{2})$ × Spring constant × Extension²

   b. Plug in the values

   Elastic potential energy = $(\frac{1}{2})$ × 49.05 Nm^{-1} × $(0.1\ m)^2$

   c. Calculate the energy

   Elastic potential energy = 0.24525 J

   Therefore, the elastic potential energy stored in the spring is 0.25 Joules, rounded to two decimal places.

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A car's suspension system uses springs to absorb shocks from the road. If a 1000 kg car compresses a spring 5 cm when parked,

   a. What is the spring constant of the suspension?

b. How much energy is stored in the spring when it is compressed? (g = 9.81 ms^{-2})

2. A bungee jumper with a mass of 70 kg jumps from a bridge with a bungee cord that has an unstretched length of 50 meters. If the jumper stretches the cord to a maximum length of 75 meters before bouncing back,
   a. What is the spring constant of the bungee cord?
   b. How much energy is stored in the cord at its maximum extension? (g = 9.81 ms^{-2})
3. A spring-loaded toy gun has a spring constant of 100 N/m. If the gun stores 0.5 Joules of energy when the spring is compressed, what is the maximum extension of the spring?
4. A car's suspension system has a spring constant of 50,000 N/m. If the car's weight compresses the spring by 5 cm, how much energy is stored in the spring?

YOUNG'S MODULUS

Imagine a rubber band. When you pull it, it stretches. The force you're applying to stretch it, per unit of its cross-sectional area, is called **stress**. The percentage increase in length is called **strain**.

Tensile stress is the ratio of force to cross-sectional area. It is expressed in Nm^{-2}.

Mathematically, tensile stress = $\frac{F}{A}$

Tensile strain is the ratio of extension to the original length of the material. It has no unit as it is simply a scale factor by which the length has changed.

Mathematically, tensile strain = $\frac{e}{l_o}$

Young's Modulus

Young's modulus is a measure of how stretchy or stiff a material is. It is similar to the spring constant, k, but takes into account the dimensions of the object under stress. The Young Modulus of a particular material is always the same, whereas the spring constant will depend on the length and cross-sectional area of the object.

A rubber band has a low Young's modulus, meaning it stretches easily. A metal rod has a high Young's modulus, meaning it's very stiff and doesn't stretch much.

An alternative wording of Hooke's law is: provided the elastic limit is not exceeded, stress is proportional to strain.

$stress \propto strain$

$stress = E \times strain$

Then **Young's modulus** E is defined as the ratio of tensile stress to tensile strain. It is expressed in Nm^{-2}.

$$E = \frac{stress}{strain}$$

$$E = \frac{F}{A} \div \frac{e}{l_o}$$

$$E = \frac{F l_o}{Ae}$$

Where F is the force required to stretch the elastic string or spring of length l_o and cross-sectional area A, through a length e.

Activity 1.21 Researching stress

Draw diagrams to show the effect of tensile, compressional and shear stress. Describe the effects that these different types of stresses can have on materials.

You should also research materials which have a particularly high breaking stress; what sorts of applications are these materials used in?

Activity 1.22 Calculating Tensile Stress, Tensile Strain, and Young's Modulus

Read the worked example below before attempting the example questions that follow.

Worked example

1. A metal wire of length 2 metres and a cross-sectional area of 0.001 m^2 is stretched by 0.005 metres when a tensile force of 1000 N is applied. Calculate:

a. the tensile stress on the wire.

b. the tensile strain in the wire.

c. the Young's modulus of the material.

Step-by-Step Solution

1. **Calculate Tensile Stress**

Identify the formula for tensile stress:

$$Tensile\ Stress = \frac{Force}{Cross - sectional\ Area} = \frac{F}{A}$$

Substitute the known values and compute to get the answer

From the problem, we know that:

- Force F = 1000 N
- Cross-sectional area A = 0.001 m^2

Now, substitute these values into the formula:

$$Tensile\ Stress = \frac{1000\ N}{0.001\ m^2}$$

$$Tensile\ Stress = 1{,}000{,}000\ Nm^{-2}$$

2. **Calculate Tensile Strain**

Identify the formula for tensile strain

$$Tensile\ Strain = \frac{Extension}{Original\ length} = \frac{e}{L}$$

Substitute the known values and compute to get the answer

- Extension e = 0.005 metres
- Original length L = 2 metres

Now, substitute these values into the formula:

$$Tensile\ Strain = \frac{0.005\ m}{2\ m}$$

$$Tensile\ Strain = 0.0025 \text{ or } 0.25\%$$

3. **Calculate Young's Modulus**

Identify the formula for Young's modulus

$$Young's\ modulus = \frac{Tensile\ Stress}{Tensile\ Strain}$$

Substitute the known values and compute to get the answer

From the previous steps, we know that:

- Tensile stress = 1,000,000 N/m^2
- Tensile strain = 0.0025

Now, substitute these values into the formula:

$$Young's\ modulus = \frac{1{,}000{,}000\ Nm^{-2}}{0.0025}$$

$$Young's\ modulus = 400{,}000{,}000\ Nm^{-2}$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A steel guitar string has a length of 0.8 metres and a cross-sectional area of 0.0005 m^2. When tuned, the string stretches by 0.002 metres under a tension force of 600 N.
   a. Calculate the tensile stress in the guitar string.
   b. Determine the tensile strain in the string.
   c. Find the Young's modulus of the steel string.
2. A construction worker uses a steel rod with a cross-sectional area of 0.002 m^2 to lift materials. The rod is 2 metres long and stretches by 0.001 metres under a load of 5000 N.
   a. Calculate the tensile stress in the steel rod.
   b. Determine the tensile strain in the rod.
   c. What is the Young's modulus of the steel rod?
3. A copper wire has an original length of 1.5 metres and an extension of 0.003 metres when subjected to a load. The wire has a cross-sectional area of 0.0004 m^2, and the Young's modulus of copper is $1.1 \times 10^{11}\ Nm^{-2}$. Calculate the force applied to the copper wire.

Activity 1.23 Young's Modulus Comparison and Application through Discussion

Objective

1. To compare the Young's modulus of various materials using provided data.
2. To discuss the significance of these comparisons in material selection and engineering applications.

Data

Table 1.2: Young's Modulus of Various Materials

Material	Young's Modulus (GPa)
Steel	200
Aluminium	70
Copper	120
Rubber	0.01
Wood (Oak)	10-12
Glass	60-70
Plastic (Nylon)	1.5-3

What to do

1. Identify a friend or friends to form a small learner group.
2. Observe the provided data, and examine the Young's modulus values for each material. Identify the materials with the highest and lowest Young's modulus.
3. Analyse if there are any trends or patterns in the data based on material properties (e.g., metals vs. non-metals, crystalline vs. amorphous).
4. Engage in group discussions with the following discussion prompts:
   a. How does the structure of a material relate to its Young's modulus?
   b. Can you explain the trends observed in the Young's modulus values of different materials?
   c. How can the Young's modulus of a material be related to its other mechanical properties (e.g., strength, ductility)?
   d. In what types of engineering applications is a high Young's modulus desirable?
   e. Can you think of examples where a low Young's modulus is beneficial in engineering applications?
5. Each group should appoint one member to summarise and record the answers from the discussions.
6. After the discussions, each group should share one key point from their discussion with the class or peers.

Activity 1.24 Experimental Determination of Young's Modulus of a Wire

Objective

To experimentally determine the Young's modulus of a wire by measuring its stress and strain under increasing loads. *Note: in the absence of practical equipment an online simulation could be used*

https://www.doitpoms.ac.uk/tlplib/thermal-expansion/simulation.php

You can also watch a video detailing the experimental set up and procedure here:

https://www.youtube.com/watch?v=OxV4S8pU6Co

Materials needed

1. Length of wire (such as constantan), minimum 1.5m
2. Vernier callipers or micrometer screw gauge
3. Metre ruler(s)
4. Stand or clamp
5. Pulley
6. Hanging masses
7. Fiduciary marker

What to do

1. **Measure wire's cross-sectional area**
   a. Measure the diameter of the wire using vernier callipers or a micrometer screw gauge.

b. Calculate the cross-sectional area of the wire using the formula: $Area = \pi \frac{d^2}{4}$

2. **Set up the experiment**

a. Attach one end of the spring to a stand or clamp.

b. Hang a pulley over the edge of the stand or clamp.

c. Attach a mass hanger to the end of the spring that passes over the pulley.

3. **Measure initial length**

a. Place a fiduciary marker on the wire approximately 15cm away from the point where it passes over the pulley. Leave a metre ruler in place underneath the fiduciary marker such that changes in its position will be measurable.

b. Measure the initial position of the fiduciary marker relative to the clamped end of the wire, using a metre ruler.

4. **Apply loads and measure extensions**

a. Gradually add masses to the hanging mass hanger.

b. For each added mass, measure the new position of the fiduciary marker and calculate the extension of the wire.

c. Record the force applied (weight of the hanging masses) and the corresponding extension.

5. **Calculate stress and strain**

a. Calculate the stress on the wire using the formula:

$$Stress = \frac{Force}{Cross - sectional\ Area}$$

b. Strain: Calculate the strain on the wire using the formula:

$$Strain = \frac{Extension}{Original\ length}$$

c. Record your values in a tabular form

Table 1.3: Table to record values obtained from determining Young's Modulus of a wire

Force/N	Diameter/m	Area/ m^2	Final length/m	Extension/m	Stress/ Nm^{-2}	Strain

6. **Plot the stress-strain curve**
   a. Plot the stress values on the y-axis and the strain values on the x-axis.
   b. Determine the slope of the linear portion of the stress-strain curve which represents the Young's modulus of the wire.

Notes

1. Ensure accurate measurements of diameter, length, and extension.
2. Choose a suitable range of loads to observe the wire's behaviour within its elastic limit.
3. Use appropriate data analysis techniques (e.g., linear regression) to determine the Young's modulus.
4. Handle masses and equipment carefully to avoid accidents.

Activity 1.25 Preparation of a Poster on Material Properties

Objective

1. To research and understand the properties of brittle, ductile, and malleable materials.
2. To create a visual representation of the properties and provide examples of materials exhibiting each behaviour.

Materials needed

1. Poster board or paper
2. Markers, pens, or coloured pencils
3. Research materials (books, internet, scientific journals)

What to do

1. **Research material properties**
   a. Research the definitions of brittle, ductile, and malleable materials.
   b. Research about the characteristics of each type of material, such as their behaviour under stress or deformation.
   c. Find examples of materials that exhibit each property.
2. **Organise information**
   a. Decide on the layout and organisation of your poster or summary sheet.

   b. Outline the key points you want to include, such as definitions, examples, and visual aids.

3. **Design and create the poster or summary sheet:**
   a. Use diagrams, illustrations, or images to represent the properties and examples.
   b. Write clear and concise explanations of the terms and characteristics.
   c. Include specific examples of materials for each property.
   d. Use colours and fonts that are visually appealing and easy to read.

4. **Review and revise:**
   a. Ensure that the information is accurate and up-to-date.
   b. Make sure the poster or summary sheet is easy to understand and visually appealing.
   c. Check that all the required information is included.

EXTENDED READING

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2. Asiedu, P., & Baah-Yeboah, H. A. (n.d.). *Physics for Senior High Schools* (4th ed., pp. 24-25, 40-44,127-129). Aki-Ola Publications.
3. Giancoli, D. C. (2008). *Physics for scientists and engineers* (4th ed., pp. 49-54, 160-163). Pearson Prentice Hall.
4. Halliday, D., Resnick, R., & Walker, J. (2013). *Fundamentals of physics* (10th ed., pp. 51-56, 103-105, 145-147). Wiley.
5. Serway, R. A., & Jewett, J. W. (2013). *Physics for scientists and engineers with modern physics* (9th ed., pp. 22-28, 116-118, 210-214). Brooks/Cole.
6. Young, H. D., & Freedman, R. A. (2012). *University Physics with Modern Physics* (13th ed., pp. 97-99). Pearson.

REVIEW QUESTIONS

Review Questions – Dimensional Analysis and Vectors

1. State three uses of dimensional analysis.
2. Check the validity of the equation: $pv = mv^2 - mgh$ where P represents momentum by a body, V represent the velocity of the body, m represents the mass of the body, h represents the height of the body above the ground and g represents the acceleration due to gravity.
3. The period T of oscillation of a mass m attached to a spring might depend on: The mass m, the spring constant k, and the acceleration due to gravity g. Using dimensional analysis, determine how the period T of the mass-spring system depends on these quantities.
4. A car climbs a hill with an acceleration of 5 ms^{-2}. If the road makes an angle of 20° with the horizontal, calculate the horizontal and vertical components of the car's acceleration.
5. A hunter lies on the ground and aims his gun at a bird on a tree. The angle between the gun and the ground is 50°. When he shoots at the bird, the bullet travels a total displacement of 50 m. Calculate the
   a. distance on the ground between the gun from the base of the tree, and
   b. the position of the bird from bottom of the tree

Review Questions – Density and Flotation

1. Define density.
2. State Archimedes' principle.
3. What condition must be met for an object to float on a fluid?
4. A cube has a side length of 5 cm and a mass of 500 g. What is its density?
5. A solid object has a volume of 0.5 m^3 and is completely submerged in a fluid. If the density of the fluid is 1000 kgm^{-3}, calculate the buoyant force on the object.
6. An object with a mass of 500 g displaces 400 cm^3 of water when floating. Will the object sink or float in water, and why?

7. Why does ice, which is solid water, float on liquid water, even though both are made of the same substance?
8. You have a solid block of unknown material and are tasked with identifying its composition using only a scale and a graduated cylinder filled with water. How would you determine the material's identity?

Review Questions - Deformation

1. Define Elastic Deformation.
2. Fill in the table below by grouping the following scenarios under elastic and plastic deformations: A rubber band stretching when pulled, A paperclip bending but returning to shape, A metal wire being twisted, A spring compressing and then expanding, A piece of clay being shaped into a sculpture, A car frame bending in an accident.

Elastic deformation	Plastic deformation

Review Questions – Hooke's Law and Young's Modulus

1. State Hooke's law.
2. What are the two physical quantities used to calculate Young's modulus?
3. A car's suspension system uses a spring that compresses by 0.15 metres when a load of 3000 N is applied.
   a. What is the spring constant of the suspension spring?
   b. How much energy is stored in the spring when it is compressed by 0.15 metres?
4. A steel wire of length 2 m and cross-sectional area 1 mm^2 is stretched by 0.5 mm when a force of 1000 N is applied. Calculate the stress and strain in the wire. Then, determine Young's modulus for the steel wire.
5. Explain how Young's modulus defines the stiffness of a material. How does the modulus relate to the ability of a material to resist stretching or compressing when a force is applied?

6. A copper wire has a length of 3 m and a cross-sectional area of 2 mm^2. The wire is stretched by 0.25 mm when a force is applied. Given that the Young's modulus of copper is 1.1×10^{11} Pa, calculate the force applied to the wire.
7. Two springs, A and B, have spring constants of 200 N/m and 300 N/m, respectively. A force of 50 N is applied to both springs. Which spring stretches more, and why? Use Hooke's Law in your explanation.
8. Two wires, A and B, are made of different materials with Young's moduli of 200 GPa and 150 GPa respectively. Both wires experience the same tensile stress. Which wire will experience a greater strain, and why? Explain using the relationship between stress, strain, and Young's modulus.
9. You are designing a container to transport a substance by sea. The material of the container is very dense, but you still want it to float. What strategies can you use to ensure it will float, and why will they work?

Review Questions – Density and Flotation

1. Density is the mass per unit volume of a substance.
2. Archimedes' Principle states that, when a body is wholly (fully) or partially immersed in a fluid (liquid or gas), there is an upthrust (upward force) that acts on the body and is equal to the weight of the fluid displaced by the body.
3. An object floats on a fluid if the weight of the object is equal to the buoyant force exerted by the displaced fluid. This occurs when the density of the object is less than or equal to the density of the fluid.

   4 gcm^{-3}

   4900 N
4. Since the density of the object (1.25 gcm^{-3}) is greater than the density of water (1 gcm^{-3}), the object will sink.
5. Ice floats on water because it has a lower density than liquid water. When water freezes, its molecules arrange in a crystal structure that takes up more space, making ice less dense than liquid water.
6. First, measure the mass of the block using the scale.

   Next, place the block in the graduated cylinder and measure the volume of water displaced. This gives the volume of the block.

Use the formula for density: $\rho = \frac{m}{v}$, where m is the mass and V is the volume.

Once the density is calculated, compare it to known densities of materials to identify the block's composition.

Review Questions – Deformation

1. Elastic deformation is a temporary change in shape or size of a material when a stress is applied. The material returns to its original shape once the stress is removed.

2.

Elastic deformation	Plastic deformation
A rubber band stretching when pulled	A metal wire being twisted
A paperclip bending but returning to shape	A piece of clay being shaped into a sculpture
A spring compressing and then expanding	A car frame bending in an accident

Review Questions – Hooke's Law and Young's Modulus

1. Hooke's law is stated as provided the elastic limit is not exceeded, the extension, e in an elastic material is proportional to the load or applied force.

2. The two physical quantities used to calculate Young's modulus are stress (force per unit area) and strain (the ratio of change in length to original length).

3. a. 20,000 N/m

   b. 225 J

4. Stress = 1×10^9 Nm^{-2}, Strain = 2.5×10^{-4}, Young's Modulus = 4×10^{12} Nm^{-2}

5. Using Hooke's Law:

   For spring A, the spring will stretch by 0.25m and

   For spring B: the spring will stretch by =0.167m.

Therefore**,** Spring A stretches more than spring B because it has a lower spring constant, meaning it's less stiff.

F = 18,333 N (note $2mm^2 = 0.000002m^2$)

6. Young's modulus defines the stiffness of a material by measuring its ability to resist deformation under stress. It is the ratio of stress (force per unit area) to strain (deformation as a fraction of the original length). A material with a high Young's modulus is stiff, meaning it deforms very little when subjected to force, while a material with a low modulus is more flexible and deforms more easily.
7. Young's Modulus is the ratio of tensile stress to tensile strain. Since both wires experience the same tensile stress, the strain is inversely proportional to the Young's modulus. Wire A has a higher Young's modulus (200 GPa) than wire B (150 GPa). Therefore, wire B will experience a greater strain because a lower Young's modulus means more deformation for the same stress.

SECTION

2 MEASUREMENT OF HEAT

ENERGY

Heat

INTRODUCTION

In this section, we will look at heat capacity and specific heat capacity to understand how different materials take in and store heat. This will help explain why some substances or materials heat up or cool down faster than others. We will also explore phase or state changes, focusing firstly on the latent heat of fusion which will help us understand melting and freezing processes. Similarly, we will study the latent heat of vaporisation which tells us how much energy is needed to change a liquid into a gas. This will help us understand processes like boiling, evaporation, and condensation.

These thermal properties are important for understanding how materials behave when heated or cooled. They are also useful in real-world applications, like refrigerators and energy management systems, and help explain everyday phenomena, such as cooking and how weather patterns form.

KEY IDEAS

- Heat capacity is the quantity of heat that must be supplied or removed from a body to change its temperature by 1 ^{o}C or by 1 K without a change in state.
- Specific heat capacity is the quantity of heat that must be supplied or removed from a body to change the temperature of 1 kg of a substance of by 1 ^{o}C or by 1 K without a change in state.
- Latent heat of fusion is the quantity of heat required to change the solid state of a substance to the liquid state or from the liquid state of the substance to the solid state without a change in temperature.
- Specific latent heat of fusion is the quantity of heat required to change 1 kg of a substance from the solid state to the liquid state or from the liquid state to the solid state without a change in temperature.

- Latent heat of vaporisation is the quantity of heat required to change the liquid state of a substance to the gaseous state or from the gaseous state to the liquid state without a change in temperature.
- Specific latent heat vaporisation is the quantity of heat required to change 1 kg of the liquid state of a substance to the gaseous state of the substance or from the gaseous state to the liquid state without a change in temperature.

SPECIFIC HEAT CAPACITY

Figure 2.1: Two pots of water on fire

Imagine you have two pots of water. One pot is small, and the other is large. If you put both pots on a stove and heat them for the same amount of time, which pot will reach a higher temperature? Usually, the smaller pot will heat up more than the larger one. This is because the smaller pot has a lower heat capacity.

Heat capacity is the quantity of heat that must be supplied or removed from a substance for the temperature to change by 1°C or 1 K. In simpler terms, it tells you how much heat it takes to warm something up. The standard unit for heat capacity is J/°C or J/K.

The concept of heat capacity helps classify materials as good or poor conductors of heat. Good conductors have low heat capacity, allowing them to transfer or absorb heat quickly with minimal energy needed to increase their temperature. In contrast, poor conductors (insulators) have high heat capacity, meaning they absorb heat slowly and require more energy to change their temperature. This property is essential for applications in cooking, construction, and temperature control systems.

$$H_c = \frac{Q}{\Delta\theta}$$

Where H_C = heat capacity, $\Delta\theta$ = temperature change, Q = quantity of heat (energy)

Consider; if you have two pots of the same size, one made of aluminium and the other made of copper, both filled with the same amount of water and heated for the same amount of time, which pot will become hotter? Discuss your thoughts and potential explanations with your neighbour.

You might assume both pots would heat up equally, but that's not necessarily true. The material of the pot affects how quickly it heats. In this case, the aluminium pot will heat up faster than the copper pot because aluminium has a lower specific heat capacity than copper. Specific heat capacity is the heat capacity per unit mass.

Specific heat capacity is defined as the amount of heat required to change the temperature of 1 kg of a substance by 1°C or 1 K. The standard unit for specific heat capacity is J/kg°C or J/kgK.

$$c = \frac{Q}{m\,\Delta\theta}$$

Where c = specific heat capacity, m = mass, $\Delta\theta$ = temperature change, Q = quantity of heat

Activity 2.1 Identify good and poor conductors of heat

Order the materials in the table from the best to the worst conductor of heat based on it specific heat capacity:

Table 2.1: Good and poor conductors of heat

Order from best (1) to worst (6)	Material	Specific heat capacity (J/kg°C)
	Air	1003
	Carbon dioxide	839
	Iron	412
	Steel	466
	Water (room temperature)	4181
	Water (boiling point)	2080

Activity 2.2 Investigating the effect of material on conduction

Objective: To observe the temperature rise of two different materials of the same mass having absorbed the same amount of heat.

Materials

1. Heat source (oven or direct sunlight)
2. Two materials of the same size and dimensions (e.g. a plastic cup full of water and a plastic cup full of oil)
3. Thermometer

Procedure

1. Prepare your two objects of identical mass and shape.
2. Measure the initial temperature of the objects using the thermometer.
3. Place the objects a) into an oven on a low temperature (50 degrees Celsius) or b) into direct sunlight. Leave them in place for several minutes until there is a notable change in temperature.
4. Measure the final temperature of the materials.

Conclusion: Which of the materials had the higher specific heat capacity? How can you tell?

Activity 2.3 Comparing Methods for Determining Specific Heat Capacity

Objective: To research and compare different methods for determining specific heat capacity, analysing their relative benefits and drawbacks.

Materials

1. Access to computers or devices with internet connectivity
2. Textbooks or scientific journals
3. Note-taking materials

Procedure

1. Identify a friend or friends to form a small learner group.
2. **Group Research**
   a. In groups, research the methods for determining specific heat capacity: Method of Mixtures, Electrical Method, Continuous Flow Method etc.
   b. Use textbooks, online resources, or scientific journals to gather information about each method.
   c. Search for videos demonstrating each method and watch.
3. **Analysis**
   Analyse the strengths and weaknesses of each method, considering factors such as accuracy, precision, user-friendliness, cost, time required, and applicability to different materials.
4. **Comparison and Discussion**
   a. Compare and contrast the different methods in a class discussion.
   b. Discuss the advantages and disadvantages of each method.
   c. Identify the most suitable method for different applications based on the analysis.
5. **Presentation**
   a. Prepare a presentation summarising your findings.
   b. Present your findings to the class, explaining your preferred method and discussing its advantages and disadvantages.

Activity 2.4 Experimental determination of the specific heat capacity of a solid by method of mixtures

Objective: To determine the specific heat capacity of a solid by observing the heat transfer between the solid and a liquid (usually water) of known specific heat capacity.

Materials Needed

1. Solid sample (e.g., metal)
2. Water (or any liquid with known specific heat capacity)
3. Calorimeter (can be a simple insulated container)
4. Thermometer
5. Balance (for measuring mass)
6. Stirrer
7. Thread
8. Bunsen burner/heating coil
9. Container for heating (e.g. glass beaker)

What to do

1. Weigh and record the mass of the solid sample (m_s).
2. Weigh and record the mass of the empty calorimeter (m_c).
3. Pour water into the calorimeter to about ¾ full, weigh and record the mass of the calorimeter and the water (m_{cw}).
4. Obtain the mass of the water in the calorimeter $m_w = m_{cw} - m_c$.
5. Measure the initial temperature of the water θ_i.

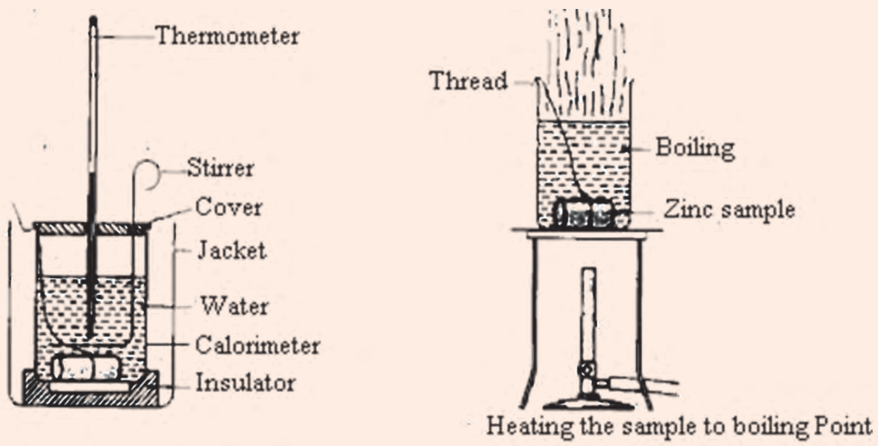

Figure 2.2: Experiment to determine the specific heat capacity of solid by method of mixtures

6. Tie the metal sample with the thread and lower it gently into boiling water.
7. By leaving the metal in the water for approximately three minutes, allow the solid to reach thermal equilibrium with the heating source. Then, quickly measure the temperature of the water (and therefore the temperature of the metal) θ_s.
8. Transfer the hot solid into the calorimeter containing the liquid.
9. Stir gently to ensure uniform temperature distribution in the liquid.
10. Use the thermometer to monitor the temperature of the mixture.
11. Record the final equilibrium temperature once it stabilises (θ_f).
12. Determine the heat capacity from the theory below. Use $c_w = 4181$ J/kg°C.

    Assume there is no heat lost to the surroundings and no heat transferred to the calorimeter itself,

    $$[\textit{Heat lost by solid}] = [\textit{Heat gained by cold water}]$$

    $$m_s c_s(\theta_s - \theta_f) = m_w c_w(\theta_f - \theta_i)$$

    Calculate the specific heat capacity of the solid using the formula

    $$c_s = \frac{(m_w c_w)(\theta_f - \theta_i)}{m_s(\theta_s - \theta_f)}$$

Conclusion: Compare your experimental value of the specific heat capacity with one which you research from the internet or from a textbook. Why might yours be different? List any likely reasons for the discrepancy.

Activity 2.5 Calculating Specific Heat Capacity

Read the worked examples below before attempting the problems that follow.

Worked examples

1. A 2 kg block of copper is heated from 20°C to 80°C. Given that the specific heat capacity of copper is = 390 J/kg°C, calculate the amount of heat energy required to raise its temperature.
2. A 100 g block of an unknown metal at 100°C is dropped into 200 g of water at 25°C. The final temperature of the mixture is 30°C. Calculate the

specific heat capacity of metal. (Assume no heat is lost to the surroundings and the specific heat capacity of water is 4.18 J/g°C.)

Step-by-Step Solution for Question 1

Step 1: Identify the given information

m is the mass of the substance (in kg) = 2 kg

c is the specific heat capacity of the substance (in J/kg°C) = 390 J/kg°C

ΔT is the change in temperature (in °C) $= 80°C - 20°C = 60°C$

Step 2: Introduce the heat energy (Q) Formula:

$Q = m \cdot c \cdot \Delta T$

Where:

- Q is the heat energy (in joules),
- m is the mass of the substance (in kg),
- c is the specific heat capacity of the substance (in J/kg°C),
- ΔT is the change in temperature (in °C).

Step 3: Substitute the known values:

$Q = 2\,kg \times 390\,J/kg°C \times 60°C$

Step 4: Calculate and get your answer:

$Q = 2 \times 390 \times 60 = 46{,}800\,J$

So, the heat energy required is 46,800 J.

Step-by-Step Solution for Question 2

Step 1. Identify the known quantities:

Mass of metal, $M_m = 100$ g

Initial temperature of metal, $TI_m = 100°C$

Mass of water, $M_W = 200$ g

Initial temperature of water, $T_{IW} = 25°C$

Final temperature, $T_F = 30°C$

Specific heat capacity of water, $C_W = 4.18$ J/g°C

Step 2: Identify which of the substances loses or gains heat

Metal loses heat

Water gains heat

Step 3: Introduce the heat formula for heat lost by metal and substitute:

$Q_m = M_m \times C_m \times (TI_m - T_F)$

Since the metal cools down, the temperature difference is $TI_m - T_F = 100 - 30 = 70°C$.

$Q_m = 100 \times C_m \times 70$

Step 4: Introduce the heat formula for heat gained by water:

$Q_W = M_W \times C_W \times (T_F - T_{IW})$

the temperature difference is $T_F - T_{IW} = 30 - 25 = 5°C$.

$Q_W = 200 \times 4.18 \times 5 = 4180$ J

Step 5: Apply the principle of conservation of energy

Heat lost by metal = Heat gained by water

$Q_m = Q_W$

Therefore: $100 \times C_m \times 70 = 4180$

Step 6: Solve for C_m:

$$C_m = \frac{180}{100 \times 70}$$

$$= 0.597 \text{ J/g°C}$$

The specific heat capacity of the metal is 0.597 J/g°C or 597 J/kg°C.

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A 1.5 kg block of aluminium is heated from 25 °C to 75 °C. Given that the specific heat capacity of aluminium is 900 J/kg°C, calculate the amount of heat energy required to raise its temperature.
2. A 500 g solid block at 150 °C is placed in 600 g of water at 25 °C. If the final temperature is 35 °C, calculate the specific heat capacity of the solid. (Specific heat capacity of water = 4.18 J/g°C.)
3. A 200 g block of metal is heated to 200 °C and then dropped into 400 g of water at 25 °C. If the final temperature of the water and metal is 30 °C, and the specific heat capacity of water is 4.18 J/g°C, calculate the specific heat capacity of the metal.

Activity 2.6 Real world applications of specific heat capacity

Objective: Research and present on the applications of specific heat capacity in various industries.

Materials Needed

1. Access to the internet for research (laptops/tablets)
2. Notebooks or digital devices for note-taking
3. Presentation software (e.g., PowerPoint, Google Slides)
4. Whiteboard or flip chart for brainstorming
5. Markers or pens

What to do

1. Identify friends to form a group
2. **Explore Applications of Specific Heat Capacity:** Research on the various industries below using search engines.
   a. Manufacturing
   b. Construction
   c. Energy efficiency
3. **Gather Information**
   a. Take notes on key points, examples, and diagrams that illustrate the significance of specific heat capacity in each application.
   b. Identify real-world examples or case studies that highlight its importance.
4. **Presentation Preparation**
   a. Organise your findings into a clear presentation format.
   b. Assign sections to each group member based on their research focus.
   c. Include visuals such as charts, images, or videos to enhance your presentation.
   d. Present your findings to the class, ensuring each member shares their section.
   e. Engage with classmates by inviting questions and discussions about the applications of specific heat capacity.

LATENT HEAT

The word "latent" means hidden or concealed. It refers to something present but not directly observable.

In the context of heat, "latent heat" refers to the heat energy absorbed or lost when there is a change of phase or state of a substance (e.g. from solid to liquid or liquid to gas), without any change in temperature (hence this process is 'hidden' as it is undetectable by a thermometer). The temperature does not change because the applied heat is being used to break the bonds between the molecules rather than increase the kinetic energy of the particles.

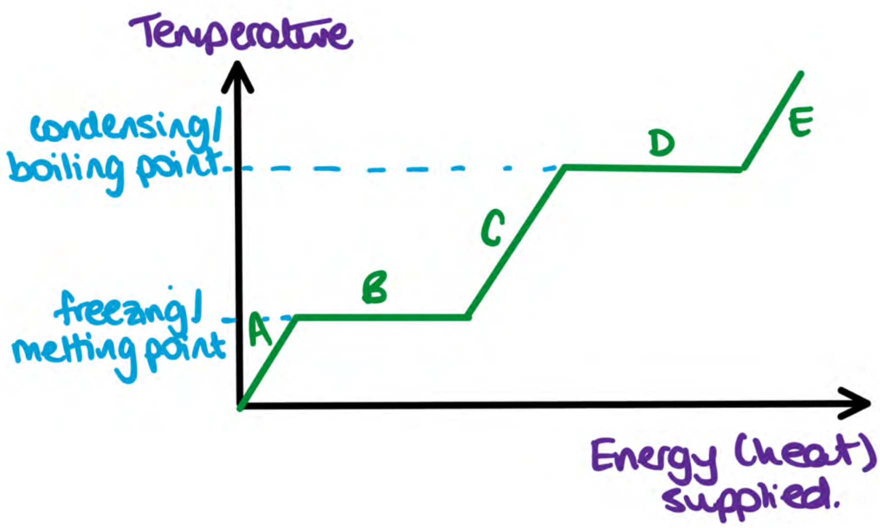

Figure 2.3: The temperature of a substance as heat is supplied.

From the diagram, Sections A, C and E show an increase in temperature while the substance is in its solid, liquid and gaseous states respectively. Sections B and D show no change in temperature whilst the substances changes state (melts and evaporates respectively)

Latent heat of fusion

When you put a bottle of water in the freezer, it turns into ice. When you take that frozen bottle out, the ice melts back into liquid water. This shows that water can switch between liquid and solid states.

When water freezes into ice, its temperature remains constant, even as it loses heat. This heat lost during the change from water to ice is called the latent heat of fusion. Similarly, ice absorbs this same amount of heat to melt back into water when taken out of the freezer.

Specific latent heat of fusion is the amount of heat required or removed to change 1 kg of a substance from solid to liquid (or vice versa) without changing its temperature. The standard unit for specific latent heat of fusion is J/kg.

Latent heat of vaporisation

When you boil water, it changes into steam through boiling. If you cover the boiling water with a lid, you'll see droplets forming on the underside of the lid as the steam cools and condenses back into liquid.

These two processes—evaporation and condensation—are opposites of each other.

When water boils, even though you keep adding heat, the temperature of the water stops rising once it reaches its boiling point. All the extra heat is used to turn the water into steam, and this energy is called the latent heat of vaporisation.

On the other hand, when steam cools and turns back into water (condensation), it releases this same amount of energy, still called latent heat of vaporisation because it's the reverse of evaporation.

Specific latent heat of vaporisation is the quantity of heat required or removed when 1 kg of a substance changes from liquid to vapour or from vapour to liquid without a change in temperature. The standard unit for specific latent heat of vaporisation is J/kg.

Mathematical representation of specific latent heat

$$l = \frac{Q}{m}$$

Where;

l is specific latent heat [l_f for fusion, l_v for vaporisation]

Q is the quantity of heat absorbed or lost

m is the mass of the substance

Activity 2.7 Matching the process with the definition

Match the letters with the numbers in the lists below to provide the correct definition for each word:

Table 2.3: Process matching

Process	Definition
A Melting	1 The process of a solid changing directly into a gas without passing through the liquid state. This process requires the addition of heat energy to the solid.
B Freezing	2 the process of a liquid turning into vapour (gas) throughout the volume of the liquid, at its boiling point. It also involves the addition of heat.
C Boiling	3 The process of a solid turning into a liquid at its melting point. This involves the addition of heat energy.
D Condensation	4 The process by which a gas turns directly into a solid without passing through the liquid state. It occurs when a gas is cooling.
E Sublimation	5 The process of a gas turning into a liquid in the course of cooling. This occurs at the condensation point of the substance, which is the same as its boiling point.
F Deposition	6 The process of a liquid turning into a solid at its freezing point. This involves the removal of heat energy.

Activity 2.8 Modelling the behaviour of particles

For this activity you should be in groups of approximately 20 learners. Split into two sub-groups of around 10 people. Name yourselves group 1 and group 2.

Group 1 are the advisors. They will watch group 2 and offer constructive feedback on how group 2 could improve their model.

Group 2 are the modellers. They should follow the instructions below, step by step:

1. Arrange yourselves as though you are each individual particle that are making up a solid.
2. Act as though you are increasing in temperature but remaining solid.
3. ‘Melt’ into a liquid.

4. Increase in temperature, remaining liquid.
5. 'Evaporate' into a gas.

Activity 2.9 Comparing Methods for Determining Specific Latent Heat

Objective: To research and compare different methods for determining specific latent heat, analysing their relative benefits and drawbacks.

Materials needed

1. Access to computers or devices with internet connectivity
2. Textbooks or scientific journals
3. Note-taking materials

What to do

1. Identify a friend or friends to form a small learner group.
2. **Group Research**
   a. In groups, research the methods for determining specific latent heat of fusion and vaporisation: Method of Mixtures, Electrical Method, Continuous Flow Method etc
   b. Use textbooks, online resources, or scientific journals to gather information about each method.
   c. Search for videos demonstrating each method and watch.
3. **Analysis**
   Analyse the strengths and weaknesses of each method, considering factors such as accuracy, precision, ease of use, cost, time required, and applicability to different materials.
4. **Comparison and Discussion**
   a. Compare and contrast the different methods in a class discussion.
   b. Discuss the advantages and disadvantages of each method.
   c. Identify the most suitable method for different applications based on the analysis.
5. **Presentation**
   a. Prepare a presentation summarising your findings.
   b. Present your findings to the class, explaining your method and discussing its advantages and disadvantages.

Activity 2.10 Determination of specific latent heat of fusion of ice

Materials needed

1. Calorimeter
2. Stirrer
3. Thermometer
4. Ice (in small pieces)
5. Blotting paper (for drying ice)
6. Water
7. Balance/scale (for measuring mass)
8. measuring cylinder (optional, for measuring water volume),
9. Insulating material (to minimise heat loss)

What to do

1. Weigh the empty container (calorimeter) and its stirrer. Write down its weight as m_c.
2. Fill the container halfway with water, let it sit for five minutes, and record the water's temperature as θ_1.
3. Weigh the container again to find out the mass of water m_w inside.
4. Dry some ice using a paper towel and add the ice to the water, a little at a time.
5. Stir the water until all the ice melts completely.
6. Check and record the new temperature of the water after all of the ice has melted, calling it θ_2.
7. Weigh the container again to figure out the mass of ice added m_i.
8. The heat lost by the water and container is equal to the heat needed to melt the ice and warm it up to the final temperature, θ_2. Calculate the SHC (l_f) of the ice as follows (assume no heat is transferred from surroundings or from the calorimeter itself):

   [*Heat gained by ice*] = [*Heat lost* by water]

   $m_i l_f + m_i c_w (\theta_2 - 0) = m_w c_w (\theta_1 - \theta_2)$

   $m_i (l_f + c_w \theta_2) = m_w c_w (\theta_1 - \theta_2)$

   $l_f = \dfrac{m_w c_w (\theta_1 - \theta_2)}{m_i} - c_w \theta_2$

Note: we have assumed the starting temperature of the ice to be zero degrees Celsius, but this could be verified using a thermometer.

If you do not have the equipment necessary to perform this practical, please watch the video below:

QR code for specific latent heat video

Activity 2.11 Determination of the specific latent heat of vaporisation of water

Materials needed

1. Kettle
2. Power source
3. Stirrer
4. Stopwatch
5. Water
6. Balance/scale (for measuring mass)

What to do

1. Note the power of the kettle by finding in on the label (usually 1200-1500W). Note this down as P_k.
2. Half-fill the kettle with water.
3. Leave the kettle on top of the balance and set the balance to zero.
4. Turn the kettle on, with its lid off (or lifted). Start the stopwatch then the kettle begins to boil.
5. Let the kettle boil for $t = 5$ minutes. At the end of the time, note down the mass of water which has boiled away m_w (the value on the balance, which will be negative).

6. Calculate the energy supplied during the boiling by:

Energy Q = Power P_k × time t

Calculate the specific latent heat of vaporisation by:

$$l_v = \frac{Q}{m_w}$$

Conclusion: Why is your value an approximation only? Is the value higher or lower than the true value, and why?

Activity 2.12 Calculating Specific Latent Heat

Read the worked example below before attempting the problems that follow.

Worked example

1. Calculate the amount of energy required to convert 250 g of water at 100°C into steam at 100°C? The latent heat of vaporisation of water is 2,260,000 J/kg

Step-by-Step Solution for Question 1

Step 1: Identify the given information

m = 250 g = 0.25 kg

l_v = 2,260,000 J/kg

Step 2: Introduce the formula for the heat energy (Q) required for the phase change

$$l_v = \frac{Q}{m}$$

$$Q = m\,l_v$$

Step 3: Substitute the known values into the formula:

Q =0.25 kg × 2,260,000 J/kg

Step 4: Calculate and get your answer:

Q = 0.25·2,260,000=565,000 J

So, the heat energy required is **565,000 J**

Practice Problems

1. How much heat energy is required to melt 500 g of ice at 0°C, given that the latent heat of fusion of ice is l_f=334,000 J/kg?
2. A 0.15 kg block of a solid substance at 0°C is added to 0.40 kg of water at 8.0°C in a well-insulated calorimeter. If the final temperature of the water after all the ice melts is 0°C, calculate the specific latent heat of fusion of the substance. Assume no heat is lost to the surroundings, and the specific heat capacity of water is 4200 J/kg°C.

Activity 2.13 Investigating Latent Heat and Its Real-World Applications

Objective: Research and present on the applications of latent heat in various industries.

Materials Needed

1. Access to the internet for research (laptops/tablets)
2. Notebooks or digital devices for note-taking
3. Presentation software (e.g., PowerPoint, Google Slides)
4. Whiteboard or flip chart for brainstorming
5. Markers or pens

What to do

1. Identify friends to form a group
2. **Explore Applications of Latent Heat:** Research on the various industries and applications below using search engines.

   Applications of latent heat

   i. Refrigeration and Air Conditioning
   ii. Melting of Ice in Roads
   iii. Phase Changes in Power Plants
   iv. Cooking with Steam
   v. Body Cooling through Sweating

3. **Gather Information**

   a. Take notes on key points, examples, and diagrams that illustrate the significance of latent heat in each application.

   b. Identify real-world examples or case studies that highlight its importance.

4. **Presentation Preparation**
   a. Organise your findings into a clear presentation format.
   b. Assign sections to each group member based on their research focus (e.g., one person covers HVAC systems, another covers food preservation).
   c. Include visuals such as charts, images, or videos to enhance your presentation.
   d. Present your findings to the class, ensuring each member shares their section.
   e. Engage with classmates by inviting questions and discussions about the applications of latent heat.

Activity 2.14 Investigating the Effects of Salt on Ice Melting Time

Objective: Conduct an experiment to compare the melting times of ice cubes made from pure water and those made with added salt.

Materials Needed

1. Ice cubes (made from pure water)
2. Ice cubes (made from saltwater)
3. Two transparent containers (e.g., bowls)
4. Room temperature water
5. Stopwatch or timer
6. Thermometer (optional)
7. Measuring cup (for water)
8. Notebook or digital device for recording observations

What to do

1. **Set Up the Experiment**
   a. Fill both transparent containers with the same amount of room temperature water.
   b. Place one ice cube made from pure water in one container and one ice cube made from saltwater in the other.

2. **Conduct the Experiment**
   - **a.** Start the timer as soon as you place the ice cubes in the water.
   - **b.** Observe and record the time it takes for each ice cube to completely melt.
   - **c.** Note any differences in melting rates between the two types of ice cubes.
3. **Record Observations**
   - **a.** Write down your observations, including:
     - **i.** The time taken for each ice cube to melt.
     - **ii.** Any noticeable differences in how the ice melts (e.g., bubbling, temperature changes).
4. **Write Your Explanation**
   - **a.** In your notebook or digital document, write a detailed explanation of your observations:
     - **i.** Discuss how latent heat is involved in the melting process.
     - **ii.** Explain why the ice cube with added salt melted faster due to its lower freezing point.
5. **Summarise Practical Applications**
   - **a.** Research and summarise how this phenomenon applies to food preservation and refrigeration:
     - **i.** Explain how salt is used in food preservation methods (e.g., salting meats).
     - **ii.** Discuss how refrigeration systems utilize latent heat principles to maintain food quality.

EXTENDED READING

1. Asiedu, P., & Baah-Yeboah, H. A. (n.d.). *Physics for Senior High Schools* (4th ed., pp. 217-234). Aki-Ola Publications.
2. Abbott, A. F. (n.d.). *Principles of Physics* (5th ed., pp. 184, 204-212, 472-483). Longman.
3. Giancoli, D. C. (2008). *Physics for scientists and engineers* (4th ed., pp. 453-464). Pearson Prentice Hall.

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5. Nelkon, M., & Parker, P. (1970). *Advanced level physics* (3rd ed., pp. 119-219). Heinemann Educational Books.
6. Serway, R. A., & Jewett, J. W. (2013). *Physics for scientists and engineers with modern physics* (9th ed., pp. 388-398). Brooks/Cole.
7. Young, H. D., & Freedman, R. A. (2012). *University physics with modern physics* (13th ed., pp. 515-524). Pearson.

REVIEW QUESTIONS

Review Questions 2.1 (Specific Heat Capacity)

1. What is the formula used to calculate the heat energy required to raise the temperature of a substance?
2. a. Define specific heat capacity.

   b. Explain how it affects the amount of heat needed to change a substance's temperature.
3. A 500 g block of copper (specific heat capacity = 0.39 J/g°C) is heated from 20°C to 80°C. How much heat energy is absorbed by the block?
4. A 1 kg sample of a substance is heated, and its temperature rises by 10°C. The specific heat capacity of the substance is 0.5 J/g°C. If a second sample with double the mass is heated under the same conditions, what will be the temperature rise?
5. Coastal areas often experience milder temperatures than inland areas due to the specific heat capacity of water. Explain how the specific heat capacity of water influences temperature regulation in coastal areas and contributes to the moderation of extreme temperatures.

Review Questions 2.2 (Latent Heat)

1. Define specific latent heat of vaporisation and state its SI units.
2. Explain why the temperature of a substance undergoing a phase change remains constant.
3. A block of ice of unknown mass at 0°C is added to 0.315 kg of water at 10°C in a well-insulated calorimeter. If the final temperature of the water after all the ice melts is 5°C, calculate the mass of the ice. Assume there is no heat loss to the surroundings and the specific heat capacity of water is 4200 J/kg°C, the specific latent heat of fusion of ice is 334000 J/kg.
4. After a rain shower on the skin, the drops of water begin to dry off and one begins to feel cold. Describe the process that leads to the drying of the water and explain why the sensation of coldness is felt.

SECTION

3 ELECTROSTATICS

ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Electrostatics

INTRODUCTION

This section explores electric field concepts and Coulomb's law of electrostatics to understand how electric forces between charges depend on their magnitude and separation. We will study electric field strength, which measures the intensity at a point in an electric field, and potential difference, which reflects the energy needed to move a charge between two points. Capacitors, which store energy by holding charge on their plates as well as their arrangement and behaviour will be examined in both DC and AC circuits focusing on charging and discharging. Understanding how capacitors store and manage energy is essential for applications like power supplies, signal filtering, and energy storage, as well as for understanding how electronic devices and electric fields function in real-world scenarios like camera flashes, defibrillators (used to provide high voltages to start the heart), touchscreens and sensors, etc.

KEY IDEAS

- A capacitor is a charge storing device.
- Capacitance is the ratio of the charge to the potential to which it is raised.
- Charging a capacitor is the process of depositing charges on the plates of a capacitor when it is connected to a DC source.
- Coulomb's law of electrostatics states that: *"the magnitude of the electrostatic force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them"*.
- Discharging a capacitor is a process in which the voltage across the capacitor decreases due to the flow of charges through a resistor, which has a voltage across it proportional to the current flowing through it.

- Electric field is the region or area around a charged body where the electric force of the charged body can be experienced.
- Electric field strength is the force per unit positive charge at a point.
- Potential difference is the work done in moving a unit charge from one point to another in an electric field.

ELECTRIC FIELDS

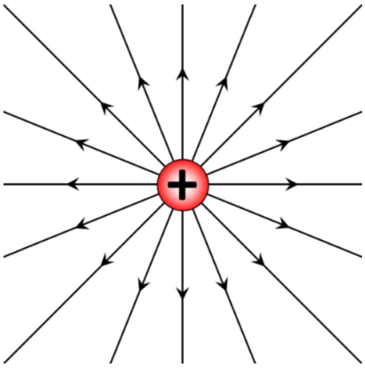
Electric Field Patterns

When a magnetic material is placed near a permanent magnet, it experiences a magnetic force because it is within the magnet's magnetic field. Similarly, an electric field can either attract or repel charges depending on their nature. Just as a magnet's field draws magnetic materials toward it, the charges influenced by the electric field experience an electric force because they are located within that field.

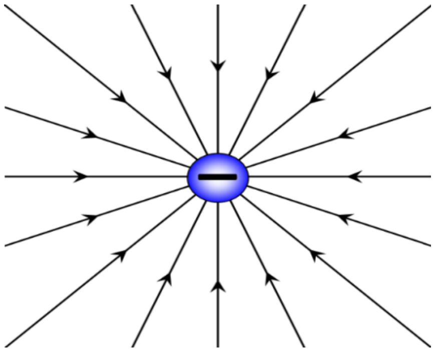
An electric field is the area or region around a charge where the electric force of the charge can be experienced. An electric field is represented with electric field lines of electric lines of force.

Some characteristics of electric field lines

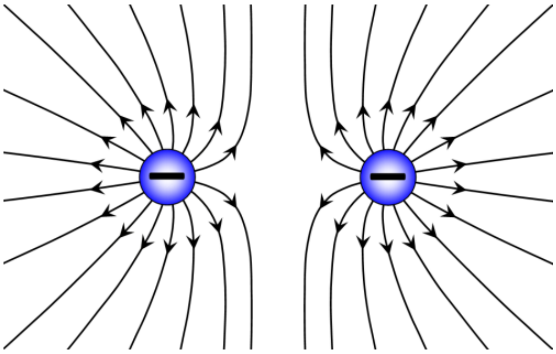
1. The direction of the electric field at any point is indicated by the direction of the field lines at that point.
2. Electric field lines never intersect or cross each other.
3. Closer lines indicate a stronger electric field.
4. Electric field lines point away from positive charges and toward negative charges.
5. Electric field lines meet surfaces at 90 degrees to the surface.
6. For two like charges, the field lines repel and curve outward.
7. For two opposite charges, the lines attract and connect the two charges directly.



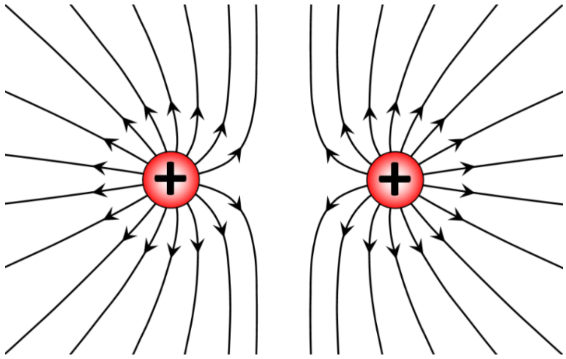
A: Electric field lines of a positive charge



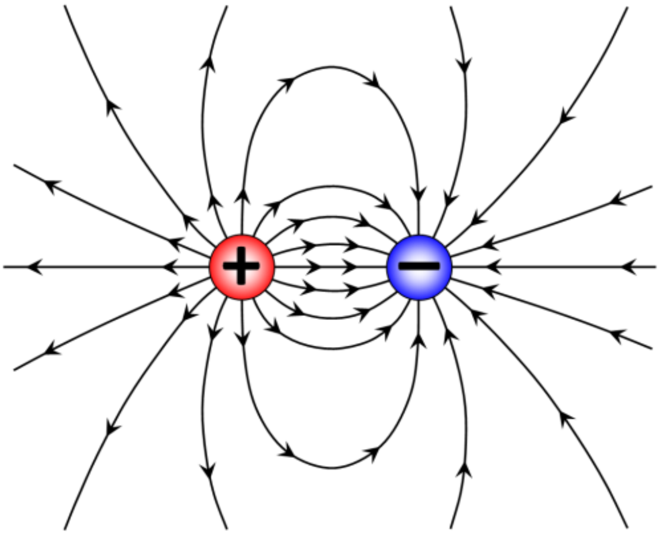
B: Electric field lines of a negative charge



C: Electric field lines of positive charges repelling



D: Electric field lines of negative charges repelling



E: Electric field lines of opposite charges attracting

Figure 3.1: Electric field lines

Activity 3.1 Exploring Electric Fields

Materials Needed

1. Balloons (preferably two of different colours)
2. Small pieces of lightweight paper (cut or ripped into small squares)
3. String (to hang the balloons)
4. A clear area to conduct the experiment

What to do

1. Inflate the two balloons and tie them securely.
2. Cut the lightweight paper into small squares to serve as "charged particles."
3. Hang the balloons from a string in a space where they can move freely, ensuring they are about 1-2 feet apart.
4. Rub each balloon on your hair or a piece of fabric to give them static charge.
5. Slowly bring the two charged balloons close together and record your observation.
6. Now, take the small pieces of papers and gently sprinkle them around the balloons.

Figure 3.2: Papers sprinkled on balloon

7. Record your observation.
8. Identify friends in your class and discuss your observations from the activity in relation to these questions:
   a. How did the balloons behave when brought close together?
   b. What happened to the confetti (small pieces of coloured paper) near the charged balloons?

Activity 3.2 Exploring Electric Field Patterns through Video Research

Objective: To understand electric field patterns by researching and watching videos that demonstrate the visualisation of these patterns using semolina on an oil surface.

Materials Needed

1. Access to the internet (computers, tablets, or smartphones)
2. Video platforms (YouTube, educational websites)
3. Notebook and pen/pencil (for taking notes)

What to do

1. In small groups, review what you know about electric fields.
2. Use your device (computer, tablet, or smartphone) to search for videos that demonstrate the visualisation of electric field patterns using semolina on an oil surface. Here are some suggested search terms:
   a. "Electric field visualisation semolina oil"
   b. "Electric field patterns demonstration"
   c. "Physics experiments with electric fields"
3. Choose at least two videos to watch. Look for videos that clearly explain the setup and the results of the experiment.
4. Watch the videos but as you watch each video, pay close attention to and take notes on:
   a. the materials used in the experiment.
   b. how the semolina behaves in response to the electric field.
   c. any explanations provided about the principles behind what you are observing.
   d. key observations about the electric field patterns.
   e. important scientific concepts or terminologies mentioned.
   f. any questions or thoughts that arise during the viewing.
5. After watching, prepare to share your findings with your classmates. Think about:
   a. what you found most interesting or surprising.
   b. how this experiment helps you understand electric fields better.
   c. any differences you noticed between the videos you watched.

6. Participate in a group discussion where you will share your observations and insights with your classmates. Be ready to discuss your notes and answer questions from others.
7. After the discussion, write a short reflection (1-2 paragraphs) about what you learned from this activity. Consider how visual demonstrations can enhance your understanding of abstract concepts like electric fields.

Activity 3.3 Experiment to Visualise Electric Fields Using Semolina

Materials Needed

- A large flat tray or shallow dish
- Castor oil
- Semolina (or fine sand)
- Two metal objects (e.g., two metal plates, spheres, nails etc)
- A high-voltage power supply
- A piece of cardboard or stiff paper
- Electrical wires with alligator clips
- A ruler (optional)

Procedure

1. Place the flat tray or shallow dish on a stable surface. Fill it with a thin layer of castor oil, which has been warmed on a radiator, spreading it evenly across the bottom.

2. Position the two metal objects in the tray, one near each side. These will serve as the electrodes. Ensure that both ends are submerged in the castor oil.

3. Attach electrical wires with alligator clips to the metal objects. Connect the wires to the high-voltage power supply.

4. Sprinkle a thin later of iron filings over the top.

5. Set the high-voltage power supply to a low voltage first. Gradually increase the voltage. As you increase the voltage, the electric field created by the metal objects will begin to influence the semolina on the tray. The semolina grains will shift and settle into patterns that reflect the shape of the electric field. These patterns are formed because the grains are small and lightweight, and they move in response to the electric forces.

6. Sketch a diagram of what you see.
7. Try changing the distance between the electrodes to see how it affects the field pattern.
8. Test different shapes and sizes of the electrodes (e.g., using spheres or flat plates) to see how they influence the field lines.

Tips

- Make sure the voltage is not too high to avoid any risk of electrical shock.
- The patterns may be clearer if you gently tap the tray to settle the semolina into position.

Activity 3.4 Hypothesising Electric Field Patterns

For each of the diagrams below, sketch your prediction of the shape and direction of the electric field pattern that would be produced between the two charged objec

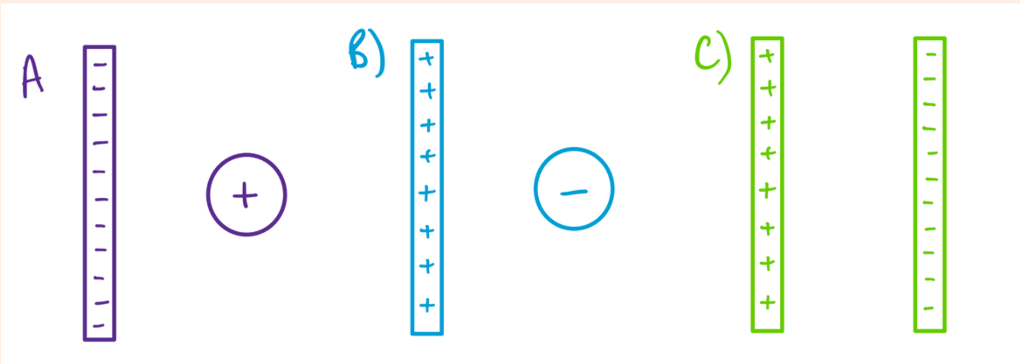


Figure 3.3: Arrangements of Charged Objects

Coulomb's law of electrostatics

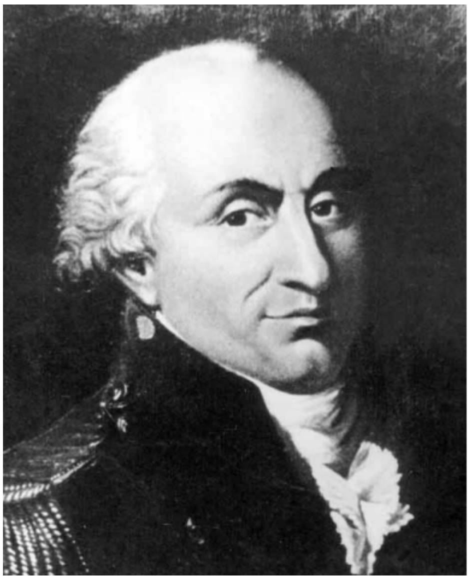


Figure 3.4: Charles Coulomb

Coulomb's Law is all about how electric charges interact with each other. As learnt earlier, when you have two balloons and you rub them on your hair, they get static electricity and can stick to each other or even repel (push away) from each other. Coulomb's Law helps us understand why that happens!

The Basics of Charges

There are two types of electric charges: positive (+) and negative (−)

1. **Like Charges Repel**: If you have two positive charges or two negative charges, they push away from each other.
2. **Opposite Charges Attract**: If you have one positive charge and one negative charge, they pull towards each other.

Coulomb's Law tells us how strong the force is between two charges. Here's how it works:

1. **Distance Matters**: The closer the charges are to each other, the stronger the force. Imagine if you and your friend are trying to hug.
2. **Amount of Charge Matters**: The more charge something has, the stronger the force.

Coulomb's law of electrostatics states that: *"the magnitude of the electrostatic force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them"*

Mathematically, this can be expressed as:

$$F \propto \frac{|q_1 \times q_2|}{r^2}$$

$$F = k\frac{|q_1 \times q_2|}{r^2}$$

Where:

- F is the electrostatic force
- k is Coulomb's constant
- q_1 and q_2 are the magnitudes of the charges
- r is the distance between the charges

Coulomb's constant, k, is equal to $\frac{1}{4\pi\varepsilon 0}$.

ε_0 is known as the permittivity of free space, a constant which reflects the ability of an electric field to pass through a vacuum.

Activity 3.5 Finding the unit for Coulomb's constant and for permittivity of free space

By analysing the units in the formula for Coulomb's law (above), find the unit for Coulomb's constant. Note: you should start by rearranging the formula to make k the subject. Choose the correct answer from the options below:

1. m^2C^{-2}
2. NmC^{-2}
3. Nm^2C^{-2}
4. Nm^2C^2

Next, use this result to find the unit for permittivity of free space.

Activity 3.6 Exploring Coulomb's Torsion Balance and Electrostatic Forces

Objective: To learn about Coulomb's torsion balance and discover the relationship between electrostatic force, distance, and charge.

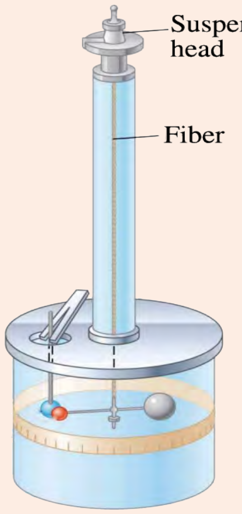


Figure 3.5: Coulomb's Torsion Balance

What You Will Do

1. Find and watch the video titled **"Coulomb's Torsion Balance"** on YouTube.
2. While watching the video, take notes on the following points:
   a. How does the torsion balance measure electrostatic force?
   b. What happens to the angle of twist when charges are introduced?
   c. How do distance and charge affect the electrostatic force?
3. After watching the video, you will participate in a group discussion with your classmates. Share your notes and observations. Discuss these questions:
   a. What did you find most interesting about Coulomb's experiments?
   b. Why is understanding electrostatic forces important in physics?
   c. Can you think of real-world applications of Coulomb's findings?
4. Write a short reflection in your notebook about what you learned from this activity. Include:
   a. Your understanding of the relationship between charge, distance, and electrostatic force.
   b. How Coulomb's work has influenced modern physics.

Activity 3.7 Calculating Electrostatic Force

Read the worked examples below before attempting the example questions that follow.

Worked Example 1

Two point charges of +3 μC and -5 μC are separated by a distance of 2 metres in a vacuum. Calculate the magnitude of the force between them. (Use Coulomb's constant $k = 9 \times 10^9$ Nm²/C².)

Step-by-Step Solution for Question 1

Step 1: Identify the given values

Charge 1, $q_1 = +3\ \mu C = 3 \times 10^{-6}$ C

Charge 2, $q_2 = -5\ \mu C = -5 \times 10^{-6}$ C

Distance between the charges, r = 2 m

Coulomb's constant, $k = 9 \times 10^9$ N·m²/C²

Step 2: Introduce the Coulomb's Law

$$F = k\frac{|q_1 \times q_2|}{r^2}$$

Step 3: Substitute the known values into the formula

$$F = 9 \times 10^9 \frac{3 \times 10^{-6} \times 5 \times 10^{-6}}{2^2}$$

Step 4: Simplify and calculate to obtain the answer

$$F = 9 \times 10^9 \frac{1.5 \times 10^{-11}}{4}$$

$$F = 3.375 \times 10^{-2} N$$

Worked Example 2

Three charges are positioned along a straight line. +1 μC is at the origin, -3 μC is 2 metres to the right, and +4 μC is 3 metres to the right of the +1 μC charge. Calculate the net force on the +1 μC charge. (Use $k = 9 \times 10^9$ Nm²/C²).

Step-by-Step Solution

Step 1: Identify the given values:

Charge 1 (q_1): +1 μC = $+1 \times 10^{-6}$ C (at origin)

Charge 2 (q_2): -3 μC = -3×10^{-6} C (2 m to the right)

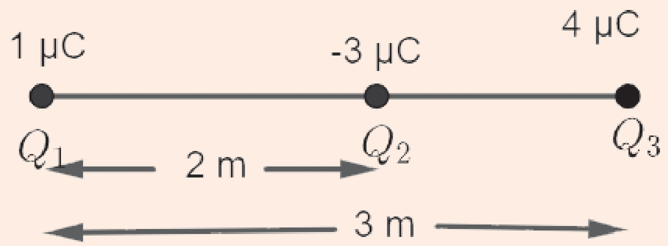
Charge 3 (q_3): +4 μC = $+4 \times 10^{-6}$ C (3 m to the right)

Distance between q_1 and q_2 (r_{12}): 2 m

Distance between q_1 and q_3 (r_{13}): 3 m

Coulomb's constant (k): 9×10^9 N·m²/C²

Step 2: Sketch the diagram to show the distribution of charges on a straight line



Step 3: Calculate the force between q_1 and q_2 (F_{12})

$$F_{12} = k\frac{|q_1 \times q_2|}{r_{12}^2}$$

$$F_{12} = 9 \times 10^9 \frac{|+1 \times 10^{-6} \times -3 \times 10^{-6}|}{2^2}$$

$$F_{12} = 9 \times 10^9 \frac{3 \times 10^{-12}}{4}$$

$$F_{12} = 6.75 \times 10^{-3} \text{ N}$$

Since q_1 and q_2 have opposite charges, the force F_{12} is attractive, and it acts towards the right.

Step 4: Calculate the force between q_1 and q_3 (F_{13})

$$F_{13} = k\frac{|q_1 \times q_3|}{r_{13}^2}$$

$$F_{13} = 9 \times 10^9 \frac{|+1 \times 10^{-6} \times +4 \times 10^{-6}|}{3^2}$$

$$F_{13} = 9 \times 10^9 \frac{4 \times 10^{-12}}{9}$$

$$F_{13} = 4 \times 10^{-3} \text{ N}$$

Since q_1 and q_3 have the same charge, the force F_{13} is repulsive, and it acts towards the left.

Step 5: Determine the net force on q_1

Since F_{12} acts towards the right and F_{13} acts towards the left, we subtract the smaller force from the larger one to find the net force:

Net force = F_{12} - F_{13}

Net force = 6.75×10^{-3} N - 4×10^{-3} N

Net force = 2.75×10^{-3} N

Therefore, the net force on the +1 µC charge is 2.75×10^{-3} N, directed towards the right.

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. Two point charges, +2 µC and -4 µC, are separated by a distance of 3 metres in a vacuum. Calculate the magnitude of the electrostatic force between them. (Use k = 9×10^9 N·m²/C²).
2. Two positive charges of +5 µC each are placed 5 metres apart in a vacuum. Determine the magnitude of the repulsive force between them. (Use k = 9×10^9 N·m²/C²).
3. Two point charges, +4 µC and -6 µC, exert an attractive force of 0.3 N on each other in a vacuum. Calculate the distance between the charges. (Use k = 9×10^9 N·m²/C²).
4. Three charges are positioned along a straight line. A +2 µC charge is at the origin, a -5 µC charge is 3 metres to the right, and a +6 µC charge is 4 metres to the right of the +2 µC charge. Calculate the net force on the +2 µC charge. (Use k = 9×10^9 N·m²/C²).

Activity 3.8 Design an experiment to verify Coulomb's Law

Design an experiment which could be used to verify Coulomb's inverse-square law; i.e. to prove that the force acting on a charged particle in an electric field decreases with distance according to $\frac{1}{r^2}$.

You are not expected to conduct your experiment.

Activity 3.9 Research task

Conduct research on the use of Coulomb's Law in technology. Prepare a report and presentation explaining its importance in devices such as electrostatic precipitators and photocopiers.

ELECTRIC FIELD STRENGTH AND POTENTIAL DIFFERENCE

Electric field strength

We know that a body raised above the ground level has a certain amount of gravitational potential energy which, by definition, is given by the amount of work done in raising it to that height. The body falls because there is attraction due to gravity. Its fall always proceeds from a place of higher potential energy to one of lower potential energy.

Now, consider an electric field. Imagine an isolated positive charge Q placed in air. Like Earth's gravitational field, it has its own electrostatic field which theoretically extends up to infinity. If the charge q is very far away from Q, say, at infinity, then the force on it is zero. As q is brought nearer to Q, a force of repulsion acts on it (as similar charges repel each other), hence work or energy is required to bring it to a point *within* in the electric field (point A).

Hence, when at point A, charge q has some amount of electric potential energy. Similar other points in the field will also have some potential energy.

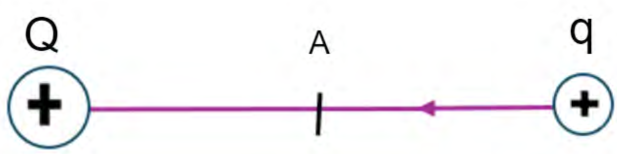


Figure 3.7: Source charge Q with field E and test charge q

The strength of the field at any point is defined as the force experienced by a unit positive charge placed at that point. Its direction is the direction along which the force acts.

Mathematically, the field strength can be determined as; $E = \frac{F}{q}$ measured in NC^{-1},
Where:

E is the electric field strength

F is the force of attraction or repulsion in newton (N)

q is charge in coulomb (C)

but

$$F = k\frac{|Q \times q|}{r^2}$$

Then the electric field strength (E) due to a point charge (Q) at a distance r is given by:

$E = k\frac{|Q|}{r^2}$

Electric potential (V)

It is the work done (W) or energy spent on bringing a unit test charge from infinity to a point in an electric field, i.e., the work done per unit charge in moving from infinity to a point in an electric field.

Mathematically stated, $V = \frac{W}{q}$, $in\ JC^{-1}$ or volts

You may wonder, if a charge is already in the field, and is moving between any two points within the field, does it have to do any work? Certainly yes, just the way you do some work in moving from your classroom to the school field. The work done by a unit charge is the difference in electric potential between the two points. It is called the **potential difference,** or **voltage.**

For example, if a unit charge moves from point **A** to another point **B**, the work done, or potential difference $\Delta V = V_A - V_B$

Relationship between E and V: Uniform electric fields

Consider two parallel conducting plates, A and B, separated by d,

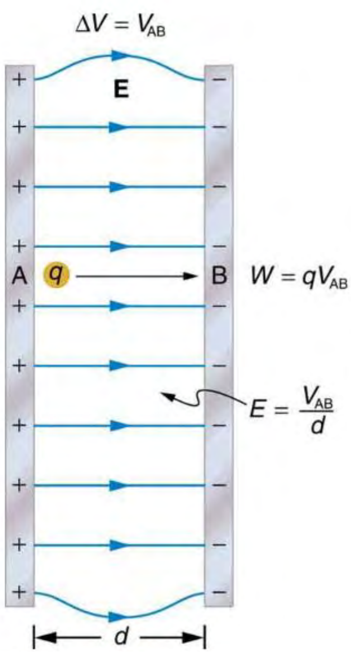


Figure 3.8: Parallel conducting plates

The potential at A is V_A and that at B is V_B.

$$E = \frac{F}{q} = \frac{(W\_d)}{q} = \frac{W}{qd} = \frac{V}{d}$$

$$E = \frac{V}{d}$$

$\left[E = \frac{V}{d} = \frac{V_{AB}}{d}\right]$, measured in Vm^{-1}

For a charge q moving from A to B, the potential difference is:

$$V_{AB} = V_B - V_A = \Delta V$$

$$V_{AB} = -\left(V_A - V_B\right) = \Delta V$$

$$V_{AB} = \left(V_A - V_B\right) = -\Delta V$$

Where $V_{AB} = \Delta V$ *in magnitude*

Therefore, the work done W, in moving the charge is:

$$w = Fd,$$

$$but\ F = Eq,\ and\ Ed = V$$

$$W = Eqd$$

$$W = Vq,$$

$$but\ V = -\Delta V = V_{AB}$$

$$W = -q\,\Delta V$$

$$\boldsymbol{W = qV_{AB}}$$

Activity 3.10 Differences between Electric Potential and Electric Field Intensity

Fill in the table below

Table 3.1: Electric Potential and Electric Field Intensity

	Electric Potential	Electric Field Intensity
Definition		
Unit		
Scalar or vector		
Variation with distance from source charge		

Activity 3.11 How Electric Field Strength and Potential Vary with Distance in a Uniform Field

Materials needed

1. Mathematical set
2. Calculator
3. At least four graph sheets

What to do

1. Form groups of three, copy and complete the table below using the following information:

   $E = \frac{V}{d}$, given that $E = 8.99 \times 10^7\ Vm^{-1}$.

d/m	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
V/V										

2. Plot two graphs:
   a. E on the vertical axis and d on the horizontal axis
   b. V on the vertical axis and d on the horizontal axis
3. Compare your graphs with the solutions in **Annex A**.
4. Explain how the graphs confirm the relationship established in the equations above.

Activity 3.12 How electric field strength and potential vary with distance

Materials needed

1. Mathematical set
2. Calculator
3. At least four graph sheets

What to do

1. Form groups of three, copy and complete the tables below using the following information:

   $E = k\frac{Q}{r^2}$............1,

$k = 8.99 \times 10^9\ Nm^2C^{-2},\ Q = 1.0\ \mu C$

$V = k\frac{Q}{r}$..........2

r/m	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
r^2/m^2										
E/ NC^{-1}										
V/V										

2. Plot two graphs

a. E on the vertical axis and r on the horizontal axis

b. V on the vertical axis and r on the horizontal axis

3. Compare your graphs with the solutions in **Annex A**.

4. Explain how the graphs confirm the relationship established in the equations [1 and 2] above.

Activity 3.13 Calculating Electric field strength and Electric potential

Read the worked examples below before attempting the example questions that follow.

Worked Example 1

Two points, A and B, are in an electric field created by a point charge. The electric potential at point A is V_A=120 V, and at point B, it is V_B = 80 V. What is the potential difference between points A and B?

Step-by-Step Solution for Question 1

Step 1: Identify the given values

$V_A = 120$ V

$V_B = 80$ V

Step 2: Introduce the potential difference ΔV formula

$\Delta V = V_A - V_B$

Step 3: Substitute the given values:

$\Delta V = 120\ V - 80\ V$

Step 4: Calculate to get your answer

$\Delta V = 120\,V - 80\,V = 40\,V$

The potential difference between points A and B is 40 V

Worked Example 2

A uniform electric field exists between two parallel plates separated by a distance of 0.05 m. If the potential difference between the plates is 200 V, calculate the electric field strength between the plates.

Step-by-Step Solution

Step 1: Identify the given values

$d = 0.05\ m$

$V = 200\ V$

Step 2: Introduce the formula for electric field strength E

$E = \frac{V}{d}$

Step 3: Substitute the given values:

$E = \frac{200}{0.05}$

Step 4: Calculate to get your answer

$E = 4000\ V/m$

The electric field strength between the plates is **4000 V/m.**

Worked Example 3

A 2×10^{-6} C charge is moved between two points in an electric field where the potential difference is 50 V. How much work is done to move this charge?

Step-by-Step Solution

Step 1: Identify the given values

$q = 2\times10^{-6}\ C$

$V = 200\ V$

Step 2: Introduce the formula for work done W to move a charge q across a potential difference V

$W = qV$

Step 3: Substitute the given values

$W = 2\times10^{-6}\times50$

Step 4: Calculate to get your answer

$W = 1\times10^{-4}\,J$

The work done to move the charge is **0.0001 J** or **1×10^{-4} J**

Worked Example 4

A charge +5 μC is placed in a uniform electric field 2×10^{4} N/C. Calculate the force experienced by the charge.

Step-by-Step Solution

Step 1: Identify the given values

$q = 5\mu C = 5\times10^{-6}\,C$

$E = 2\times10^{4}\,N/C.$

Step 2: Recall the formula for electric field strength and make force the subject

$E = \frac{F}{q}$

$F = qE$

Step 3: Substitute the given values

$F = (5 \times 10^{-6}) \times (2 \times 10^{4})$

Step 4: Calculate to get your answer

$F = 0.1\,N$

Worked Example 5

Two charges, +3 μC and -2 μC , are separated by a distance of 0.5 m. Calculate the electric field strength at a point midway between them. The Coulomb constant is $k = 9 \times 10^{9}\,Nm^2/C^2$.

Step-by-Step Solution

Step 1: Recall the formula for the electric field due to a point charge

$E = k\frac{|Q|}{r^2}$

Where:

- E = electric field strength (in N/C),
- k = Coulomb constant (9×10^9 N·m²/C²),
- Q = magnitude of the charge (in C),
- r = distance from the charge to the point of interest (in m).

Step 2: Identify the midpoint and distances

The point of interest is midway between the charges. Therefore:

$$r = \frac{0.5}{2} = 0.25\ m$$

Step 3: Calculate the electric field due to each charge

a. Electric field due to Q1:

$$E_1 = k\frac{|Q_1|}{r^2}$$

b. Substituting the values:

$$E_1 = \frac{9 \times 10^9 \times 2 \times 10^6}{0.25^2}$$

$$E_1 = 4.32 \times 10^5 \text{ N/C}$$

c. Electric field due to Q2:

$$E_1 = k\frac{|Q_2|}{r^2}$$

d. Substituting the values:

$$E_1 = \frac{9 \times 10^9 \times 3 \times 10^6}{0.25^2}$$

$$E_2 = 2.88 \times 10^5 \text{ N/C}$$

Step 4: Determine the directions of the fields

The electric field due to Q_1 (positive charge) points away from Q_1. The electric field due to Q_2 (negative charge) points towards Q_2. At the midpoint, both fields point in the same direction (towards Q2) because the charges are oppositely signed.

Step 5: Add the electric fields to et the net electric field strength

Since the fields point in the same direction, the net electric field is:

$$E_{net} = E_1 + E_2$$

$$E_{net} = (4.32 \times 10^5) + (2.88 \times 10^5)$$

$$E_{net} = 7.2 \times 10^5 \text{ N/C}$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. Two points, X and Y, are in an electric field created by a point charge. The electric potential at point X is 150 V, and at point Y, it is 90V. What is the potential difference between points X and Y?
2. The potential difference across two parallel plates is 300 V, and they are separated by a distance of 0.03 m. Calculate the electric field strength between the plates.
3. A charge of 5×10^{-6} C is moved between two points in an electric field where the potential difference is 30 V. Calculate the work done in moving this charge.
4. Two charges, $Q_1 = +4\,\mu C$ and $Q_2 = -3\,\mu C$, are separated by a distance of 0.6 m. Calculate the electric field strength at a point midway between them. The Coulomb constant is $k = 9 \times 10^9$ Nm²/C².

CAPACITOR DESIGN AND CAPACITOR ARRANGEMENT

Having a water tank at home is essential for storing water for use when the tap stops running. The tank holds a specific volume of water, which represents its capacity. When water is pumped into the tank, it fills up to a certain level. The pressure of the water being pumped influences how quickly the tank reaches its full capacity. When the tap stops running and you open the tap at the bottom of the tank, water begins to flow out, and eventually, the tank will become empty.

Figure 3.11: Capacitor

A capacitor is essential for storing electrical energy in a circuit, acting as a backup energy source when needed. It has a specific **capacitance**, which indicates the maximum amount of electric charge it can hold, measured in **Farads**.

When voltage is applied to a capacitor, it allows electric current to flow in, charging the capacitor until it reaches its maximum capacity. The voltage across the capacitor influences the charging speed; higher voltages can result in a quicker charging process, similar to how higher water pressure fills a water tank more rapidly.

When connected to a circuit that requires energy, the capacitor discharges its stored electric charge, supplying power to the circuit components. Once the capacitor has provided its energy, it becomes discharged and can be recharged, much like refilling a water tank.

Capacitance is defined as the ratio of the charge to the potential to which it is raised.

$$C = \frac{Q}{V}$$

where C = capacitance, Q = charge, V = voltage or potential difference.

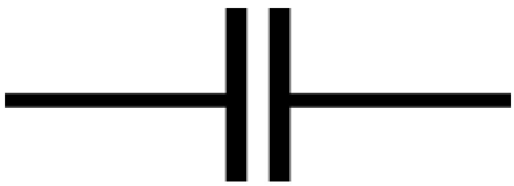


Figure 3.12: Circuit symbol for a capacitor

Parallel plate capacitors

A parallel plate capacitor is a simple type of capacitor that consists of two parallel conducting plates separated by a dielectric material.

Key Components

- Plates: These are typically made of metal and act as electrodes. They are equal in size and shape.
- Dielectric: This is an insulating material placed between the plates. It can be air, paper, ceramic, or other materials. The dielectric increases the capacitor's capacitance.

How it works

1. Charging: When a voltage is applied across the plates, one plate becomes positively charged and the other negatively charged.
2. Electric Field: The electric field forms between the plates, storing energy in the electric field.
3. Capacitance: The ability of the capacitor to store charge is measured by its capacitance (C), which depends on the area of the plates (A), the distance between them (d), and the permittivity of the dielectric material (ε):

   $C = \frac{\varepsilon A}{d}$

   But $\varepsilon = \varepsilon_o \varepsilon_r$

   Where ε_o is permittivity of vacuum, ε_r is relative permittivity

   $C = \frac{\varepsilon_o \varepsilon_r A}{d}$

   But for no dielectric $(\varepsilon_r = 1)$

   Therefore $C = \frac{\varepsilon_o A}{d}$

Activity 3.14 Modelling Parallel Plate Capacitors

Under the supervision of your teacher, stand up and arrange yourselves into a large circle.

Designate the following role to some individuals:

Person A: Positive terminal of the battery

Person B: Negative terminal of the batter

Person C: Switch

Person D: Positive plate of capacitor

Person E: Negative plate of the capacitor

(**Note**: persons A and B should be stood next to one another, as should persons D and E)

All other class mates should act as individual electrons able to 'flow' when the switch is closed.

Consider the questions below and use these, with your teacher's guidance, to model the action of the electrons in a circuit containing a capacitor:

1. What is the charge on an electron?

2. Which way will it travel around the circuit, given that the positive plate of the battery is over here (Person A)

3. The charges build up on one side of the capacitor as they reach it. Which side must that be?

4. What kind of material must be between the plates of a capacitor to ensure that the electrons do not 'jump the gap' and continue to flow around the circuit?

5. What is happening to the electrons on the other plate of the capacitor? Why? What charge does this give that plate?

When you have finished your model, draw a diagram to summarise the knowledge you have acquired.

Activity 3.15 Exploring Capacitance with Interactive Simulations

Objective: To use interactive simulations to explore how changing variables like plate area, distance between plates, and dielectric material affects the capacitance of a capacitor.

Materials Needed

1. Computer or Tablet

2. Internet Connection

3. Notebook and Pen/Pencil

What You Will Do

1. Open the PhET Capacitor Lab simulation on your computer or tablet. Make sure you are familiar with the interface and tools available in the simulation.

Figure 3.13: PhET Capacitor Lab

2. Begin by observing how a basic capacitor works. Adjust the voltage and watch how charges build up on the plates.
3. Experiment with different variables:
   a. Plate Area: Change the size of the capacitor plates and observe how this affects capacitance.
   b. Distance Between Plates: Increase and decrease the distance between the plates to see its impact on capacitance.
4. As you conduct your experiments, record your observations in your notebook. Note how each variable affects capacitance. Consider using a table to organise your data clearly.
5. After completing your experiments, analyse your recorded data. Look for patterns or trends that emerge from changing each variable. Answer these questions in your analysis:
   a. How does increasing plate area affect capacitance?
   b. What happens when you increase the distance between plates?
6. Based on your analysis, draw conclusions about the relationships between plate area, distance, dielectric material, and capacitance.

Activity 3.16 Building a Simple Capacitor with Aluminium Foil and Wax Paper

Objective: To learn how to construct a simple capacitor using aluminium foil and wax paper.

Materials Needed

1. Aluminium foil
2. Wax paper (acts as the dielectric)
3. Scissors
4. Ruler
5. Tape
6. Multimeter (for testing capacitance)

What to do

1. Find and watch the instructional video titled "**How to Build a Simple Capacitor Using Aluminium Foil and Wax Paper**." Pay attention to the steps and safety precautions mentioned.
2. **Prepare the Plates**: Cut two rectangular pieces of aluminium foil to the same size. Aim for dimensions of around 10 cm by 20 cm; this size will make handling easier.
3. **Prepare the Dielectric**: Cut a piece of wax paper slightly larger than the aluminium foil pieces (about 12 cm by 22 cm). This wax paper will act as the insulator between the two pieces of foil.
4. **Assemble the Capacitor**
   - **a.** Place one piece of aluminium foil flat on a table.
   - **b.** Lay the wax paper directly on top of this first piece of aluminium foil, ensuring it fully covers the foil and extends slightly beyond the edges.
   - **c.** Place the second piece of aluminium foil on top of the wax paper, aligning it with the first piece of foil but leaving an edge of wax paper around it to prevent the plates from touching.
5. **Secure the Layers**: Use tape to hold the edges of the assembly together, making sure the foil pieces don't touch each other. This ensures the wax paper insulates the foil pieces effectively.
6. **Attach Leads (Optional)**: Use a multimeter to measure the capacitance, attach a lead to each piece of foil to act as contacts.
7. **Test the Capacitor**
   - **a.** If a multimeter with a capacitance setting is available, measure the capacitance by connecting each lead to a piece of foil.

b. Alternatively, connect the capacitor to a low-voltage (1.5V) battery briefly, then discharge it by touching the leads together. You may observe a small spark or feel a slight shock, demonstrating stored charge.

Capacitors in Series and Parallel

Capacitors can be connected in series or parallel to achieve different equivalent capacitances. Let's explore each configuration:

Capacitors in series

Multiple capacitors are said to be connected in series if the negative plate of one capacitor is connected to the positive plate of another capacitor and so on. In this grouping, current is same through each capacitor, the voltage across each capacitor is different and the charge on each capacitor is the same.

Consider 3 capacitors of capacitances C_1, C_2 and C_3 in series. V is the total voltage supplied. V_1, V_2 and V_3 are the voltage drops across C_1, C_2 and C_3 respectively (as shown in the figure below).

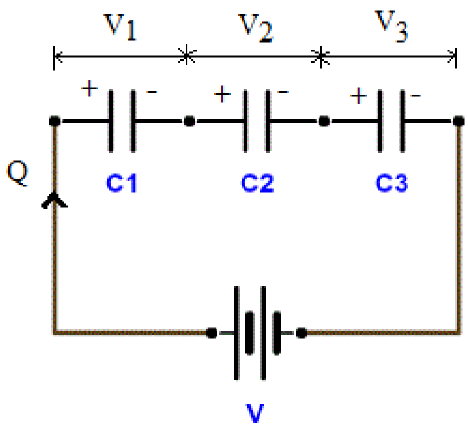


Figure 3.14: Capacitors in series

$V1 = \frac{Q}{C_1}$, $V_2 = \frac{Q}{C_2}$, $V_3 = \frac{Q}{C_3}$

The total pd, *V*, across the network

$$V = V_1 + V_2 + V_3$$

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$V = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

But $V = \frac{Q}{C}$

$$\frac{Q}{C} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Thus, for n capacitors in series, their effective or equivalent capacitance C is given by

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots \frac{1}{C_n}$$

Therefore, the equivalent capacitance is smaller than the smallest individual capacitance. Series connections are used to increase the voltage rating of a capacitor bank.

Capacitors in parallel

Multiple capacitors are said to be connected in parallel if the positive plate of each capacitor is connected to the positive terminal of battery and the negative plate of each capacitor is connected to the negative terminal of the battery. In this grouping, the voltage across each capacitor is the same.

Consider 3 capacitors of capacitances C_1, C_2 and C_3 connected in parallel. V is the supplied voltage. Q_1, Q_2 and Q_3 are the charges on capacitors C_1, C_2 and C_3 (as shown in the figure below).

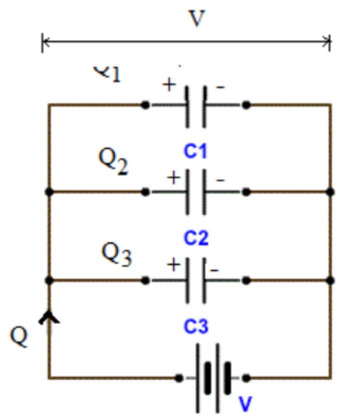


Figure 3.15: Capacitors in Parallel

The sum of the separate charges is given by

$$Q = Q_1 + Q_2 + Q_3$$

But Q =CV

$Q_1 = C_1V, Q_2 = C_2V, Q_3 = C_3V$

$$CV = C_1V + C_2V + C_3V$$

$$CV = V(C_1 + C_2 + C_3)$$

$$C = C_1 + C_2 + C_3 + ...C_n$$

Thus, for n capacitors in parallel, their effective or equivalent capacitance C is given by

$$C = C_1 + C_2 + C_3 + \ldots C_n$$

Therefore, the equivalent capacitance is greater than the largest individual capacitance.

Parallel connections are used to increase the total capacitance of a circuit.

Activity 3.17 Exploring the Arrangement of Capacitors

Objective: Investigate the behaviour of capacitors when arranged in series and parallel configurations on a breadboard, and understand how these arrangements affect total capacitance.

Materials Needed

1. Breadboard
2. 3 Capacitors of different values (e.g., 10 μF, 22 μF, 47 μF)
3. Jumper wires
4. Multimeter (to measure capacitance and voltage)
5. Power supply (e.g., 9V battery)
6. Resistor (e.g., 1 kΩ)
7. Notebook for recording observations
8. Access to a video guide

What to do

1. Review how capacitors work and the difference between series and parallel arrangements. Remember:
   a. In **series**, the total capacitance C is given by:
   $$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$
   b. In **parallel**, the total capacitance C is simply the sum:
   $$C = C_1 + C_2 + C_3$$

2. Search and watch an instructional video that demonstrates how to set up circuits with capacitors in series and parallel. Let the video also guide you through the process step-by-step.
3. Connect the three capacitors in series on the breadboard. Use jumper wires to connect:
   a. The positive terminal of the first capacitor to the negative terminal of the second capacitor.
   b. The positive terminal of the second capacitor to the negative terminal of the third capacitor.
   c. Connect the free positive terminal of the first capacitor to the positive terminal of your power supply.
   d. Connect the free negative terminal of the third capacitor to ground (negative terminal) of your power supply.
4. Measure Total Capacitance in Series:
   a. Use a multimeter to measure the total capacitance across the series connection. Record this value in your notebook.
   b. Compare this measured value with your calculated value using the series formula.
5. Now, connect the same three capacitors in parallel on a new section of the breadboard. Use jumper wires to connect:
   a. All positive terminals together and connect them to the positive terminal of your power supply.
   b. All negative terminals together and connect them to ground (negative terminal) of your power supply.
6. Measure Total Capacitance in Parallel:
   a. Again, use a multimeter to measure the total capacitance across this parallel connection. Record this value in your notebook.
   b. Compare this measured value with your calculated value using the parallel formula.
7. Analyse Your Results:
   a. Compare your measured capacitances from both configurations with theoretical calculations.
   b. Discuss how changing from series to parallel affects total capacitance and what that means for circuit design.

Activity 3.18 Calculating Electrostatic Force

Read the worked examples below before attempting the example questions that follow

Worked Example 1

A capacitor has a charge of 24 μC and a voltage of 12 V across its plates. Calculate the capacitance of the capacitor.

Step-by-Step Solution for Question 1

Step 1: Identify the given values

Charge Q = 24 μC = 24×10^{-6} F

Voltage V = 12 V

Step 2: Identify the formula

$$C = \frac{Q}{V}$$

Step 3: Substitute the given values into the formula

$$C = \frac{24 \times 10^{-6}\ \text{F}}{12\ \text{V}}$$

Step 4: Calculate the capacitance:

C = 2×10^{-6} C = 2 μC

Worked Example 2

Two parallel plates are separated by a distance of 3 mm and have an area of 0.04 m^2. The space between the plates is filled with air. Calculate the capacitance of the parallel-plate capacitor. (Given $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m)

Step-by-Step Solution

Step 1: Identify the given values

Given:

A = 0.04 m^2

d = 3 mm = 3×10^{-3} m

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Step 2: Identify the formula for the capacitance of a parallel-plate capacitor

$$C = \frac{\varepsilon_o A}{d}$$

Step 3: Substitute the known values into the formula

$$C = \frac{8.85 \times 10^{-12}\ \text{F/m} \times 0.04\ \text{m}^2}{3 \times 10^{-3}\ \text{m}}$$

Step 4: Calculate to get the answer

$$C = 1.18 \times 10^{-10}\ \text{F}$$

Worked Example 3

Three capacitors, $C_1 = 4\ \mu F$, $C_2 = 6\ \mu F$, and $C_3 = 8\ \mu F$, are connected in parallel. Calculate the equivalent capacitance of the combination.

Step-by-Step Solution

Step 1: Identify the given values

$C_1 = 4\ \mu F$

$C_2 = 6\ \mu F$

$C_3 = 8\ \mu F$

Step 2: Identify the formula

$$C = C_1 + C_2 + C_3$$

Step 3: Substitute the given values into the formula

$$C = 4\ \mu F + 6\ \mu F + 8\ \mu F$$

Step 4: Add the values:

$$C = 18\ \mu F$$

Worked Example 4

Three capacitors, $C_1 = 2\ \mu F$, $C_2 = 5\ \mu F$, and $C_3 = 10\ \mu F$, are connected in series. Calculate the equivalent capacitance of the combination.

Step-by-Step Solution

Step 1: Identify the given values

$C_1 = 2\ \mu F$

$C_2 = 5\ \mu F$

$C_3 = 10\ \mu F$

Step 2: Identify the formula

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Step 3: Substitute the given values into the formula

$$\frac{1}{C} = \frac{1}{2\ \mu F} + \frac{1}{5\ \mu F} + \frac{1}{10\ \mu F}$$

Step 4: Calculate

$$\frac{1}{C} = \frac{8}{10\ \mu F}$$

Step 5: Take the reciprocal of the result to find the equivalent capacitance

$$C = \frac{10\ \mu F}{8} = 1.25\ \mu F$$

Practice Problems

Now, using the worked example as a guide, solve the following problems in groups

1. A capacitor is charged to a voltage of 20 V, and it holds a charge of 60 μC. Calculate the capacitance of the capacitor.
2. A parallel plate capacitor has a plate area of $0.03\ m^2$ and a separation distance between the plates of 2×10^{-3} m. The dielectric between the plates is air, with a permittivity of free space 8.85×10^{-12} F/m. Calculate the capacitance of the capacitor.
3. Three capacitors, $C_1 = 5\ \mu F$, $C_2 = 10\ \mu F$, and $C_3 = 15\ \mu F$, are connected in parallel. Calculate the equivalent capacitance of the combination.
4. Three capacitors, $C_1 = 2\ \mu F$, $C_2 = 4\ \mu F$, and $C_3 = 8\ \mu F$, are connected in series. Calculate the equivalent capacitance of the combination.

Activity 3.19 Researching and Presenting Types of Capacitors

Objective: To research different types of capacitors, learn about their structures, functions, and real-world applications.

Materials Needed

1. Access to computers or tablets with internet for research

2. Notebooks and pens for note-taking
3. Presentation software (e.g., PowerPoint, Google Slides)
4. Projector or screen for presentations

What to do

1. Get together with 2-3 classmates to form a small group.
2. Decide as a group which type of capacitor you want to research. Here are some options:
   a. Ceramic Capacitors
   b. Electrolytic Capacitors
   c. Film Capacitors
   d. Supercapacitors
   e. Mica Capacitors
   f. Tantalum Capacitors
3. Use the internet to gather information about your chosen capacitor type. Focus on these key areas:
   a. Structure: Describe how the capacitor is built (materials used, design).
   b. Function: Explain how it operates and its electrical properties.
   c. Applications: Identify where this capacitor is commonly used in real-world devices.
4. Prepare a presentation summarising your findings. Include:
   a. Key points about the structure, function, and applications of your capacitor type.
   b. Visual aids such as diagrams or images to illustrate your points.
   c. Any interesting facts or historical context related to your capacitor type.
5. Take turns presenting your findings to the class. Aim for about 5-7 minutes per group. Be ready to answer questions from your classmates after your presentation.
6. After all presentations, engage in a discussion with your classmates about what you learned. Share thoughts on how different types of capacitors are used in various applications.

BEHAVIOUR OF CAPACITORS AND ENERGY STORED

Capacitor in a DC Circuit

1. **Initial Charging:** When a DC voltage is first applied to a capacitor, it starts charging. Current flows through the circuit as the capacitor plates accumulate charge.
2. **Steady State:** As the capacitor charges, the voltage across its plates increases, opposing the applied voltage. Eventually, the voltage across the capacitor equals the source voltage, and the current flow ceases.
3. **Open Circuit Behaviour:** Once fully charged, a capacitor acts as an open circuit, blocking the flow of direct current.

Activity 3.20 Building and Analysing a Simple DC Circuit with a Capacitor

Objective: To construct a simple DC circuit using a capacitor and resistor, observe the charging and discharging process, measure the voltage across the capacitor over time, and calculate the energy stored in the capacitor.

Materials Needed

1. Breadboard
2. 1 DC power supply (battery or power adapter)
3. 1 Resistor (e.g., 10 kΩ)
4. 1 Capacitor (e.g., 4200 μF)
5. Multimeter (to measure voltage)
6. Stopwatch or timer
7. Notebook for recording data
8. Graph paper

What to do

1. **Set Up the Circuit:** Connect the circuit as follows:
   a. Place the resistor and capacitor on the breadboard.
   b. Connect one terminal of the resistor to the positive terminal of the DC power supply.

c. Connect the other terminal of the resistor to one terminal of the capacitor.

d. Connect the other terminal of the capacitor to the negative terminal of the DC power supply, completing the circuit.

e. Ensure that you identify and connect the capacitor correctly, noting its polarity if it is a polarised capacitor.

2. **Charging Phase**

a. Close the switch or connect the battery to start charging the capacitor.

b. Use the multimeter to measure and record the voltage across the capacitor at regular intervals (e.g., every 10 seconds) for about 3 minutes or until it reaches a steady value.

c. Record your voltage measurements in your notebook.

3. **Discharging Phase**

a. After charging, disconnect the power supply.

b. Now, connect a short wire across the terminals of the capacitor to discharge it.

c. Again, measure and record the voltage across the capacitor at regular intervals as it discharges. Continue measuring until the voltage drops close to zero.

4. Using your recorded voltage values during both charging and discharging, create a table with time (in seconds) and corresponding voltage readings.

5. On graph paper, plot your voltage readings against time for both charging and discharging phases. You should see exponential curves representing both processes.

6. Analyse your graphs. Discuss how well they match theoretical expectations regarding exponential growth during charging and decay during discharging.

Capacitor in an AC Circuit

1. **Alternating Current:** In an AC circuit, the voltage across the capacitor continuously changes polarity.
2. **Charging and Discharging:** As the AC voltage increases in one direction, the capacitor charges. As the voltage decreases and reverses polarity, the capacitor discharges. This continuous charging and discharging process results in an alternating current flow through the capacitor.

3. **Capacitive Reactance:** Capacitors oppose the flow of alternating current. This opposition is known as capacitive reactance (Xc), which is inversely proportional to the frequency of the AC signal and the capacitance of the capacitor.

Energy stored in a capacitor

A capacitor stores energy in the form of an electric field between its plates. When a voltage is applied to the capacitor, it causes a separation of charges, with positive charges accumulating on one plate and negative charges on the other. This separation of charges creates an electric field between the plates.

The energy stored in the capacitor is equal to the work done in separating these charges. This energy can be expressed in several equivalent ways:

- $E = \frac{1}{2}CV^2$
- $E = \frac{1}{2}QV$
- $E = \frac{Q^2}{2C}$

Where:

- E is the energy stored in the capacitor (in Joules)
- C is the capacitance of the capacitor (in Farads)
- V is the voltage across the capacitor (in Volts)
- Q is the charge stored on the capacitor (in Coulombs)

This stored energy can be released later by discharging the capacitor, which allows the charges to flow back together. This release of energy can be used for various applications, such as powering flashlights, providing energy for electronic circuits, or even delivering a high-energy shock in a defibrillator.

Activity 3.21 Revisiting Activity 3.20 – Calculating Energy stored in a Capacitor

1. Look back at the data you collected during Activity 3.20.
   a. Use the formula for energy stored in a capacitor:

   $E = \frac{1}{2}C\,V^2$

   where:

   E is energy in Joules,

C is capacitance in Farads,

V is voltage across the capacitor at each time point.

b. Calculate E for various measured voltages during both charging and discharging phases.

Activity 3.22 Exploring Capacitor Applications

Objective: To research and discover how capacitors are used in various electronic applications.

Materials Needed

1. Access to the internet for research
2. Notebook or digital document for recording your findings
3. Blank table template (see below)

What to do

1. Review what a capacitor is and its basic function in electronic circuits.
2. Use the internet to find examples of where and how capacitors are used. Focus on at least three different applications. Here are some areas to explore:
   - **a.** Power supplies
   - **b.** Filters (such as audio or RF filters)
   - **c.** Timing circuits
   - **d.** Energy storage systems
   - **e.** Tuning circuits
3. As you research, fill in the table below with details about each application you discover.

Table 3.3: Capacitor Usage

Application Name	Description of use	Type of Capacitor Used	Benefits

4. Once you have completed your research and filled in the table, be ready to share your findings with your classmates. Highlight interesting facts and discuss why capacitors are important in each application.

$$E = \frac{1}{2}CV^2$$

Activity 3.23 Calculating Energy stored in Capacitor

Read the worked example below before attempting the example questions that follow.

Worked Example

A capacitor with a capacitance of 4 μF is charged to a voltage of 50 V. Calculate the energy stored in the capacitor.

Step-by-Step Solution

Step 1: Identify the given values

Capacitance, $C = 4\,\mu F = 4 \times 10^{-6}\,F$

Voltage, $V = 50\,V$

Step 2: Identify the formula

$$E = \frac{1}{2}CV^2$$

Step 3: Substitute the given values into the formula

$$E = \frac{1}{2} 4 \times 10^{-6} \times 50^2$$

Step 4: Calculate

$$E = \frac{1}{2} 4 \times 10^{-6} \times 2500$$

$$E = 0.005\ J$$

Practice Problems

Now, using the worked example as a guide, solve the following problems in groups

1. A capacitor of 5 μF is charged to a voltage of 10 V. Calculate the energy stored in the capacitor.
2. A capacitor stores 2 mJ of energy when connected to a 20 V source. Calculate the capacitance of the capacitor.
3. A capacitor holds a charge of 30 μC at a voltage of 15 V. Calculate the energy stored in the capacitor.

Activity 3.24 Revisit Activity 3.17 – Exploring the arrangement of capacitors

Set up your experiment again as in Activity 3.17.

Use the formulae for energy stored on a capacitor to compare the total energy stored in both series and parallel arrangements compared to the energy stored by the cumulative energy stored by the constituent capacitors connected individually to the same power supply.

Activity 3.25 Disassembling Old Electronics

Many electronic devices contain capacitors. If you have any such devices at home, have a go at disassembling them to identify the location of the capacitor. Can you suggest the purpose of the inclusion of a capacitor in the design?

ADDITIONAL READING MATERIALS

- Asiedu, P., & Baah-Yeboah, H. A. (n.d.). *Physics for Senior High Schools* (4th ed., pp. 385-399). Aki-Ola Publications.
- Halliday, D., Resnick, R., & Walker, J. (2018). *Fundamentals of Physics* (11th ed., pp. 599-613, 609-622, 630-650). John Wiley & Sons.
- Serway, R. A., & Jewett, J. W. (2018). *Physics for Scientists and Engineers with Modern Physics* (9th ed., pp. 568-580, 741-754). Brooks/Cole Cengage Learning.
- Giancoli, D. C. (2013). *Physics: Principles with Applications* (7th ed., pp. 431-442, 557-563). Pearson Education.
- Physics LibreTexts. (n.d.). *Capacitors and capacitance*. Retrieved from https://phys.libretexts.org/Bookshelves/Electricity_and_Magnetism/Capacitance
- Physics LibreTexts. (n.d.). *Capacitors in series and parallel*. Retrieved from https://phys.libretexts.org/Bookshelves/Electricity_and_Magnetism/Capacitors_in_Series_and_Parallel

REVIEW QUESTIONS

Review Questions 3.1

1. State Coloumb's law of electrostatics.
2. Sketch the electrostatic field due to two unlike point charges.
3. Two point charges 3×10^{-6} C and 5×10^{-6} C, are separated by a distance of 0.2 m. Calculate the magnitude of the electrostatic force between the two charges using Coulomb's law. (Use $k = 8.99 \times 10^9$ N·m²/C² as the electrostatic constant.)
4. Two point charges 2×10^{-6} C and 4×10^{-6} C exert an electrostatic force of 1.8 N on each other. Using Coulomb's law, calculate the distance between the charges. (Use $k = 8.99 \times 10^9$ N·m²/C² as the electrostatic constant.)
5. Three point charges are placed along a straight line. Charge $q_1 = 3 \times 10^{-6}$ C is located at $x = 0$ m, charge $q_2 = -2 \times 10^{-6}$ C is located at $x = 0.5$ m, and charge $q3 = 4 \times 10^{-6}$ C is located at $x=1.0$ m. Calculate the net electrostatic force acting on q_2 due to q_1 and q_3. (Use $k = 8.99 \times 10^9$ N·m²/C² as the electrostatic constant.)
6. Two identical spherical conductors, each with a charge of +5 μC, are initially placed 1 metre apart. When they are touched together, they share their charge equally and are then separated back to the original distance.
   a. What is the new charge on each sphere after they are separated?
   b. Calculate the electrostatic force between the two spheres after they have been re-separated. How does this force compare to the initial force when they each had a charge of +5 μC? Provide a detailed explanation of your reasoning.

Review Questions 3.2

1. Define the following terms:
   a. Electric field strength
   b. Electric potential
2. Using their formulae, derive SI units for electric field strength, and electric potential.

3. A charged particle is placed in an electric field with an electric field strength of $4.0 \times 10^3\, NC^{-1}$ and experiences a force of 0.8 N. Calculate the charge of the particle.
4. Two parallel conducting plates are separated by a distance of 0.08 m and have a potential difference of 550 V between them. Calculate the electric field strength between the plates.
5. Two parallel plates are separated by a distance of 0.05 m and connected to a 300 V power supply, creating a uniform electric field between them. An electron (charge $q = -1.6 \times 10^{-19}$ C and mass $m = 9.1 \times 10^{-31}$ kg) is released from rest at the negative plate.
   a. Calculate the electric field strength between the plates.
   b. Determine the final speed of the electron when it reaches the positive plate, assuming no other forces are acting on it (hint: use conservation of energy principles to solve this problem)

Review Questions 3.3

1. What is the formula for calculating the capacitance of a capacitor?
2. What happens to the voltage across capacitors connected in parallel compared to those connected in series?
3. How does the capacitance of a parallel plate capacitor change if the distance between the plates is doubled?
4. You have three capacitors of values 2.0 μF, C_2=3.0 μF and C_3=6.0 μF connected in series. Calculate the total capacitance of the series combination.
5. You have three capacitors connected in series with capacitances of C_1=5.0 μF and C_2=10.0 μF, and the total capacitance of the series combination is given as C_s=2.0 μF; calculate the capacitance of the third capacitor, C_3.

Review Questions 3.4

1. What is the formula for calculating the energy stored in a capacitor?
2. How does the energy stored in a capacitor change if the voltage across it is doubled?
3. A capacitor with a capacitance of 100 μF is charged to a voltage of 12 V. Calculate the energy stored in the capacitor.

SECTION

4

PHOTOELECTRIC EFFECT AND RADIOACTIVITY

ATOMIC AND NUCLEAR PHYSICS

Atomic Physics

INTRODUCTION

In this section, we will explore some exciting ideas in modern physics. First, we'll talk about the photoelectric effect, which shows how light can 'knock' electrons out of materials, proving that light behaves like tiny particles in certain situations. We'll also learn about Einstein's law, which helps explain this effect. Next, we'll discuss wave-particle duality, an idea that tells us that tiny things like electrons can act both like waves and particles. Finally, we'll look at radioactivity, which is when unstable atoms release energy and particles. This process is important for things like medical treatments and power generation. Together, these areas help us understand how light, matter, and energy work in our world!

KEY IDEAS

- The photoelectric effect is the emission of electrons from the surface of a metal when exposed to radiation which meets or exceeds the threshold frequency for that metal.
- Wave-particle duality is the concept that quantum objects, such as light and electrons, can exhibit both wave-like and particle-like properties, depending on the experimental context.
- Einstein's equation of photoelectric effect states that

  $E = W_o + KE_{max}$
- Radioactivity is the spontaneous disintegration or decay of an unstable nucleus with the emission of radiation (α-particles, β-particles, γ-rays) and the release of energy to form a more stable nucleus.
- The decay law states that the activity of a given nuclide at any time is directly proportional to the number of nuclei N of the nuclide present $A \propto N$

PHOTOELECTRIC EFFECT AND WAVE-PARTICLE DUALITY

Wave-Particle Duality

Wave-particle duality is a fundamental concept in quantum mechanics that describes how every particle or quantum entity, such as light and electrons, exhibit both wave-like and particle-like properties. This duality challenges classical physics, which traditionally categorised light as a wave and matter as particles.

Key Concepts

Wave Properties: Particles can exhibit behaviours typical of waves, such as diffraction and interference. For instance, when electrons are passed through a thin sheet of graphite, they are diffracted by the lattice of ions and create an interference pattern similar to light waves, indicating their wave-like nature.

Particle Properties: Conversely, waves can exhibit particle-like behaviour when they interact with matter. The photoelectric effect shows that light can be quantised into photons, each carrying a specific amount of energy related to its frequency.

Complementarity Principle: Niels Bohr proposed that wave and particle descriptions are complementary aspects of quantum entities. Depending on the experimental setup, one aspect may become more apparent than the other, but both are necessary for a complete understanding of quantum phenomena.

Historical Background

The concept of wave-particle duality emerged from several key experiments and theories:

Thomas Young's Double-Slit Experiment (1801): This experiment demonstrated that light behaves like a wave. When light passes through two closely spaced slits, it creates an interference pattern on a screen, indicative of wave behaviour. This phenomenon occurs because waves can overlap and interfere with each other, producing regions of constructive and destructive interference.

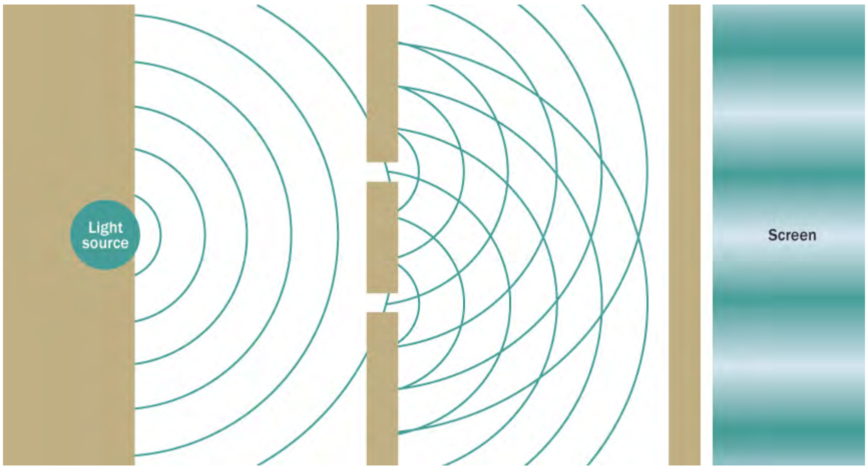


Figure 4.1: The pattern of bright and dark spots which appear on a screen due to wave diffraction interference

Photoelectric Effect (1905): Albert Einstein's explanation of the photoelectric effect provided evidence for the particle nature of light. He proposed that light consists of discrete packets of energy called photons. When light shines on a metal surface, it can eject electrons if the photons have sufficient energy, which is dependent on their frequency rather than intensity. This observation could not be explained solely by wave theory.

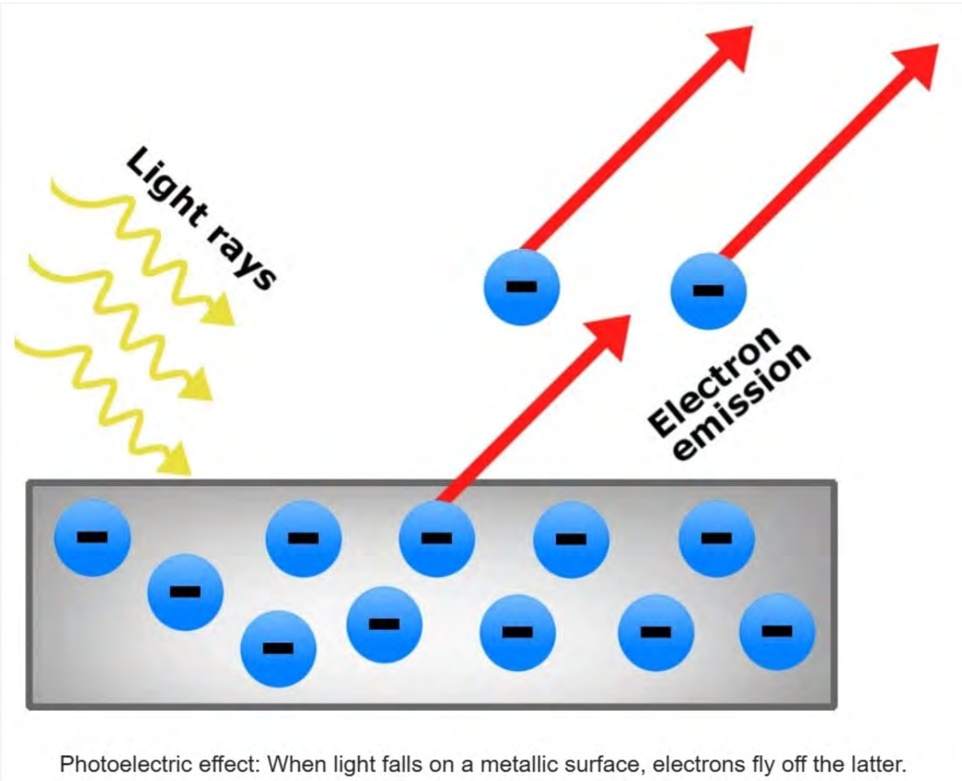


Figure 4.2: Image showing Photoelectric effect

De Broglie's Hypothesis (1923): Louis de Broglie extended the idea of wave-particle duality to matter, suggesting that particles such as electrons also exhibit wave-like behaviour. Electrons can be diffracted by thin sheets of graphite to produce a diffraction pattern; a behaviour attributed to waves rather than particles.

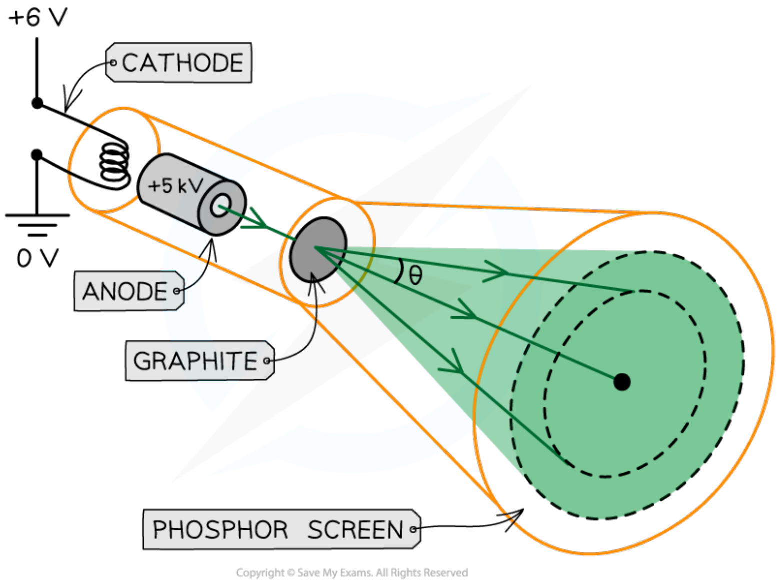


Figure 4.3: The circular diffraction pattern produce when electrons are diffracted through a sheet of graphite

Activity 4.1 Wave-particle duality

Video

Watch the following video explaining wave-particle duality: click here

Figure 4.4: Link to wave-particle duality video

Photoelectric effect

The photoelectric effect is a special phenomenon that happens when light hits certain materials, like metals. It suggests that light can 'knock' tiny particles called electrons out of those materials. Let's break it down!

Activity 4.2 Solar panel investigation

Conduct the following experiment to verify that light (photons) can create electricity by the liberation of electrons:

Figure 4.5: Experimental set up

Materials needed

- Table lamp
- Connecting wires
- Crocodile clips
- Small (1.5V) bulb
- Small solar panel / photovoltaic cell

Procedure

1. Connect up the solar panel, wires and bulb as shown in the image above.
2. Shine the table lamp light at the solar panel.
3. Observe the behaviour of the bulb.
4. If the bulb does not light, try moving the table lamp closer to the solar panel or using sunlight to illuminate the solar panel instead.

Conclusion: What are your observations? Did the brightness or type of light affect the behaviour of the bulb? Why are solar panels a preferred method for generating electricity?

Key points of the photoelectric effect include:

1. **Photon energy**: Einstein proposed that light consists of discrete packets of energy called **photons**, and each photon has an energy E proportional to its frequency f. The energy of the emitted electrons depends on the frequency of the incident light, with higher-frequency (or shorter wavelength) light causing the emission of more energetic electrons.

   Energy of the photon (E) is given as

   $E = hf$ or $E = h\frac{c}{\lambda}$

   Where;

   E is the energy of the photon in Joules

   h is Planck's constant (6.63×10^{-34} J·s)

   c is the speed of light (3.0×10^{8} m/s)

   f is the frequency of the incident light in Hertz

   λ is the wavelength of the incident light in metres

2. **Threshold frequency**: There is a minimum frequency of light required for the ejection of electrons. If the frequency is below this threshold, no electrons are emitted, regardless of the intensity of the light.

   Threshold frequency f_0 is the minimum frequency of an electromagnetic radiation which must be exceeded to be able to eject electrons from the surface of a given metal.

   Work function of a metal w_0 is the minimum amount of energy needed to just liberate an electron from a metal surface.

   a. If the photon's energy is less than the work function ($E < W_o$), no electrons are ejected.

      $W_o = hf_o = h\frac{c}{\lambda_o}$

      where λ_o is also known as the threshold wavelength.

   b. If the photon's energy exceeds the work function ($E > W_o$), the excess energy is converted into the kinetic energy of the ejected electron.

3. **Instantaneous emission**: The emission of electrons happens instantaneously when light of the correct frequency strikes the material, indicating that the energy transfer occurs at the moment of photon absorption.
4. **Intensity Effect**: Increasing intensity of the light increases the number of photons, hence more electrons are emitted, but it does not affect the kinetic energy of the emitted electrons. The kinetic energy depends solely on the frequency of the light.

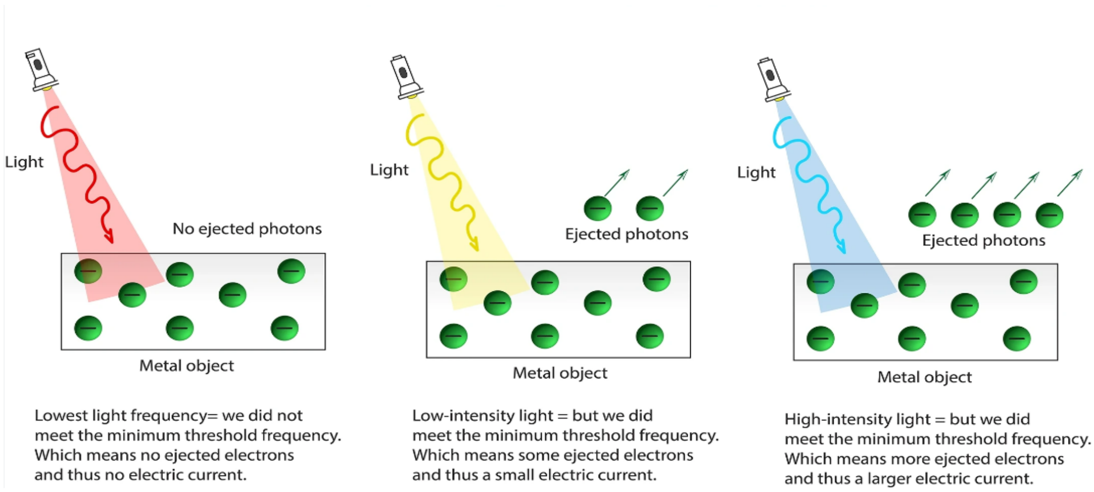


Figure 4.6: Image showing that the intensity of light affects the number of electrons emitted

This phenomenon was explained by Albert Einstein in 1905, which helped solidify the concept of light behaving as both a wave and a particle.

Activity 4.3 Photoelectric effect

Video

Watch the following video explaining the photoelectric effect:

https://www.youtube.com/watch?v=jWbwDTPju-M

Figure 4.7: Link to video on the photoelectric effect

Einstein's equation of photoelectric effect

Albert Einstein's equation for the **photoelectric effect** explains how light energy is transferred to electrons during this phenomenon. The equation is expressed as:

$E = W_o + KE_{max}$

Where:

E is the **energy of the photon**,

W_o (or ϕ) is the **work function** of the metal, i.e., the minimum energy required to eject an electron from the surface,

KE_{max} is the **maximum kinetic energy** of the ejected electron.

Activity 4.4 Computer Simulation of the Photoelectric Effect

Objective: To explore the photoelectric effect by using computer simulations, allowing you to adjust variables such as light frequency, intensity, and metal type, predict outcomes, and confirm your predictions through experimentation.

Materials Needed

1. A computer or tablet with internet access
2. Access to a photoelectric effect simulation (e.g., PhET Simulation: Photoelectric Effect or similar)
3. Notebook or digital document for recording predictions and observations
4. Calculator (optional for calculations)

What to do

1. Open a web browser and navigate to a photoelectric effect simulation site, such as the PhET Interactive Simulations website. Look for the simulation specifically designed for the photoelectric effect. You can also use the link below.

Figure 4.8: PhET Interactive Simulation on Photoelectric effect

2. Spend a few minutes exploring the interface of the simulation. Understand how to adjust parameters such as:
   a. **Light Frequency**: This controls the colour of light used in the experiment.
   b. **Light Intensity**: This determines how much light is shining on the metal surface.
   c. **Metal Type**: Different metals have different threshold frequencies and work functions.
3. Before adjusting any parameters, make predictions about what you think will happen when you change each variable:
   a. **Light Frequency**: Predict how changing the frequency will affect electron ejection. Consider what you know about threshold frequency.
   b. **Light Intensity**: Predict how increasing or decreasing intensity will impact the number of electrons emitted.
   c. **Metal Type**: Predict how changing the metal will affect the results based on its work function.
4. Start by adjusting one parameter at a time. For example:
   a. Set a specific metal and adjust the light frequency to see if it exceeds the threshold frequency.
   b. Change the intensity of light while keeping other variables constant.
5. After each adjustment, run the simulation to observe what happens. Take note of whether electrons are emitted and any changes in current or kinetic energy.
6. Use your notebook or digital document to record your predictions and actual outcomes for each trial. Note any discrepancies between your predictions and what you observed in the simulation.
7. After completing several trials with different combinations of parameters, analyse your results:
   a. Did your predictions match the outcomes?
   b. What patterns did you notice regarding light frequency, intensity, and metal type?
   c. How does each parameter influence electron emission?

8. If you're working with classmates, discuss your findings together. Share your predictions and outcomes, and explore any differences in results based on varying parameters.

Activity 4.5 Experiment to find the threshold frequency

Read the following information and then write your own method for the experiment. Afterwards, use the data provided below to plot a graph of the results and use the graph to find the threshold frequency.

With the correct equipment, it would be possible to vary the frequency of the light incident on a solar panel. We would slowly increase the frequency of the light so that it appears red, then yellow, then blue, and finally ultraviolet.

The device needed to produce a variable frequency output of light is very specialist; if you have access to one, you could perform an experiment to find the threshold frequency of a metal.

If not (as is probably the case!) you should still write your own method for how this experiment could be carried out. Include an equipment list and a diagram to support your method.

Next, plot a graph of the following data (y axis = current, x axis = frequency) and use it to find the threshold frequency.

Table 4.1

Frequency ($\times 10^{15}$ Hz)	Current (A)
0.5	0.0
0.7	0.0
0.9	0.0
1.1	0.2
1.3	0.2
1.5	0.2
1.7	0.2

Finally, plot this alternative data (y axis = kinetic energy of ejected electrons, x axis = frequency) and use it to find the threshold frequency.

Table 4.2

Frequency ($\times 10^{15}$ Hz)	Kinetic energy of photoelectrons ($\times 10^{-19}$ J)
2.00	5.90
2.50	9.21
3.00	12.52
3.50	15.84
4.00	19.15

Extension: you can also use the second graph to find the value of Planck's constant. Can you work out how?

Activity 4.6 Calculating threshold frequency and wavelength, kinetic energy of ejected electrons.

Study the worked examples carefully below before attempting the example questions that follow

Worked Example 1

Calculate the energy of a photon with a wavelength of 500 nm.

$h = 6.63 \times 10^{-34}$ *Js,* $c = 3.0 \times 10^{8}$ *m/s*

Step 1: Convert the wavelength to metres

Since the wavelength is given in nanometres (1 nm = 10^{-9} m):

$\lambda = 500 \text{ nm} = 500 \times 10^{-9} \text{ m} = 5.0 \times 10^{-7} \text{ m}$

Step 2: Introduce the formula relating energy to wavelength

$E = h\frac{c}{\lambda}$

Step 3: Substitute the values

$$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{5.0 \times 10^{-7}}$$

Step 4: Calculate to obtain the answer

$E = 3.978 \times 10^{-19}$ J

Worked Example 2

Calculate the threshold wavelength and threshold frequency of a metal with a work function of 3.4 eV.

$h = 6.63 \times 10^{-34}$ *Js*, $c = 3.0 \times 10^{8}$ *m/s*, *1 eV* $= 1.6 \times 10^{-19}$ *J*

Step 1: Convert the work function to joules

The work function (W_o) is given in electron volts (eV). Convert it to joules (J) using:

W_o (in J) $= W_o$ (in eV) $\times 1.6 \times 10^{-19}$

Substitute $W_o = 3.4$ eV:

$W_o = 3.4 \times 1.6 \times 10^{-19} = 5.44 \times 10^{-19}$ J

Step 2: Calculate the threshold frequency

a. Introduce the relationship between the work function and threshold frequency

$W_o = h \times f_o$

b. Rearrange to find the threshold frequency:

$$f_o = \frac{W_o}{h}$$

c. Substitute $W_o = 5.44 \times 10^{-19}$ J and $h = 6.63 \times 10^{-34}$ J·s:

$$f_o = \frac{5.44 \times 10^{-19}}{6.63 \times 10^{-34}}$$

d. Calculate to obtain the answer

$f_o = 8.20 \times 10^{14}$ Hz

Step 3: Calculate the threshold wavelength

a. Introduce the relationship between frequency and wavelength

$$\lambda_o = \frac{C}{f_o}$$

b. Substitute $c = 3.0 \times 10^{8}$ m/s and $f_o = 8.20 \times 10^{14}$ Hz:

$$\lambda_o = \frac{3.0 \times 10^{8}}{8.20 \times 10^{14}}$$

c. Calculate to obtain the answer

$\lambda_o = 3.66 \times 10^{-7}$ m

Worked Example 3

A metal surface has a work function of 2.2 eV. When it is exposed to light with a wavelength of 300 nm, electrons are ejected from the surface. Calculate the maximum kinetic energy of the ejected electrons.

$h = 6.63 \times 10^{-34}$ Js, $c = 3.0 \times 10^{8}$ m/s, 1 eV $= 1.6 \times 10^{-19}$ J

Step-by-Step Solution:

Step 1: Calculate the energy of the incoming photon (E):

a. ***Introduce the formula***

$$E = h\frac{c}{\lambda}$$

b. ***Substitute the values:***

$$E = \frac{(6.63 \times 10^{-34}) \times (3.0 \times 10^{8})}{(300 \times 10^{-9})}$$

c. ***Calculate to obtain the value of the energy of the incoming photon***

$E = 6.63 \times 10^{-19}$ J.

Step 2. Convert the work function (W_o) from eV to joules:

The work function is $W_o = 2.2$ eV. Using the conversion 1 eV $= 1.6 \times 10^{-19}$ J:

$W_o = 2.2 \times 1.6 \times 10^{-19}$ J

$W_o = 3.52 \times 10^{-19}$ J.

Step 3. Introduce the photoelectric equation to find the maximum kinetic energy

$KE_{max} = E - W_o$

Step 4: Substitute ***the values of the energy of the incoming photon and the work function***

$KE_{max} = 6.63 \times 10^{-19} - 3.52 \times 10^{-19}$

Calculate to obtain the answer

$KE_{max} = 3.11 \times 10^{-19}$ J

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

$h = 6.63 \times 10^{-34}$ *Js, speed of light* $c = 3.0 \times 10^{8}$ *m/s, and* $1\ eV = 1.6 \times 10^{-19}$ *J*

1. Calculate the energy of a photon with a wavelength of 500 nm.
2. Calculate the threshold wavelength and threshold frequency of a metal with a work function of 2.5 eV.
3. A metal has a work function of 3.0 eV. When light of wavelength 400 nm is incident on the surface, electrons are emitted. Calculate the maximum kinetic energy of the ejected electrons in Joules.

Applications of photoelectric effect

Figure 4.9: Application of photoelectric effect

The photoelectric effect is used in many daily applications, including:

1. **Solar panels**: They convert sunlight into electricity using a metal that releases energy when light hits it
2. **Digital cameras**: They use photoelectric sensors to detect and record light
3. **Smartphone lighting sensors**: They automatically adjust brightness based on lighting
4. **Electric eye door openers**: They use photoelectric sensors to detect when someone approaches, triggering the doors to open automatically
5. **Light meters**: These are used in photography to measure light intensity and ensure proper exposure
6. **Photostatic copying**: a process that uses the photoelectric effect to transfer images onto paper
7. **Imaging technology**: Used in television camera tubes and image intensifiers to enhance low-light images

8. **Scientific research**: Used to study nuclear phenomena and chemically analyse materials
9. **Photomultiplier tubes**: Convert light intensity into electrical currents
10. **Scintillators**: Emit light when they attract radiation
    $\lambda = \frac{h}{p}$

Activity 4.7 Research Project on the Photoelectric Effect

Objective: Investigate an application of the photoelectric effect, such as its role in solar panels or medical imaging devices, and present your findings in a research paper and class presentation.

Materials Needed

1. Access to the internet for research
2. Notebook or digital document for recording your findings
3. Presentation software (e.g., PowerPoint, Google Slides) for your presentation
4. Research paper format guidelines (if provided by your teacher)

What to do

1. Select an application of the photoelectric effect to research from the list above.
2. Conduct your research by using reliable sources to gather information about your chosen topic. Look for:
   a. How the photoelectric effect operates in your selected application.
   b. Different materials used and their properties.
   c. Efficiency ratings, advantages, and limitations of these materials or technologies.
   d. Recent advancements or research findings related to your topic.
3. Create an outline for your research paper. Include sections such as:
   a. Introduction to the photoelectric effect.
   b. Detailed explanation of your chosen application.
   c. Discussion on materials and their efficiencies or roles.
   d. Conclusion summarising key points and future implications.

4. Write a comprehensive research paper based on your outline. Ensure to include citations for all sources used. Follow any specific formatting guidelines provided.
5. Create a presentation summarising your research findings. Include:
   a. Key points from each section of your paper.
   b. Visual aids such as graphs, images, or charts to illustrate concepts.
   c. A clear explanation of how the photoelectric effect is applied in your topic.
6. Share your research with the class through your presentation. Be prepared to answer questions and discuss your findings with your classmates.
7. After completing the project, reflect on what you learned about the photoelectric effect and its applications. Consider how this knowledge could apply to future studies or real-world scenarios.

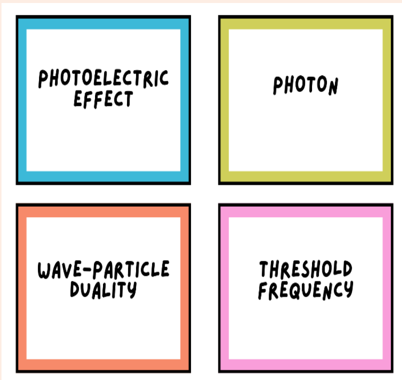
λ_o

Activity 4.8 Flashcard Matching Challenge

Objective: To reinforce your understanding of atomic physics terms by matching terms with their definitions using provided flashcards.

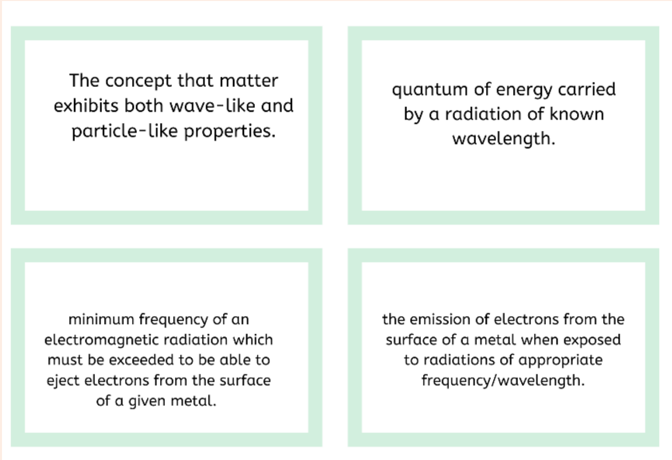
Materials Needed

1. Flashcards
   a. **Set A**: Flashcards with key terms
   b. **Set B**: Flashcards with corresponding definitions
2. Pen or Pencil



SET A

Figure 4.10: Flashcards on atomic physics terms



SET B

Figure 4.11: Flashcards of some definitions on atomic physics terms

What to do

1. Take a few minutes to read through both sets of flashcards. Familiarise yourself with the terms in Set A and their corresponding definitions in Set B.
2. To test your memory, close your eyes or turn away from the learner material to avoid looking at the definitions. This will help you recall the definitions based on the terms.
3. Start with the first term in Set A. Think about its meaning and try to recall which definition in Set B matches it.
4. Write down your answer.
5. Proceed through all the terms in Set A, matching each one to its definition in Set B. Take your time and think carefully about each match.
6. Once you have matched all the terms, go back through the flashcards to check your answers. Look at each term and its corresponding definition to see if they align correctly.
7. For any incorrect matches that are incorrect, review the definitions again to understand why they do not match. Take notes on any challenging terms.

RADIOACTIVITY

When the nucleus of an atom has an imbalance between protons and neutrons, it becomes unstable. To regain stability, the nucleus undergoes disintegration, releasing energy and subatomic particles in the process. This phenomenon is called radioactivity.

If the disintegration occurs naturally without external influence, it is referred to as natural or spontaneous radioactivity. On the other hand, if the process is triggered by human intervention (e.g., by bombarding the nucleus with particles), it is called induced or artificial radioactivity.

Note that, the words “decay” and “disintegration” will be used interchangeably in subsequent discussions.

The Decay Law

This law describes the relationship between the rate of decay of a radioactive sample and the amount of it present at any time. It is stated as follows:

The rate of disintegration/decay of a given nuclide at any time is directly proportional to the number of nuclei N of the nuclide present.

This means that, as the amount (N) gets smaller over time, the rate of decay also gets smaller (slower), because there are fewer nuclei available to decay.

This statement is stated mathematically as follows:

$$-\frac{dN}{dt} \propto N$$

$$-\frac{dN}{dt} = \lambda N,$$

where the negative sign (-) indicates that the nuclei reduce in number as time passes.

Applying calculus to the above equation, $N(t) = N_0 e^{-\lambda t}$

Note that: "$N(t)$" means N is a function of time t, not $N \times t$.

Where t is the duration or period of the decay,
N is the amount of the sample not yet decayed at the end of time t,
N_0 is the initial amount of the sample not decayed, at the beginning of the time t,
λ is called the decay constant.

Half-life

The half-life of a radioactive nuclide or radioisotope is defined as the time interval during which half of a given number of radioactive nuclei decay.

In one half-life, half of the original nuclei will decay. In the second half-life, half of those remaining will decay, leaving one-fourth (a quarter) of the original number.

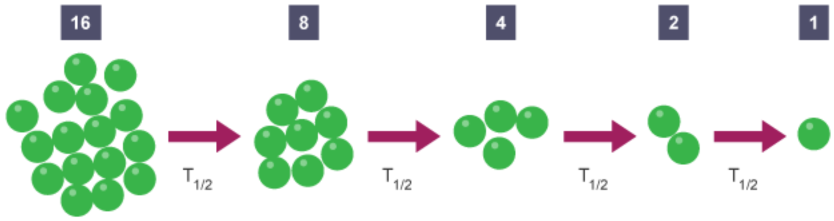


Figure 4.12: Diagram to show the number of undecayed nuclei in a sample after every half life.

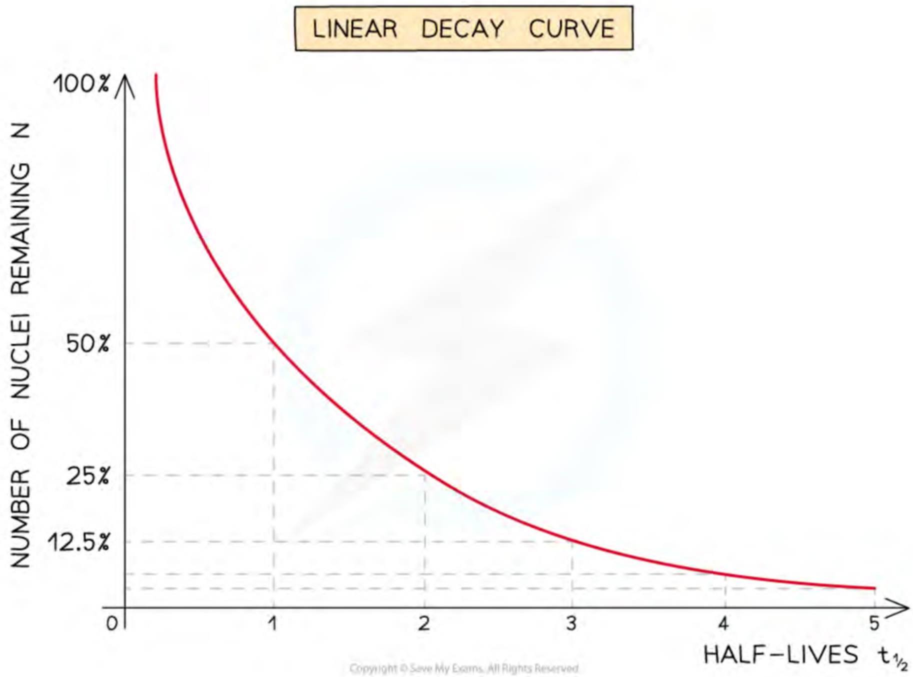


Figure 4.13: A graph showing the percentage of the initial number of undecayed nuclei remaining after every half life.

Half-life is unique to a radioactive element. It is different for different elements; some half lives of a few seconds where others have a half life of hundreds of thousands of years.

Mathematical statement of half-life:

$N = N_0 e^{-\lambda t}$

$e^{\lambda t} = \frac{N_0}{N}$

From the definition, let the time taken for N_0 to decay to half be $T_{\frac{1}{2}}$ and $N = \frac{N_0}{2}$

$e^{\lambda T\frac{1}{2}} = \frac{N_0}{\left(\frac{N_0}{2}\right)}$

$e^{\lambda T_{\frac{1}{2}}} = 2$

$\lambda T_{\frac{1}{2}} = \ln 2$

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$

Generally, the age or time elapsed (t) of any sample/specimen can be found using the formula; $t = \frac{\ln\left(\frac{N_0}{N}\right)}{\lambda}$.

Activity 4.9 Group Discussion on Radioactivity Concepts

Objective: To enhance understanding of key concepts related to radioactivity through collaborative discussion and clarification of ideas among peers.

Materials Needed

1. A comfortable space for group discussion
2. Whiteboard or flip chart
3. Markers or pens
4. Notebook or digital document for taking notes
5. Phones or other internet-enabled devices for conducting research

What to do

1. Organise yourselves into small groups of not more than four-six. This size will allow everyone to participate actively in the discussion.
2. Establish some basic ground rules for the discussion to ensure a respectful and productive environment:
   a. Listen actively to each other.
   b. Allow everyone a chance to speak.

   c. Stay on topic and respect differing opinions.

3. Before starting the discussion, take a few minutes to review key concepts related to radioactivity that you have learned previously. This may include terms like radioactive decay, half-life, and applications of radiocarbon dating.
4. Begin the discussion by addressing the first guided question:
   a. "What is radioactive decay?"

   Encourage each group member to share their understanding of the concept. Discuss different types of radioactive decay (e.g., alpha decay, beta decay) and their significance. Use internet research to help you if you are stuck.
5. After discussing radioactive decay, move on to the next guided question:
   a. "How do we measure half-life?"

   Discuss how half-life is defined and its importance in understanding radioactive materials. Share examples of how half-life is used in various fields, such as archaeology and medicine.
6. Continue the discussion with additional guided questions such as:
   a. "What factors influence the rate of radioactive decay?"
   b. "How does radiocarbon dating work?"
   c. "What are some limitations of radiocarbon dating?"
7. As you discuss these topics, encourage group members to ask questions for clarification or further exploration. If someone is unsure about a concept, invite others to provide explanations or examples.
8. Designate one person in the group to take notes during the discussion. These notes can include key points, definitions, and any questions that arose during the conversation.
9. At the end of the discussion, take a few minutes to summarise the key points that were discussed. Each member can share one important takeaway from the conversation.

Activity 4.10 Visualising radioactive decay

Watch the following video / animation to reinforce the concept of radioactive decay: click here

Figure 4.14: QR link to video

Activity 4.11 Computer Simulation of Radiocarbon Dating Using PhET

Objective: To understand the principles of radiocarbon dating by using the PhET simulation that models the decay of carbon-14 over time, allowing you to observe how the decay process works and its implications for dating organic materials.

Materials Needed

1. A computer or tablet with internet access
2. Access to the PhET Interactive Simulations website: PhET Radioactive Dating Game
3. Notebook or digital document for recording data and observations

What to do

1. Open a web browser and navigate to the PhET Interactive Simulations website. Click on the **Radioactive Dating Game** simulation.

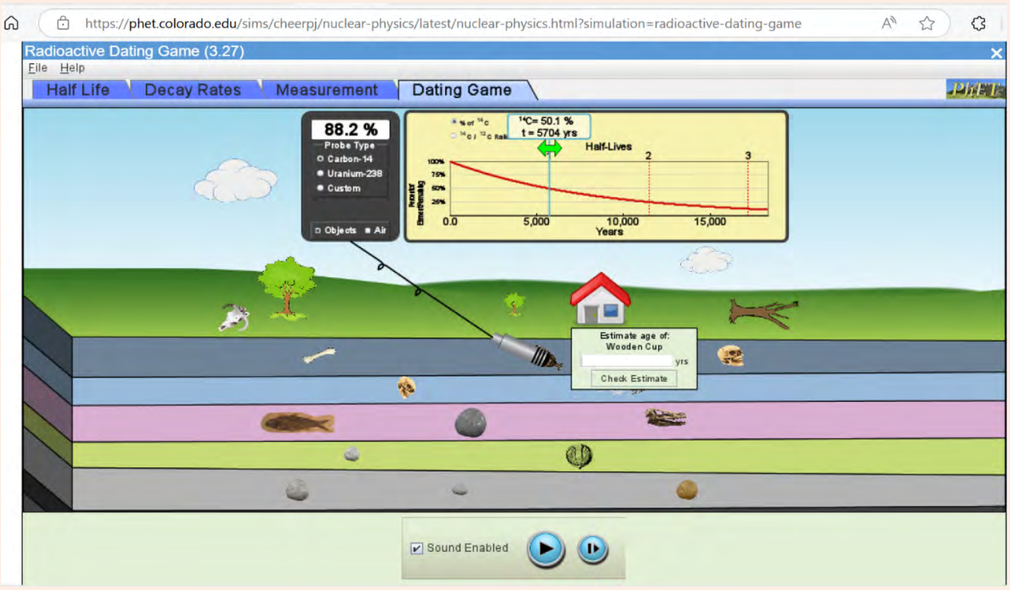


Figure 4.15: PhET radioactive dating game simulation

2. Spend a few minutes exploring the interface of the simulation. You will see options to select different isotopes, including carbon-14, and how they decay over time.
3. In the simulation, choose **Carbon-14** as your isotope for dating. This option will allow you to model how carbon-14 decays over time.
4. Use the simulation to drag a probe to an object (e.g., a piece of wood or bone) that you want to date. The simulation will show you the percentage of carbon-14 remaining in that object.
5. Based on the percentage of carbon-14 remaining, use the slider or input box to estimate the age of the object. Type your estimated age into the provided box.
6. Click on **"Check Estimate"** to see if your estimated age is correct. The simulation will provide feedback on your estimate.
7. Create a table in your notebook to record your observations about different objects and their estimated ages based on remaining carbon-14:

Object	Percentage of Carbon-14 Remaining	Estimated Age (Years)	Correct Age (Years)
Wood			
Bone			
Sample 3			

8. Try dating various objects by repeating steps 4 through 7 for different samples available in the simulation. Record your findings in your table.
9. After completing several estimates, analyse your data:
   a. How does the percentage of remaining carbon-14 relate to the estimated age?
   b. Discuss any patterns you notice regarding how much carbon-14 remains in older versus younger samples.

Activity 4.12 Carbon dating research

Objective: Having completed Activity 4.10, research and summarise the use of carbon dating in a field of your choice.

Methodology

1. Using the internet or textbook resources, find choose a field of dating which interests you. This could be, for example, the dating of ancient artefacts or of human remains.
2. Summarise onto a poster or fact-sheet how carbon dating is used in this context, including any notable or interesting discoveries that you come across in your research.

Expected outcomes: You should allow your peers access to your poster for them to read and learn, or could alternatively present your poster to your peers.

Activity 4.13 Dice Simulation of Radioactive Decay

Objective: To model the process of radioactive decay using dice, allowing you to visualise the decay process, calculate half-life, and understand the randomness of radioactive decay.

Materials Needed

1. **100 six-sided dice** (each die represents a nucleus in a sample of a radioactive substance)
2. A notebook or digital document for recording data
3. A graphing tool (graph paper or digital graphing software)
4. A calculator (optional for calculations)

Figure 4.16: Dice

What to do

1. Start with **100 dice**. Each die represents a nucleus in a sample of a radioactive substance.
2. For this simulation, define a rule for decay: if a die shows a **6**, it is considered "decayed." All other numbers (1-5) represent undecayed nuclei.
3. Roll all 100 dice at once. After rolling, determine which dice will be considered "decayed" based on your rule.
4. Count the number of dice that show a 6 and remove those from your total. Record the number of remaining "undecayed" dice in your notebook.
5. Roll the remaining undecayed dice again. Apply the same rule to determine which dice are "decayed." Record the new count of undecayed dice after each roll.
6. Continue this process for **10–15 rolls**, documenting the number of undecayed dice after each roll.
7. Use the following table format to record your results:

Roll Number	Initial Dice	Decayed Dice	Remaining Undecayed Dice
1	100		
2			
3			
4			
5			
6			
7			
8			
9			
10			

8. After completing your rolls, create a plot with the number of rolls on the horizontal axis and the number of remaining undecayed dice on the y-axis. This visual representation will help you see how the number of undecayed nuclei decreases over time.

9. Determine when approximately half of your original number of dice remain undecayed. For example, if you started with 10 dice, identify

when there are about 5 remaining. Note how many rolls it took to reach this point; this is an estimate of the half-life for your simulated decay process.

10. Reflect on how this simulation illustrates the randomness of radioactive decay:

   a. Discuss how each roll represents an independent event and how some nuclei decay while others do not.

   b. Consider how this randomness relates to real-world radioactive substances.

   c. Talk about the concept of decay constant and how it relates to the probability of decay in actual radioactive materials.

Activity 4.14 Popcorn to simulate radioactive decay

Objective: To model the process of radioactive decay using popcorn, allowing you to visualise the decay process and understand the randomness of radioactive decay.

Materials needed

1. 100 un-popped popcorn kernels
2. A saucepan with a small amount of oil in the bottom
3. A clear lid, or sieve to use as a lid
4. A phone or video camera
5. A stopwatch or wristwatch
6. A notebook and pen
7. Graph paper

Figure 4.17: Popcorn in a pan with a sieve lid, Savvysurf.co.uk

What to do

1. Set up the phone or camera to record the content of the pan with the stopwatch or wristwatch in the shot.
2. Add the un-popped kernels to the pan, turn on the heat, add the lid and press record on the camera.
3. Record the kernels popping, shaking the pan occasionally to stop the kernels from sticking and burning, ensuring that the ticking stopwatch can be seen on the screen.
4. Turn off the heat and stop the recording when all the kernels have popped.
5. Re-play the video in slow motion, making a note of how many un-popped kernels remain every 10 seconds. Record this data into a table.
6. Plot onto graph paper the number of un-popped kernels (y axis) against time (x axis).
7. Compare the shape of the graph to a radioactive decay curve and write a conclusion as to the similarities and differences; how well does popcorn model radioactive decay?

Activity 4.15 Calculating Half-life

Materials Needed

1. Worksheet
2. Calculator
3. Pen/pencil
4. Study the worked examples below carefully before attempting the example questions that follow

Worked Example 1

The decay constant of a radioactive substance is 0.001 s^{-1}. Calculate its half-life.

Step-by-Step Solution

Step 1: Recall the formula for half-life

$$T_{\frac{1}{2}} = \frac{1n2}{\lambda}$$

Step 2: Substitute the given values

$$T_{\frac{1}{2}} = \frac{1n2}{0.001}$$

$$T_{\frac{1}{2}} = \frac{1n\,2}{0.001}$$

Step 3: Calculate to obtain the answer

$$T_{\frac{1}{2}} = 693\ s$$

Worked Example 2:

A radioactive substance has a half-life of 10 years. If the initial mass of the substance is 80 grams, how much remains after 30 years?

Step-by-Step Solution

Step 1: Identify the known values

- Initial mass N_0=80 g
- Half-life $T_{\frac{1}{2}} = 10\ years$
- Time (t) = 30 years

Step 2: Calculate the decay constant

$$T_{\frac{1}{2}} = \frac{1n2}{\lambda}$$

$$\lambda = \frac{1n2}{T_{\frac{1}{2}}}$$

$$\lambda = \frac{1n2}{10}$$

$$\lambda = 0.069314718056\ per\ year$$

Step 3: Introduce the decay law formula

$$N = N_0 e^{-\lambda t}$$

Step 4: Substitute the known values

$$N = 80\,e^{-(0.069314718056 \times 30)}$$

Step 5: Calculate to obtain the answer

$$N = 80 \times \frac{1}{8}$$

$$N = 10\ grams$$

After 30 years, **10 grams** of the substance remains.

Worked Example 3

A radioactive sample decays from 100 grams to 25 grams in 12 years. What is the half-life of the sample?

Step-by-Step Solution

Step 1: Identify the known values

Initial mass $N_0 = 100\ grams$

Remaining amount $N = 25\ grams$

Time elapsed $t = 12\ years$

Step 2: find the decay constant as follows

a. Introduce the decay law formula and rearrange it to make the decay constant the subject

$$\lambda = \frac{1\text{n}\left(\frac{N_0}{N}\right)}{t}$$

b. Substitute the values

$$\lambda = \frac{1\text{n}\left(\frac{100}{25}\right)}{12}$$

c. Calculate to obtain the decay constant

$$\lambda = 0.1155$$

Step 3: calculate half-life using the half-life formula

a. Introduce the half-life formula

$$T_{\frac{1}{2}} = \frac{1\text{n}2}{\lambda}$$

b. Substitute the known and calculated values

$$T_{\frac{1}{2}} = \frac{1\text{n}2}{0.1155}$$

c. Calculate to obtain the answer

$$T_{\frac{1}{2}} = \frac{0.693}{0.1155} = 6\ years$$

Worked Example 4

A fossil is found to have 25% of its original C-14 remaining. How old is the fossil? ($T_{\frac{1}{2}} = 5730 years$)

Step-by-Step Solution

Step 1: Identify the known values

- Remaining percentage $\frac{N}{N_0} = \frac{25}{100} = \frac{1}{4}$
- Half-life $T_{\frac{1}{2}} = 5{,}730\ years$

Step 2: Calculate the decay constant

$$\lambda = \frac{1n2}{T_{\frac{1}{2}}} = \frac{1n2}{5730} = 1.2097 \times 10^{-4}\ per\ year$$

Step 3: Introduce the decay law formula and rearrange

$$N = N_0 e^{-\lambda t}$$

$$t = \frac{1n\left(\frac{N_0}{N}\right)}{\lambda}$$

Step 4: Substitute the known and calculated values

$$t = \frac{1n(4)}{1.2097 \times 10^{-4}}$$

Step 5: Calculate to obtain your answer

$$t = 11,\ 460\ years$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

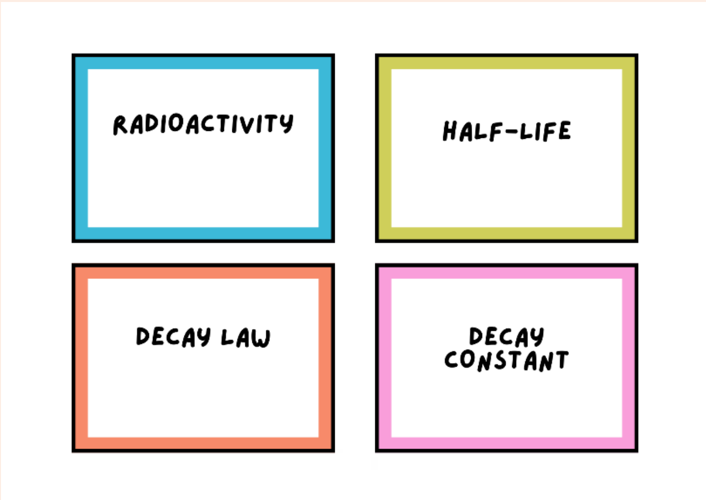
1. A radioactive substance has a half-life of 12 years. What is its decay constant?
2. A sample of radioactive substance has an initial amount of 150 g. If its half-life is 4 years, how much will remain after 10 years.
3. A sample decays to 10 grams after 6 years. If the half-life is 3 years, how much was there initially?
4. A radioactive sample decays to 20% of its original amount in 5 years. What is its half-life?

Activity 4.16 Flashcard Matching Challenge

Objective: To reinforce your understanding of nuclear physics terms by matching terms with their definitions using provided flashcards.

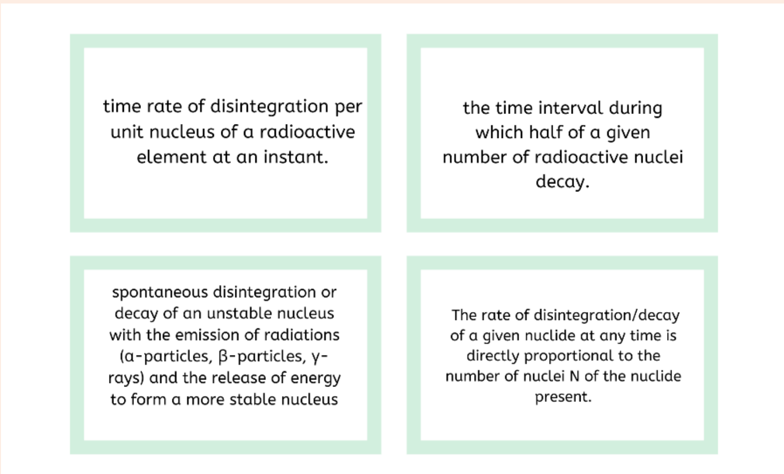
Materials Needed

1. Flashcards
   - **Set A**: Flashcards with key terms
   - **Set B**: Flashcards with corresponding definitions
2. Pen or Pencil



Set A

Figure 4.18: Flashcards with key terms on nuclear physics



Set B

Figure 4.19: Flashcards with some definitions on nuclear physics

What to do

1. Take a few minutes to read through both sets of flashcards. Familiarise yourself with the terms in Set A and their corresponding definitions in Set B.
2. To test your memory, close your eyes or turn away from the learner material to avoid looking at the definitions. This will help you recall the definitions based on the terms.
3. Start with the first term in Set A. Think about its meaning and try to recall which definition in Set B matches it.
4. Write down your answer
5. Proceed through all the terms in Set A, matching each one to its definition in Set B. Take your time and think carefully about each match.
6. Once you have matched all the terms, go back through the flashcards to check your answers. Look at each term and its corresponding definition to see if they align correctly.
7. For any incorrect matches, review the definitions again to understand why they do not match. Take notes on any challenging terms.

Activity 4.17 Online quiz

Visit the website linked below to practice applying your understanding of half life: **click here**

Figure 4.20: QR link to multiple choice quiz

ADDITIONAL READING MATERIALS

1. Giancoli, D. C. (2008). *Physics for Scientists and Engineers with Modern Physics* (4th ed., pp. 582-585). Prentice Hall.
2. Serway, R. A., & Jewett, J. W. (2014). *Physics for Scientists and Engineers* (9th ed., pp. 1292-1295). Brooks/Cole.
3. Knight, R. D. (2016). *Physics for Scientists and Engineers: A Strategic Approach* (4th ed., pp. 1125-1127). Pearson.
4. OpenStax College. (2019). *College Physics* (2nd ed., pp. 975-978). OpenStax.

REVIEW QUESTIONS

Review Questions 4.1

1. Define Photoelectric effect.
2. State four laws of photoelectric effect.
3. State Einstein's equation of photoelectric effect.
4. The surface of a metal is illuminated with light of wavelength 450 nm. The work function of the metal is 2.5 eV. Calculate the kinetic energy of the emitted electrons. ($h = 6.63 \times 10^{-34}$ Js, speed of light $c = 3.0 \times 10^{8}$ m/s, and 1 eV $= 1.6 \times 10^{-19}$ J)
5. Light of energy 6.2 eV strikes a metal surface, causing the emission of electrons. The maximum kinetic energy of the emitted electrons 1.5 eV. Calculate the threshold wavelength of the metal in nanometres. ($h = 6.63 \times 10^{-34}$ Js, speed of light $c = 3.0 \times 10^{8}$ m/s, and 1 eV $= 1.6 \times 10^{-19}$ J)
6. A scientist wants to design a device that uses the photoelectric effect to detect light intensity. The device uses a metal with a known work function of 2.2 eV. During an experiment, light of wavelength 400 nm is shone onto the metal surface.
   a. Explain why or why not electrons are emitted from the metal surface when the light is incident.
   b. Predict how the kinetic energy of emitted electrons, if any, would change if light with a wavelength of 300 nm is used.

      If the intensity of light at 400 nm is doubled, what will happen to the number of emitted electrons and their kinetic energy?

Review Questions 4.2

1. Name the three subatomic radiations emitted during radioactivity.
2. A radioactive sample of mass 30 grams has a half-life of 6 months. State and explain whether any of it will be left in 12 months.
3. The half-life of a certain isotope is 3 years. If 25% of the original sample remains, how many years have passed?

4. A radioactive substance has a half-life of 10 hours. How much of a 200 g sample remains after 30 hours?
5. A team managing a nuclear power plant needs to safely store a radioactive waste material with a half-life of 10 years. To reduce the material's radioactivity to less than 1% of its original level, how long must the waste be stored?

SECTION

5

PROJECTILES, FRICTION, CIRCULAR MOTION

MECHANICS AND MATTER

Kinematics

INTRODUCTION

This section explores key concepts of motion, including projectile motion, friction, circular motion, banking, and skidding. Projectile motion involves the curved paths objects follow under the influence of gravity. Friction, the resistive force between surfaces in contact, impacts movement and stability. Circular motion examines objects moving in curved paths, analysing the forces required for such motion. Banking refers to the tilting of roads or tracks to help vehicles navigate curves safely, while skidding highlights the loss of traction, often resulting from inadequate friction. These areas connect theory with real-life applications, such as sports, transportation, and engineering, fostering an understanding of forces and motion in various scenarios. By analysing these principles, key problem-solving skills can be developed, enhancing comprehension of both natural and man-made systems.

KEY IDEAS

- A projectile is any object that is launched or thrown into the air and moves solely under the influence of gravity
- Banking is the act of constructing roads in a manner that will help cars negotiate curves at relatively higher speeds.
- Centripetal force is the force that is required to keep bodies moving in a circular track.
- Circular motion is a type of motion in which an object moves around a fixed point while maintaining a constant distance from that point.
- Friction is the force that opposes the relative motion or the tendency of such motion of two surfaces in contact.

PROJECTILES

A projectile is any object that is launched or thrown into the air and moves solely under the influence of gravity (i.e. all other forces are negligible). Common examples include kicking a football, throwing a javelin, or tossing a handball into the air.

Figure 5.1: Image of an athlete throwing a javelin

When a projectile travels through the air without any additional propulsion, it follows a curved path known as a parabolic trajectory. This motion is referred to as projectile motion. While forces like air resistance may act on the projectile, their effects are typically minor compared to gravity and are often ignored in simple analyses of projectile motion.

Components of projectile motion

Have you ever tried plucking a mango fruit from a tree using a stone before? What can you say about the direction of motion of the stone? It travels both upward (vertically) and forward (horizontally) at the same time. This means both initial velocity and displacement of stone have components in the vertical and horizontal directions. Let's consider the details of these components:

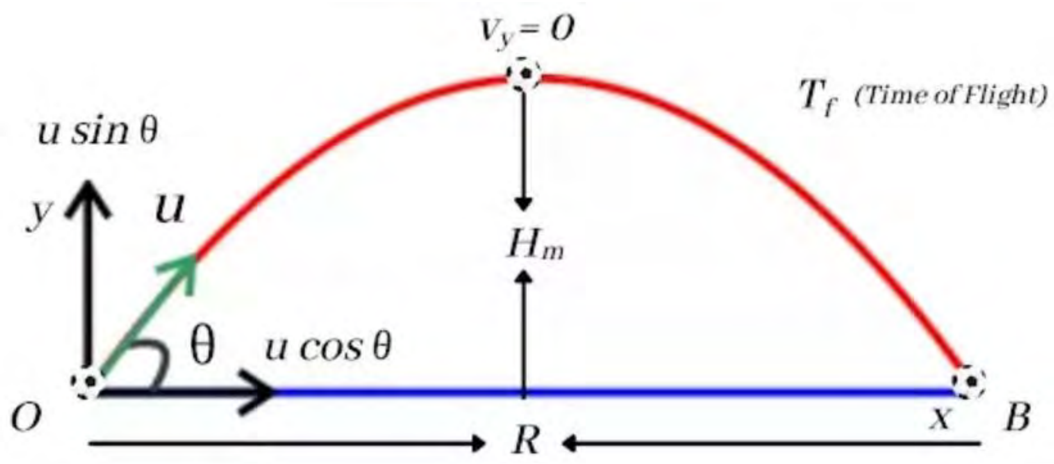


Figure 5.2: a diagrammatic representation of the projectile motion of a football

Equations of motion to remember: $v = u + at$, $v^2 = u^2 + 2as$, $s = ut + \frac{1}{2}at^2$

In projectile motion, we will use **y** or sometimes h in place of **s** for a vertical distance, **x** in place of **s** for a horizontal distance and **g** in place of **a**.

Given the angle of projection θ, the initial velocity **u** has the vector components $u_x = u\cos\theta$ *and* $u_y = u\sin\theta$ in the horizontal and vertical directions respectively.

The final velocities are accordingly given as v_x *and* v_y.

Activity 5.1 Resolving a velocity into its horizontal and vertical components

Study the worked example below carefully before attempting the example questions that follow.

Worked Example

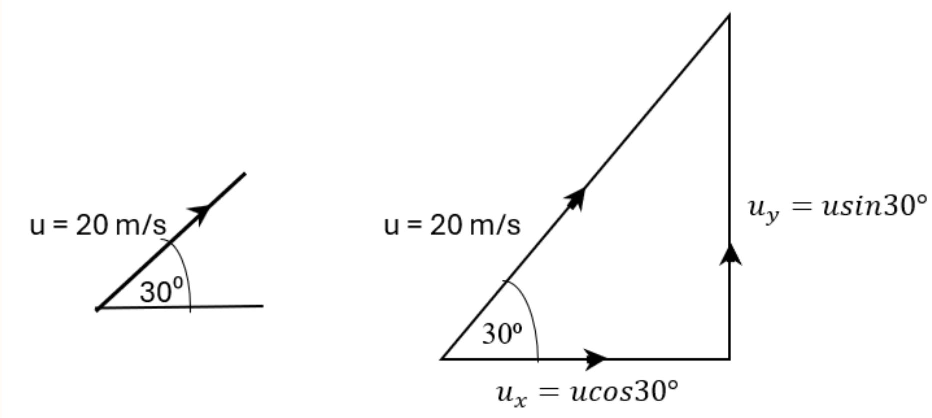
A soccer ball is kicked with an initial velocity of 20 m/s at an angle of 30 degrees above the horizontal. Draw a diagram and calculate the horizontal and vertical components of the initial velocity.

Solution

Remember:

The horizontal component is calculated using the formula: $V_x = V\cos(\theta)$

The vertical component is calculated using the formula: $V_y = V\sin(\theta)$



Horizontal Component

$V_x = V\cos(\theta)$

$= 20\cos(30°)$

$= 17.32\ m/s$

Vertical Component

$V_y = V\ sin(\theta)$

$= 20\ sin(30°)$

$= 10\ m/s$

Practice questions

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A plane flies at a constant speed of 500 km/h at an angle of 25° north of east. Draw a diagram and calculate the horizontal and vertical components of the velocity.
2. A diver leaps off a cliff with an initial velocity of 8 m/s at an angle of 45° below the horizontal. Draw a diagram and calculate the horizontal and vertical components of the velocity.

The horizontal component

Since acceleration due to gravity does not act in a horizontal direction, $g = 0$ for horizontal motion.

Therefore, substituting in to $\boldsymbol{v} = \boldsymbol{u} + \boldsymbol{at}$,

$v = \text{u}\cos\theta + (0)t = \text{u}\cos\theta.$

This means that the velocity in the horizontal direction does not change in the course of the motion.

Also, substituting in to $\boldsymbol{s} = \boldsymbol{ut} + \frac{1}{2}\mathbf{a}\boldsymbol{t}^2$,

$x = \mathrm{utcos}\theta + \frac{1}{2}(0)\,t^2 = \mathrm{ut}\ \mathrm{cos}\theta$

Summary for horizontal motion:

$\boldsymbol{v_x} = \mathrm{ucos}\boldsymbol{\theta}$,

$\boldsymbol{x} = \mathrm{utcos}\boldsymbol{\theta}$

The vertical component

The vertical component of the motion is either upward or downward, hence g is either (+) or (-). The following equations will then be applied accordingly.

$\boldsymbol{v_y} = \mathrm{usin}\boldsymbol{\theta} \pm \boldsymbol{gt}$

$\boldsymbol{v_y}^2 = \boldsymbol{u}^2\sin^2\boldsymbol{\theta} \pm 2\boldsymbol{gy}$

$\boldsymbol{y} = \mathrm{utsin}\boldsymbol{\theta} \pm \frac{1}{2}\mathbf{g}\boldsymbol{t}^2$

Aside from the quantities considered above, you may ask, how long could a projectile take to land? How high could the projectile go before beginning a downward motion? How far could it land from the point of projection? etc. See **Annex B** for an analysis of how to find these values, but remember that all of the questions above can be solved by accurate use of the three equations of motion.

Activity 5.2 Exploring Projectiles in Sports

Objective: Work in pairs to identify different sports and the objects that act as projectiles in those sports. You will discuss the paths these projectiles take and share your findings with the class.

Materials Needed

1. A notebook and pen/pencil (for recording your lists)
2. A whiteboard or large paper (optional, for group feedback)

What to do

1. In your pairs, brainstorm and list as many sports as you can think of. Aim for at least 5-10 different sports.

2. For each sport on your list, identify the objects that act as projectiles. Write down the projectile associated with each sport next to the sport's name in your notebook.
3. Discuss with your partner how each projectile moves through the air. Consider:
   a. The shape of the path (e.g., straight line, curve, parabolic).
   b. Factors that might affect the path (e.g., angle of launch, speed, air resistance).
   c. Make notes on these observations next to each projectile in your list.
4. Once you have completed your list and descriptions, prepare to share your findings with the class.
5. One pair at a time should present their list of sports and projectiles to the class for feedback Engage in a whole class discussion and discuss how different factors might influence projectile motion in various sports.
6. Watch the video linked below demonstrating some examples of projectile motion in sports.

   Projectile Motion Examples Sports

Note: you can find some examples of the applications of projectiles in **Annex B**.

Activity 5.3 Investigating Projectile Motion with Launchers

Objective: Explore how the angle of launch affects projectile motion by measuring key quantities such as time of flight and range.

Materials Needed

1. A small catapult or slingshot
2. Projectiles (e.g., small balls or bean bags)
3. Rulers (to measure distance)

4. Protractors (to measure launch angles)
5. Stopwatches (to measure time)
6. A notebook and pen/pencil (for recording data)

What to do

1. Place your catapult or slingshot on a flat surface. Ensure it is stable and secure.
2. Use the protractor to set the launcher at different angles. Suggested angles include 15°, 30°, 45°, 60°, and 75°. Record each angle in your notebook.
3. For each angle:
   a. Pull back the launcher to a consistent position for uniform launch conditions.
   b. Release the projectile while simultaneously starting the stopwatch.
4. Stop the stopwatch as soon as the projectile lands on the ground. Record this total time of flight in your notebook.
5. Measure the horizontal distance from the base of the launcher to where the projectile lands using a ruler. Record this distance as the range for each launch angle.
6. Repeat steps 3 to 5 for each launch angle you set in step 2.
7. Firstly, use the following formula to calculate initial velocity (u) based on your measured time of flight (T):

$$u = \frac{gT}{2\sin\theta}$$

   Where:

   g is 9.81 ms^{-2} (acceleration due to gravity),

   θ is the launch angle in degrees.

8. Secondly, use this formula to calculate initial velocity (u) based on your measured range (R):

$$u = \sqrt{\frac{Rg}{\sin 2\theta}}$$

9. Write down both calculated values of initial velocity for each angle in your notebook.

10. Compare the initial velocities obtained from both methods (time of flight and range). Discuss any differences you observe and consider possible reasons for these discrepancies.
11. Reflect on how changing the launch angle affected your measurements of the time of flight, range, and calculated initial velocity. Consider what you learned about projectile motion through this experiment.

Activity 5.4 Projectile Motion Simulation Experiment

Objective: To explore the principles of projectile motion by using simulations to change variables such as initial velocity, launch angle, and height of the launcher. You will measure the resulting time of flight and range, compare simulation results with theoretical calculations, and discuss any discrepancies.

Materials Needed

1. A computer or tablet with internet access
2. Access to a projectile motion simulation (e.g., PhET Interactive Simulations: https://phet.colorado.edu/en/simulations/projectile-motion)
3. Calculator (for theoretical calculations)
4. Notebook or digital document for recording data and observations
5. Graph paper (optional for plotting results)

What to do

1. Open a web browser and navigate to the PhET Interactive Simulations website. Click on the **Projectile Motion** simulation.
2. Spend a few minutes exploring the interface of the simulation. Understand how to adjust parameters such as:
   a. **Initial Velocity**: The speed at which the projectile is launched.
   b. **Launch Angle**: The angle at which the projectile is launched relative to the horizontal.

   c. **Height of Launcher**: The vertical height from which the projectile is launched (you can set this to zero).

3. Create a table in your notebook to predict your results using the formulae in step 4:

Initial Velocity (m/s)	Launch Angle (°)	Theoretical Time of Flight (s)	Theoretical Range (m)

4. For each set of parameters, decided by you and filled in to the first two columns of your table, calculate the theoretical time of flight and range using the following formulas:

   a. **Time of Flight (T)**: $T = \frac{2u\sin\theta}{g}$

   b. **Range (R)**: $R = \frac{u^2 \sin 2^{\theta}}{g}$

   Where:

   u = initial velocity

   θ = launch angle in radians

   g = acceleration due to gravity (approximately 9.81 m/s^2)

5. **Set Parameters on the Simulation**

   a. Choose the initial velocity for your projectile (e.g., 10 m/s, 20 m/s, etc.).

   b. Select a launch angle (e.g., 30°, 45°, 60°).

   c. Set the height of the launcher to **zero**.

6. Launch the projectile by clicking on the appropriate button in the simulation.

7. Observe and record the following outcomes:

   a. **ime of Flight**: How long the projectile stays in the air.

   b. **Range**: The horizontal distance travelled by the projectile.

8. After calculating theoretical values, compare them with your simulation results. Note any discrepancies between your calculated values and those obtained from the simulation.

9. Reflect on possible reasons for any differences between theoretical calculations and simulation outcomes:
   - **a.** Consider factors such as air resistance, inaccuracies in angle measurement, or limitations of the simulation.
   - **b.** Discuss how real-world conditions might affect projectile motion compared to ideal calculations.

Activity 5.5 Sports Projectiles Poster Project

Objective: To explore the concept of projectiles in various sports by creating informative posters or collages that showcase different sports and the projectiles used in each.

Materials Needed

1. Large poster boards or sheets of paper
2. Markers, coloured pencils, or crayons
3. Magazines or printed images related to sports
4. Glue or tape
5. Ruler
6. Access to research materials (books, internet, etc.)
7. Scissors

What to do

1. Organise yourselves into small groups of no more than five.
2. As a group, select **2-3 different sports** to focus on for your poster. Consider including a variety of sports that use different types of projectiles, such as:
   - **a.** Baseball (baseball)
   - **b.** Basketball (basketball)
   - **c.** Football (football)
   - **d.** Tennis (tennis ball)
   - **e.** Golf (golf ball)
   - **f.** Archery (arrow)
3. Research the projectiles used in each chosen sport. Gather information about:
   - **a.** The type of projectile used.

   b. How the projectile is used in the sport.
   c. Any interesting facts about the projectile's design or performance.
4. Discuss how you want to organise your poster. Consider dividing the poster into sections for each sport, including:
   a. The name of the sport.
   b. An image of the projectile.
   c. Key facts about the projectile.
5. Sketch a rough layout on a separate piece of paper before starting on the poster board.
6. Using your large poster board or paper, start creating your poster:
   a. Write the names of each sport in bold letters.
   b. Draw or paste images of the projectiles next to their respective sports.
   c. Include key facts and information about each projectile in clear, legible text.
   d. Make sure your poster is colourful and visually appealing.
7. Once all groups have completed their posters, display them around the classroom.
8. As a class, participate in a gallery walk where you can move around the room to view each group's poster. Take notes on interesting facts you learn from other groups' posters.

Activity 5.6 Calculating Quantities associated with projectiles

Study the worked examples below carefully before attempting the example questions that follow.

Worked Example 1

Solved problems

1. A ball is launched from the ground with an initial velocity of 30 m/s at an angle of 40^0 to the horizontal. Assume $g=9.8\,m/s^2$. Find the:
   a. maximum height reached by the ball.
   b. time taken to reach the maximum height.
   c. total time of flight of the ball.

d. range or horizontal distance travelled by the ball.

Solution

Given data: $u = 30\ ms^{-1}$, $\theta = 40°$, $g = 9.8\ ms^{-2}$

At max height: $v = 0\ ms^{-1}$

a. $H = \dfrac{u^2 \sin^2\theta}{2g}$

$H = \dfrac{30^2 \sin^2 40}{2(9.8)}$

$H = \dfrac{900 \times 0.4132}{19.6} = 18.973\ m$

b. $t = \dfrac{u\sin\theta}{g}$

$t = \dfrac{30 \sin 40}{9.8}$

$t = \dfrac{30 \times .6428}{9.8} = 1.968\ s$

c. $t_f = 2t = 2(1.968) = 3.935\ s$

$R = ut\cos\theta$

$= 30\cos 40 \times 3.935$

$= 90.4$ m

2. A cannon fires a projectile at an initial velocity of 50 m/s at an angle of 60^0 to the horizontal from a cliff 20 m above the ground. Assume $g = 9.8\ m/s^2$. Find:

a. maximum height of the projectile above the ground.

b. total time of flight until the projectile hits the ground.

c. range (horizontal distance) from the base of the cliff where the projectile lands.

Solution

Given data: $u = 50\ ms^{-1}$, $\theta = 60°$, $g = 9.8\ ms^{-2}$

At max height: $v = 0\ ms^{-1}$

a. **Step 1: find the maximum height from the point of projection h_{max}.**

$h_{max} = \dfrac{u^2 \sin^2\theta}{2g} = \dfrac{50^2 \sin^2 60}{2(9.8)} = 95.66\ m$

Step 2: add the initial height from the ground (20 m) to h_{max} and call it H_{max}

$$H_{max} = h_{max} + 20$$

$$H_{max} = 95.66 + 20 = 115.66\ m$$

So the maximum height of the projectile from the ground is **115.66 m.**

b. The time of flight here is the time the projectile took to the maximum height and fell to the ground. So, you need to find the time it took to travel the upward and downward distances separately and add them.

Step 1: find the time taken to travel h_{max} = 95.66 m, you may call it t_{up}

$$t_{up} = \frac{\bar{u}\text{-}\sin\theta}{g} = \frac{5\text{-}0 \sin 60}{9.8} = 4.415\ s$$

Step 2: find the time taken to land on the ground from the maximum height (H_{max},), you may call it t_{down}.

$$H_{max} = u\,t_{down} + \frac{1}{2} g\,t^2{}_{down},$$

As the projectile begins to come down, its initial velocity u=0,

$$\text{so } H_{max} = \left(0\right) t_{down} + \frac{1}{2} g\,t^2{}_{down},$$

$$H_{max} = \frac{1}{2} g\,t^2{}_{down},$$

$$t_{down} = \sqrt{\frac{2H_{total}}{g}} = \sqrt{\frac{2(115.66)}{9.8}} = 4.485\ s$$

Step 3: add t_{down} *to* t_{up} to get the time of flight t_f

$$t_f = t_{down} + t_{up}$$

$$t_f = 4.418 + 4.845 = 9.263\ s$$

c. $R = (u\cos\theta\big) \times t_f$

$R = (50\cos 60)(9.263)$

$R = 231.575\ m$

Practice questions

1. A football is kicked horizontally from a height of 10 m with an initial velocity of 5 m/s.

a. How long does it take to hit the ground?

   b. How far does it travel horizontally before hitting the ground?
   (Assume $g = 9.8\,m/s^2$)

2. A ball is launched with an initial velocity of 25 m/s at an angle of 45^0. Calculate the range of the projectile.
   (Use $g=9.8\,m/s^2$)

3. A ball is kicked with an initial velocity of 15 m/s at an angle of 45^0.
   a. How long does the ball stay in the air?
   b. How far does it travel horizontally before hitting the ground?
   (Assume $g=10\,m/s^2$)

FRICTION

When you push a desk on a rough concrete floor, you notice significant resistance to your effort. In contrast, pushing the same desk on a tiled floor requires less effort.

Now, if you give the desk a push and let it move freely on the concrete floor, and then do the same on the tiled floor with a similar push, you will observe that the desk moves more freely and farther on the tiled floor. This happens because the smoother tiled surface offers less resistance compared to the rough concrete floor.

In both scenarios, there is a force resisting the initial push on the desk. After the push, the desk's motion slows down or decelerates more quickly on the rough surface than on the smooth surface. This resisting force, which opposes motion or decelerates a moving object, is called friction. Friction arises between surfaces in contact and depends on the nature of those surfaces and their relative motion.

Friction is the force that opposes the relative motion or the tendency of such motion of two surfaces in contact.

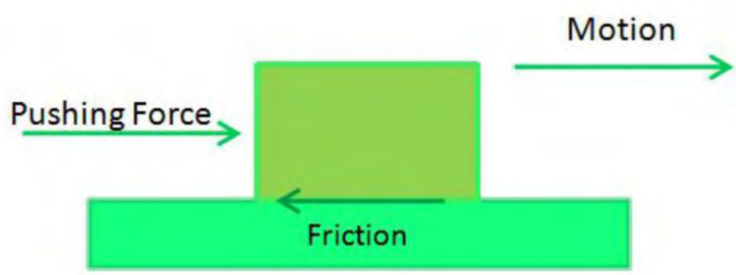


Figure 5.3: Friction between two surfaces in contact

Types of friction

1. **Static friction:** This is the force that resists the initial sliding motion between two surfaces in contact. It is also referred to as **limiting friction** because it represents **the maximum force that must be overcome to start motion**. In the scenarios above, static friction is the reason for the difficulty in getting the desk to start moving across the concrete floor.
2. **Dynamic friction:** This is the force between surfaces in contact that tends to decelerate or resist the relative motion of the bodies. In the scenarios above, this force is responsible for slowing down the moving desk and eventually bringing it to a stop.

In the process of moving a stationary object, the applied force must exceed the limiting friction before the body can accelerate or move.

The magnitude of the frictional force depends on:

1. The coefficient of friction, which in turn depends on the nature of the surfaces.
2. The normal reaction R, which is the force that acts perpendicular to the surfaces, pressing them together.

Note that, **neither the area of the surfaces nor their relative speed of motion** affects the magnitude of the frictional force.

The coefficient of friction (μ)

This is a number that quantifies the ratio of the frictional force F resisting motion to the normal reaction force R pressing the two surfaces together. It varies depending on the materials in contact and their surface conditions.

Mathematically,

$$\mu = \frac{F}{R}$$

This is a dimensionless constant and bears no SI unit. It is unique for any given pair of surfaces.

Types of Coefficients of Friction

1. Coefficient of static friction (μ_s), this:
   a. Represents the friction when an object is at rest.
   b. Determines the force required to initiate motion.
   c. Typically, greater than the kinetic coefficient.

2. Coefficient of kinetic friction (μ_k), this:
   a. Represents the friction when an object is already in motion.
   b. Determines the force required to keep maintain or sustain the object's motion.

Activity 5.7 Exploring the Role of Friction in Everyday Life

Objective: identify and discuss scenarios in everyday life where friction is advantageous, as well as situations where friction causes problems.

Materials Needed

1. Notebook and pen/pencil (for recording ideas)
2. Whiteboard or large paper (optional, for group brainstorming)
3. Markers (optional, for writing on the whiteboard)

What to do

1. Take a few minutes to think about your daily life. Write down at least three scenarios where friction is beneficial. Consider areas such as:
   a. Transportation (cars, bicycles, shoes)
   b. Sports (gripping surfaces, traction)
   c. Everyday tasks (writing, cooking, cleaning)
2. Write down at least three scenarios where friction causes problems or challenges. Think about situations like:
   a. Wear and tear on materials (tyres, machinery)
   b. Difficulty in movement (slipping on ice, heavy objects)
   c. Excessive heat generation (brakes in vehicles)
3. Find a partner and share your lists. Discuss your examples of advantageous friction and problematic friction. As you discuss, consider questions like:
   a. Why is friction important in the scenarios you identified?
   b. What specific problems does friction create in the negative examples?
   c. Are there any solutions or methods to reduce the negative effects of friction?
4. After your pair discussions, come together as a class, and share your examples of advantageous friction with the class.

5. Share your examples of problematic friction. Discuss these as a class and brainstorm possible solutions for each issue raised.

6. As a class, create two summary lists on the whiteboard or large paper:
   a. List all the scenarios discussed where friction is beneficial.
   b. List all the scenarios discussed where friction causes issues along with potential solutions.

7. Watch the video linked below demonstrating some examples of friction in everyday life.

   https://youtu.be/qy-EJRDyt-A?si=lK8aOthIk-tGtgyY

8. See **Annex B** for some examples of friction, including its disadvantages and steps which can be taken to reduce it.

Activity 5.8 Measuring Static and Dynamic Friction

Objective: Conduct experiments to measure the forces of static and dynamic friction using a spring scale on various surfaces.

Materials Needed

1. Spring scale (capable of measuring in Newtons)
2. Various surfaces (e.g., rubber mat, wooden board, metal sheet)
3. Object to test (e.g., a block or cart)
4. Ruler (for measuring dimensions if needed)
5. Notebook and pen/pencil (for recording data)
6. Weights (optional, for varying the mass of the object)

What to do

1. Choose one of the surfaces (e.g., rubber mat) and place it flat on a table or the floor. Place the object you are testing on top of this surface.

2. Attach the spring scale to the object. Gradually pull the object using the spring scale until it just starts to move.

Figure 5.4: Spring balance attached to an object

3. Record the maximum force indicated on the spring scale just before the object begins to slide. This value is the static friction force for that surface. Write down your measurements in your notebook.
4. Once the object is in motion, continue pulling it at a constant speed.
5. Record the force indicated on the spring scale while maintaining that constant speed. This value is the dynamic (kinetic) friction force for that surface. Write this measurement down in your notebook as well.
6. Change to a different surface (e.g., wooden board) and repeat steps 2,3, 4 and 5.
7. Record your measurements for static and dynamic friction forces in your notebook for each surface.
8. Continue this process for all surfaces you have available (e.g., rubber, wood, metal).
9. Organise your recorded data into a table with the following format:

Surface Type	Static Friction Force (N)	Dynamic Friction Force (N)
Rubber		
Wood		
Metal		

10. Compare the static and dynamic friction forces across different surfaces.
11. Look for trends such as which surface has the highest or lowest friction forces. Consider questions like:
    a. How does surface texture affect friction?
    b. Is there a significant difference between static and dynamic friction on each surface?

Activity 5.9 Investigating Static Friction with Interactive Simulations

Objective: Use interactive simulations to explore static friction by adjusting the weight of an object.

Materials Needed

1. A computer or tablet with internet access
2. Access to the PhET Forces and Motion simulation or a similar interactive simulation that allows exploration of static friction (https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_all.html)
3. A notebook and pen/pencil (for recording data)
4. Graph paper or graphing software (optional, for plotting your graph)

What to do

1. Open your web browser and go to the PhET Forces and Motion simulation or another interactive simulation focused on friction.
2. Spend a few minutes exploring the interface. Identify where you can adjust the weight of the object and observe how it interacts with the surface. (turn on the values button)
3. Choose an object (like a wooden box) to work with in the simulation.
4. Record the mass of the object in your notebook.
5. Gradually apply a force to the object until it just begins to move. This maximum force is the static friction force (or the displayed frictional force value)
6. Record this force in your notebook along with the corresponding mass and normal force (which can be calculated based on weight).
7. Create a table in your notebook with the following format:

Trial	Mass (kg)	Normal Force (N)	Static Friction Force (N)
1			
2			
3			
4			
5			

8. The normal force can be calculated using the formula:

Normal Force = Mass × g

Where g is approximately 9.81 ms^{-2}. Ensure you calculate this for each mass you record.

9. Change the mass using other objects or combination of objects (90, 100 kg, 140 kg, 150 kg, 180 kg) and repeat steps 5 to 7. Record all measurements in your table for comparison.

10. Using your completed table, plot a graph of Static Friction Force against Normal Force.

11. Examine your graph for trends and relationships between normal force and static friction force. Consider questions like:

a. How does increasing weight affect static friction?

b. Is there a consistent relationship between normal force and static friction?

Activity 5.10 Calculating Coefficient of friction

Study the worked examples below carefully before attempting the example questions that follow.

Worked Example 1

A 10 kg block rests on a horizontal surface. The coefficient of static friction is 0.4. What is the minimum horizontal force required to start moving the block? [g=9.8 m/s]

Solution

Step 1: Identify the given data:

mass = 10 kg, $\mu_s = 0.4$, g=9.8 m/s

Step 2: Introduce the formula for static friction

The block is horizontal and the only normal force is its weight.

So $R = mg\mu_s = \frac{F_s}{R} = \frac{F_s}{mg}$

Step 3: Substitute the given data and calculate the static friction

$0.4 = \frac{F_s}{10 \times 9.8}$

$F_s = 0.4 \times 98 = 39.2\ N$

Step 4. The minimum force applied must be equal to the static friction.

Therefore, $f = F_s = 39.2\ N$

Worked Example 2

You pushed your little brother horizontally on a wooden box with a force of 70 N. If the mass of the box is 2 kg and that of your brother is 15 kg, calculate the net force that kept your brother in motion on the box. The coefficient of kinetic friction is 0.2 and g = 10 ms^{-2}. Would your brother remain at a constant speed or accelerate?

Solution

Step 1: Identify the given data

Mass of box $m_{bx} = 2\ kg$, *the* mass of brother $m_{bro} = 15kg$, g = 10 ms^{-2}. $\mu_k = 0.2$

Step 2: Calculate the total mass m

$$m = m_{bx} + m_{br} = 2 + 15 = 17\ kg$$

Step 3: Calculate the normal reaction which is the total weight of the moving system of masses.

$$R = mg = 17 \times 10 = 170\ N$$

Step 4: Calculate the kinetic friction F_k

$$F_k = \mu_k \times R = 0.2 \times 170 = 34\ N$$

Step 5: subtract the frictional force F_k from the applied force F to determine the net force

$$F_{net} = F - F_k = 70 - 34 = 36\ N$$

Therefore, the force that kept the system moving is 36 N. The brother would accelerate as the net force is not zero.

Worked Example 3

A 5 kg block is placed on a horizontal surface. The coefficient of static friction between the block and the surface is 0.4, and the coefficient of kinetic friction is 0.3. A horizontal force of 18 N is applied to the block. Will the block move? [g=9.6]

Solution:

Step 1: Identify the given data:

Mass of block m=5 kg, $\mu_s = 0.4$, $\mu_k = 0.3$, Let's call the applied force F.

F = 18 N

Step 2: Find the static friction F_s

For a horizontal body like this particular one, the only normal reaction force is the weight of the block. So $R = mg = 5 \times 9.8 = 49\ N$

$$\mu_s = \frac{F_s}{R}$$

$$0.4 = \frac{F_s}{49}$$

$$F_s = 0.4 \times 49 = 19.6\ N$$

Step 3: Compare the static friction to the applied force to determine if the applied force is sufficient to overcome the friction and start the motion.

$$F = 18\ N,$$

$$F_s = 19.6\ N$$

Conclusion: since $F < F_s$, the block will not move.

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A block of mass 20 kg rests on a horizontal surface. It takes a horizontal force of 50 N to just start moving the block. Find the coefficient of static friction. [g=10 ms^2]
2. A 20 kg box is pulled on a horizontal surface with a constant speed using a force of 80 N. Find the coefficient of kinetic friction. [g=10 ms^2]
3. A 15 kg crate is pushed across a rough surface with an acceleration of 2 m/s^2. The coefficient of kinetic friction between the crate and the surface is 0.25. Find the applied force. [g=10 ms^2]

CIRCULAR MOTION

Circular motion is a type of motion in which an object moves around a fixed point while maintaining a constant distance from that point. The object does not need to complete an entire circle to be considered in circular motion. As the body moves in a circle, its change in position is as a result of its radius vector sweeping through an angle. The angle through which the radius vector sweeps in order for the to change its position in along the arc is known as the angular displacement.

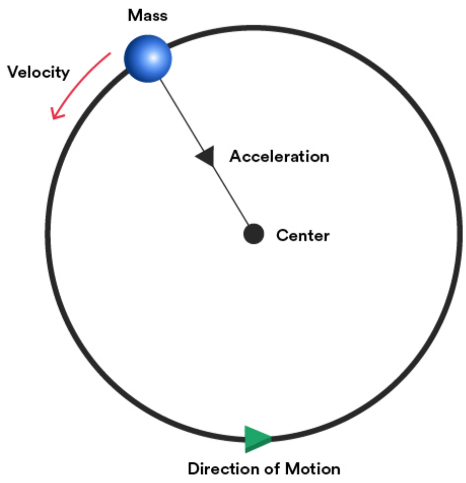


Figure 5.5: Circular motion

Examples of circular motion

1. **A Ball on a String**: Swinging a ball on a string in a circle creates circular motion, where the tension in the string provides the centripetal force to keep the ball moving in its path.
2. **Electrons in Atoms**: In simplified atomic models, electrons are often depicted as moving in circular orbits around the nucleus, due to the attraction between the negatively charged electrons and the positively charged nucleus.
3. **Planets Orbiting the Sun**: The planets move in nearly circular orbits around the Sun, held in place by the Sun's gravitational pull acting as the centripetal force.
4. **A Car negotiating a Curve**: When a car makes a turn, it follows a curved path, with the friction between the tires and the road providing the centripetal force to keep it on track.

Activity 5.11 Watch a video demonstrating some every day examples of circular motion

Objective: Watch a video demonstrating everyday examples of circular motion and analyse the concepts presented.

Materials Needed

1. Access to a computer or tablet with internet access
2. Projector or large screen (if watching as a group)
3. Paper and pens for notes
4. Access to the video link: 5 Non Uniform Circular Motion Examples In Physics & Daily Life

What to do

1. Form small groups of no more than five.
2. Watch the Video
   - **a.** Open the provided video link on your device or project it on a larger screen for the group.
   - **b.** Watch the video titled "5 Non-Uniform Circular Motion Examples In Physics & Daily Life," which showcases various examples of circular motion in everyday life.
3. While watching, take notes on the following:
   - **a.** The examples of circular motion presented in the video (e.g., spinning top, frisbee, ice skater, car on a curved road, roller coaster loop).
   - **b.** Key points about how each example demonstrates circular motion.
   - **c.** Any specific terms or concepts related to circular motion that are mentioned in the video.
4. After watching the video, come together in your groups to discuss your notes. Use the following prompts to guide your discussion:
   - **a.** What were your favourite examples of circular motion from the video? Why?

b. How do you think understanding circular motion is important in real life?

c. Can you think of other examples of circular motion that were not mentioned in the video?

5. Each group should prepare to share one key insight or interesting fact they learned from the video with the class.

6. Discuss how these concepts apply to real-world scenarios and why they are significant in understanding physics.

Angular displacement

Angular displacement tells us how much an object has turned or rotated about a point. Instead of measuring this distance in meters (like we would for straight lines), we measure it in angles.

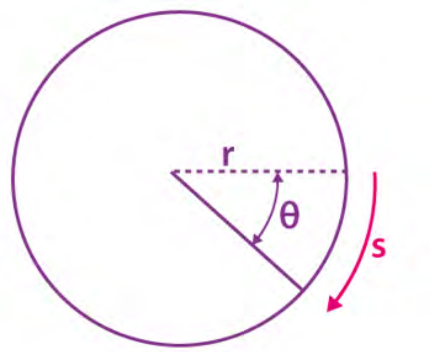


Figure 5.6: Schematic diagram of circular motion

In the diagram (Figure 5.6), if an individual walks from one point to another along the circumference of a circle, they will have undergone an angular displacement. The distance travelled depends on the radius of the circle and can be expressed as:

$\theta = \frac{s}{r}$

$s = \theta r$

Where,

θ is the angular displacement,

s is the distance travelled by the body, and

r is the radius of the circle along which it is moving.

Note that:

$2\pi = 360° = 1\ revolution$

Angular velocity

Angular velocity is the rate of change of angular displacement with time.

$$\omega = \frac{\theta}{t}$$

where θ = angular displacement, t = time, ω = angular displacement

but $\theta = \frac{s}{r}$

$$\omega = \frac{s}{tr}$$

From linear motion

$$v = \frac{s}{t} \Rightarrow$$

$$\omega = \frac{v}{r}$$

$$v = \omega r$$

The relationship between angular velocity ω and linear velocity v is

$$v = \omega r$$

Angular velocity ω is also given by $\omega = \frac{2\pi}{T} = 2\pi f$ where f is the frequency and T is the period.

Frequency is the number of complete revolutions made in a second. The period is the time taken for one complete revolution.

Angular Acceleration

Angular acceleration (α) is the rate of change of angular velocity with time.

$$\alpha = \frac{\omega}{t}$$

but $\omega = \frac{v}{r}$

$$\alpha = \frac{v}{rt}$$

Also, from linear motion

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

$$\therefore \alpha = \frac{a}{r}$$

$$a = \alpha r$$

The relationship between angular acceleration and linear acceleration is

$$a = \alpha r$$

Centripetal Force

Bodies moving along a curved path or in a circle are maintained in their trajectory by a force directed toward the centre of the circle. This force, known as **centripetal force**, prevents the body from moving in a straight line due to its inertia. If the centripetal force is removed, the body will no longer follow the curved path and will move in a straight line tangential to the circle at the point where the force was removed. For example, if you whirl a stone around your head on a string and then release it, you have removed the centripetal force and the stone will move off in a straight line from the point of release.

Centripetal force is a force that is exerted on a body moving in a circle for the body to be kept in its path.

Centripetal force is given by

$$F_c = \frac{mv^2}{r}$$

Activity 5.12 Exploring Circular Motion with a Fan/turntable

Objective: Use a fan to demonstrate circular motion.

Materials Needed

1. A standard electric fan (preferably with adjustable speed settings)/ turntable
2. Stopwatch
3. Ruler
4. Notebook and pen/pencil (for recording data)

What to do

1. Place the fan on a stable surface and ensure it is plugged in and functioning properly. Make sure the fan is set to a low or medium speed to start.
2. Identify a point on the fan blades where you will measure the radius. Use the ruler to measure the distance from the centre of the fan (the axis of rotation) to the tip of one of the blades. This distance is your radius (r). Record this value in your notebook.
3. Turn on the fan at a low or medium speed.
4. Use a stopwatch to time how long it takes for the fan to complete several revolutions (e.g., 5 or 10). Start timing as you complete your first full

revolution and stop when you reach your last revolution. Record this total time in your notebook.

5. Calculate the period (T), which is the time taken for one complete revolution:

$$T = \frac{Total\ time}{number\ of\ revolutions}$$

6. Calculate frequency, which is the number of revolutions per second:

$$f = \frac{1}{T}$$

7. Calculate angular velocity (ω) using the formula:

$$\omega = 2\pi f$$

Note that π is approximately 3.14.

8. Measure angular displacement for multiple revolutions, count how many times the object completes a full rotation during your timing and multiply by 360 degrees:

Angular Displacement = Number of Revolutions × 360°

Activity 5.13 Investigating Centripetal Force through Circular Motion

Objective: To swing a small object tied to a string in a circular path to illustrate centripetal force and to measure the radius of the circular path and the time taken for several revolutions to calculate the period, frequency, angular velocity, and centripetal force.

Materials Needed

1. A small object (e.g., a rubber ball or a small weight)
2. A length of string (about 1-2 meters)
3. Stopwatch (or a timer on your phone)
4. Ruler or measuring tape (to measure the radius)
5. Notebook and pen/pencil (for recording data)

What to do

1. Tie one end of the string securely to the small object.
2. Measure the length of the string from the centre of the object to the point where you will hold it. This length will be your radius (r) of the circular path.

3. Use a ruler or measuring tape to measure the length of the string (the radius). Record this value in your notebook.
4. Hold the other end of the string firmly in your hand and swing the object in a horizontal circular path. Make sure to keep the string taut while swinging. Try to maintain a consistent speed as you swing the object.
5. Use a stopwatch to time how long it takes for the object to complete several revolutions (e.g., 5 or 10). Start timing as you complete your first full revolution and stop when you reach your last revolution. Record this total time in your notebook.
6. Calculate the period (T), which is the time taken for one complete revolution.
7. Calculate frequency, which is the number of revolutions per second.
8. Calculate angular velocity (ω) .
9. Calculate centripetal force using the formula

   $F_c = m\omega^2 r$

   Where:

   m is the mass of the object (you can weigh it if needed),

   ω is angular velocity,

   r is the radius you measured.
10. **Extension**: Investigate how changing variables like mass or radius might affect centripetal force. Consider questions such as:
    - **a.** What happens to centripetal force if you increase speed?
    - **b.** How does increasing radius affect angular velocity?

Activity 5.14 Investigating Circular Motion using an Online Simulation

Objective: Use an online simulation to explore the variables related to circular motion, including radius, speed, and centripetal force.

Materials Needed

1. Access to a computer or tablet with internet access
2. Paper and pens for notes
3. Access to the simulation: Uniform Circular Motion Simulation

What to do

1. Form small groups of no more than five. Each group will work together to explore the simulation.
2. Click on the provided link to access the Uniform Circular Motion simulation.
3. Once the simulation loads, familiarise yourself with the interface and available controls.
4. Begin by observing the default settings of the simulation. Take note of the initial values for radius, speed, and centripetal force displayed.
5. **Investigate Variables**
   - **a. Change Radius**
     - **i.** Use the controls to adjust the radius of the circular path.
     - **ii.** Observe how changing the radius affects the speed and centripetal force required to maintain circular motion.
     - **iii.** Take notes on your observations.
   - **b. Change Speed**
     - **i.** Adjust the speed of the object moving in a circle.
     - **ii.** Record how increasing or decreasing speed impacts centripetal force and any other observed variables.
   - **c. Analyse Centripetal Force**
     - **i.** With different combinations of radius and speed, note how centripetal force changes.
     - **ii.** Discuss within your group why these changes occur based on your understanding of circular motion.
6. Create a table in your notes to summarise your findings:
   - **a.** Record different combinations of radius, speed, and centripetal force.
   - **b.** Note any patterns or relationships you observe between these variables.

7. After exploring various settings in the simulation, come together as a group to discuss your findings. Use these prompts to guide your discussion:
   - **a.** What patterns did you notice between radius, speed, and centripetal force?
   - **b.** How does increasing speed affect the amount of centripetal force needed?
   - **c.** What practical applications can you think of that relate to circular motion (e.g., cars on a curved road, satellites orbiting a planet)?

Activity 5.15 Calculating Angular velocity, Angular displacement

Study the worked examples carefully below before attempting the example questions that follow

Worked Example 1

A bicycle wheel with a radius of 0.5 meters completes 15 revolutions in 30 seconds. Calculate:

i. the angular velocity of the wheel.

ii. the linear velocity of a point on the rim of the wheel.

iii. The frequency of revolution

Solution

Step 1. Identify given variables

$\theta = 15$ rev,

$r = 0.5$ m,

$t = 30$ s,

$\omega = ?$

$v = ?$

$f = ?$

Step 2. Determine angular velocity from revolution made in the given time

30 s = 15 revs,

$1\text{ s} = \frac{1\ s}{30\ s} \times 15\text{ revs} = 0.5\text{ revs},$

$\omega = 0.5$ rev/s

1 rev = 2π rad,

0.5 rev = $\frac{0.5\ rev}{1\ rev} \times 2\pi$ rad = π rad,

$\omega = 0.5$ rev/s = π rad/s

Step 3. Determine linear velocity

$v = \omega r = \frac{\pi\ rad}{s}$ x 0.5 m,

$\pi = 3.142$,

v = 3.142/s × 0.5 m = 1.571 m/s

Step 4. Determine frequency revolution

$\omega = 2\pi f$

π rad/s = $2\pi f$

f = 0.5 Hz

Worked Example 2

A rotating fan blade starts from rest and reaches an angular velocity of 20 rad/s in 5 seconds.

Calculate:

i. the angular acceleration of the fan blade.

ii. the total angular displacement of the blade during this time.

Solution

Step 1 Identify the given variables

$\omega_i = 0$, $\omega_f = 20$ rad/s, t = 5 s, α = ? θ = ?

Step 2: Introduce the formula for angular acceleration

$$\alpha = \frac{\Delta\omega}{t} = \frac{\omega_f - \omega_i}{t} = \frac{20-0}{5} = 4 \text{ rad/s}^2$$

Step 3: Use an equation of motion to get your answer

$$\theta = \omega_i t + \frac{\alpha t^2}{2} = 0(5) + \frac{4(5^2)}{2} = 50 \text{ rad}$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A wheel rotates at a constant angular velocity of 6 rad/s. How much angular displacement does the wheel undergo in 10 seconds?
2. A merry-go-round rotates with an angular velocity of 2 rad/s. How many complete revolutions does it make?
3. A rotating platform has a radius of 2 m and completes 15 revolutions per minute.
   a. Calculate the angular velocity in radians per second.
   b. If a 2 kg object is placed on the edge of the platform, find the centripetal force acting on it.

BANKING AND SKIDDING

Have you ever wondered why motorbike riders tilt their bikes when negotiating a curve? Have you also noticed that, despite tilting, they sometimes still skid while navigating a curve?

Roads are banked to reduce the risk of skidding and to ensure safe navigation of curves. Banking involves raising the outer edge of the road at a specific angle, which helps generate a component of the normal force that acts as the necessary centripetal force.

This design enables vehicles to negotiate curves more safely by reducing reliance on friction.

Activity 5.16 Watch a video demonstrating the effect of banking

Objective: Watch a video that demonstrates the concept of banking on roads.

Materials Needed

1. Access to a computer or tablet with internet access
2. Projector or large screen (if watching as a group)
3. Paper and pens for notes

4. Access to the video link: Banking of Roads

What to do

1. Form small groups of no more than five.

2. Watch the Video

a. Open the provided video link on your device or project it on a larger screen for the group.

b. Watch the video titled "Banking of Roads," which explains how banking helps vehicles safely navigate turns by examining the forces at play.

3. While watching, take notes on the following:

a. The relationship between centripetal force and friction when a vehicle takes a turn.

b. How banking affects the maximum allowed speed while turning.

c. Key equations presented in the video, such as those relating to banking angle, radius, and velocity.

4. After watching the video, come together in your groups to discuss your notes. Use the following prompts to guide your discussion:

a. What are the main forces acting on a vehicle during a banked turn?

b. How does banking increase safety compared to flat turns?

c. What factors can affect the effectiveness of banking (e.g., weather conditions)?

d. Can you think of real-life examples where banking is applied (e.g., highways, racetracks)?

Figure 5.7: Image of a banked road

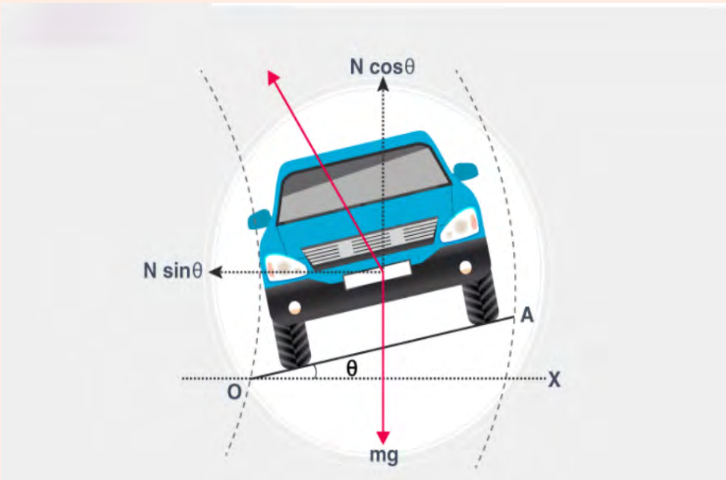


Figure 5.8: Schematic diagram of a vehicle negotiating a curve

In the diagram above, the weight (mg) of the car which acts vertically downwards is balanced by N cosθ

This gives us the expression N cos θ = mg ---------------- eqn (1)

The centripetal force $F_C = \frac{mv^2}{r}$ which is directed towards the centre of the circle, is what keeps the car along its circular path. It is provided by N sin θ because N sin θ is directed towards the centre.

This gives us the expression

$N \sin \theta = \frac{mv^2}{r}$ ---------------- - eqn (2)

Divide eqn (2) by eqn (1)

$$\frac{N \sin\theta}{N \cos\theta} = \frac{\frac{mv^2}{r}}{mg}$$

$$\tan\theta = \frac{v^2}{rg}$$

where θ = banking angle, v = **maximum speed that you can negotiate the curve without skidding**, r = radius of the curve/track, g = acceleration due to gravity.

Notably, this maximum speed is higher than it would have been without the banking.

Activity 5.17 Calculating Banking Angle

Study the worked example carefully below before attempting the example questions that follow.

Worked Example 1

A curve on a road is designed to allow cars to safely pass through at a speed of 20 m/s. If the radius of the curve is 200 m, what is the angle at which the road should be banked to prevent the car from sliding?

Step-by-Step Solution

Step 1: Identify Given data

v=200 m/s, r = 200 m, g=10 m/s^2

Step 2: Introduce the formula for banking angle

$\tan\theta = \frac{v^2}{rg}$

Step 3: substitute the given values into the formula and calculate

$\tan\theta = \frac{20^2}{200 \times 10} = \frac{400}{2000} = 0.2$

Step 4: Make the angle the subject and calculate

$\theta = \tan^{-1}(0.2) = 11.31°$

Practice Problems

Now, using the worked example as a guide, solve the following problem individually or in groups.

1. A car moves on a curved highway at a speed of 25 m/s on a curve of radius 50 m. If the acceleration due to gravity is 9.8 m/s^2, calculate the banking angle required for the curve.

2. A curve on a road is banked at an angle of 15°. If the radius of the curve is 100 m, what is the maximum speed a car can travel without relying on friction? ($g = 10\ m/s^2$)
3. A racing bike moves around a banked track with a speed of 30 m/s. If the track is designed with a banking angle of 40°, determine the radius of curvature required to keep the rider safe. ($g = 9.8\ m/s^2$)
4. A car takes a turn on a road banked at 25° with a curve radius of 80 m. Determine the maximum speed at which the car can move without relying on friction. ($g = 9.8\ m/s^2$)

The centrifuge

Mixtures can be separated by spinning them at very high speeds using a device called a centrifuge. During this process, a strong outward force acts on the components of the mixture, pushing substances with higher densities toward the outer edge, while substances with lower densities remain closer to the centre. This outward force is often referred to as centrifugal force.

Applications of a Centrifuge

Centrifuges have a wide range of applications across various fields due to their ability to separate mixtures based on density. Here are some key applications:

1. **Biological and medical applications**
   a. *Blood component separation*:
      i. Blood Banks: Separating red blood cells, plasma, and platelets from donated blood.
      ii. Clinical Diagnostics: Preparing blood samples for tests by separating serum or plasma from whole blood.

   b. *Cell fractionation*: Isolating different components of cells, such as nuclei, mitochondria, and lysosomes, for research purposes.

   c. *DNA/RNA purification*: Isolating nucleic acids from cells or tissues for genetic analysis.

   d. *Protein separation and purification:* Separating proteins based on size and density for biochemical studies.

   f. *Urine analysis:* Concentrating cells and other components from urine samples for diagnostic tests.

2. **Industrial Applications**
   a. *Food and beverage industry*
      i. Cream Separation: Separating cream from milk in dairy processing.
      ii. Juice Clarification: Removing pulp and other solids from fruit juices.
      iii. Sugar Production: Separating sugar crystals from molasses in sugar refineries.

   b. *Oil industry*
      i. Waste Oil Recycling: Removing contaminants from used oil for reuse.
      ii. Oil Extraction: Separating oil from other substances, such as in the production of essential oils.

   c. *Water Treatment:* Clarifying water by removing suspended solids and other impurities.

3. **Chemical and Pharmaceutical Applications**
   a. *Precipitate Separation*: Isolating solid precipitates from liquid mixtures in chemical reactions.
   b. *Purification of Pharmaceuticals*: Separating and purifying drugs and other chemical compounds.
   c. *Nanoparticle Separation*: Isolating nanoparticles based on size and density for research and industrial applications.

4. **Environmental Applications**
   a. *Soil Analysis*: Separating soil particles for analysis of composition and contaminants.
   b. *Wastewater Treatment*: Removing sludge and other solid particles from wastewater before discharge or reuse.

5. **Research and Development**
   a. *Laboratory Research*: Performing various types of separations in biochemical, molecular biology, and clinical research.
   b. *Material Science*: Studying the properties of materials by separating their components.

6. **Other Applications**
   a. *Aerospace*: Training astronauts and pilots by simulating high-gravity conditions in human centrifuges.

b. *Forensic Science*: Analysing samples from crime scenes, such as separating components of biological samples.

c. *Cosmetic Industry*: Formulating and testing cosmetic products by separating ingredients.

Activity 5.18 Investigating centrifuges Through Video and Hands-On Construction

Objective: Watch videos to understand the principles of centrifugation and then construct a simple centrifuge using a salad spinner to observe the effects of centrifugal force.

Materials Needed

1. Access to a computer or tablet with internet access
2. Projector or large screen (if watching as a group)
3. Video Link:
   a. Centrifugation Process
   b. Proper Use of a Centrifuge
4. Paper and pens for notes
5. A salad spinner
6. Small containers (like test tubes or small cups)
7. Water or a mixture (e.g., muddy water or coloured water)
8. Optional: food colouring, soil, or small particles for separation

What to do

Part A: Watch the Videos

1. Form small groups of no more than five.
2. Open the first video link on your device or project it on a larger screen for the group.
3. Take notes on:
   a. How centrifugation works to separate components based on density.
   b. The materials used in the demonstration and the results observed after centrifugation.
   c. Key concepts related to centrifugal force and its dependence on mass and speed of rotation.
4. Open the second video link on your device or project it on a larger screen.
5. Take notes on:
   a. The proper techniques for using a centrifuge.
   b. The importance of balancing test tubes in the centrifuge.
   c. Any safety precautions mentioned in the video.

Part B: Construct a Simple Centrifuge

6. **Prepare the Salad Spinner**
   a. Gather your salad spinner and ensure it is clean and ready for use.
   b. If you have small containers, fill them with water or a mixture (e.g., muddy water) to demonstrate separation.
7. **Load the Salad Spinner**
   a. Place the filled containers securely inside the salad spinner. Make sure they are balanced; if using multiple containers, ensure they are evenly distributed.
8. **Spin the Salad Spinner**
   a. Securely close the lid of the salad spinner.
   b. Spin the salad spinner vigorously for about 1-2 minutes.
   c. Observe what happens to the contents of the containers during spinning.

9. **Observe Results**
   a. After spinning, open the salad spinner and examine the contents of each container.
   b. Note any separation that has occurred (e.g., heavier particles settling at the bottom).
10. In your notes, create a table summarizing your findings:
   a. Describe what was in each container before and after spinning.
   b. Discuss how effective the salad spinner was in separating different components based on density.

Activity 5.19 Research and Present on Physics Concepts

Objective: Research a specific topic. You will prepare a presentation to share your findings with the class.

Materials Needed

1. Access to the internet (for research)
2. Books or articles on physics topics (optional)
3. Notebook and pen/pencil (for taking notes)
4. Presentation software (e.g., PowerPoint, Google Slides) or poster board (for creating your presentation)
5. Projector or display screen (if using digital presentations)

What to do

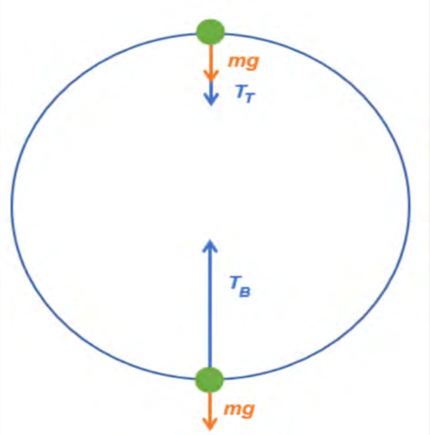
Organise yourselves into groups of no more than five.

1. As a group, select one of the following topics for your research:
   a. The physics of banked roads
   b. The use of centrifuges in medicine
   c. Another application of circular motion of your choice!
2. Use the internet, library resources, and textbooks to gather information about your chosen topic. Focus on understanding the key concepts, principles, and applications. Take notes on important points, including:
   a. Definitions and explanations of relevant physics concepts
   b. Real-world applications and examples
   c. Any interesting facts or recent developments related to your topic

3. Create an outline for your presentation. Organise your notes into sections that logically flow from one point to the next. Typical sections might include:
   a. Introduction to the topic
   b. Key principles and concepts
   c. Applications in real life
   d. Conclusion and summary of findings
4. Present your research to the class as a group. During your presentation, clearly explain each section of your topic.
5. After all presentations are completed, take some time to reflect on what you learned from both your research and from listening to others' presentations. Write down any new insights or interesting facts you discovered during this activity

MAXIMUM AND MINIMUM TENSION IN A STRING

When a body is tied to a string and whirled in a vertical circle, the weight and the tension both contribute to the net centripetal force required to keep the body moving along its circular path.



At the top of the circle, the tension T_{top} and gravitational force mg both acts downwards. The centripetal force required to keep the object moving in a circle is provided by the sum of the tension and the weight:

$$T_{top} + mg = \frac{mv^2}{r}$$

$$T_{top} = \frac{mv^2}{r} - mg$$

The tension is minimum at the top of the circle.

$$\therefore T_{min} = \frac{mv^2}{r} - mg$$

At the bottom of the circle, the tension T_{bottom} acts upward while the gravitational force mg acts downward. The centripetal force is provided by the difference between the tension and the weight:

$$T_{bottom} - mg = \frac{mv^2}{r}$$

$$T_{bottom} = \frac{mv^2}{r} + mg$$

The tension is maximum at the bottom of the circle.

$$\therefore T_{max} = \frac{mv^2}{r} + mg$$

Activity 5.20 Watch videos about the design of loop-the-loops or playground swings

Objective: Watch videos that explain the physics and design principles behind loop-the-loops in roller coasters and the energy transformations involved, focusing on concepts such as energy conservation and centripetal force.

Materials Needed

1. Access to a computer or tablet with internet access
2. Projector or large screen (if watching as a group)
3. Paper and pens for notes
4. Access to the video links:
   a. Calculating the Minimum Height for a Perfect Ride

   b. Ball Rolling Down an Inclined Track and Around a Loop

What to do

1. Form small groups of not more than five. Each group will discuss their observations after watching the videos.
2. Open the first video link on your device or project it on a larger screen for the group. Watch the video titled "Calculating the Minimum Height for a Perfect Ride," which explains how to calculate the minimum height needed for a sphere to complete a loop-the-loop without falling off.
3. While watching, take notes on:
   - **a.** Key concepts related to energy conservation and centripetal force in the context of loop-the-loops.
   - **b.** The calculations presented regarding height, speed, and forces involved.
   - **c.** Any specific design considerations mentioned that are important for ensuring safety and functionality.
4. After discussing the first video, open the second video link on your device or project it on a larger screen. Watch the video titled "Ball Rolling Down an Inclined Track and Around a Loop," which demonstrates how potential energy is converted into kinetic energy as a ball rolls down an incline and around a loop.
5. While watching, take notes on:
   - **a.** the different forms of energy discussed (potential energy, kinetic energy).
   - **b.** how energy transformations affect the ball's ability to complete the loop.
   - **c.** the relationship between initial height and velocity at different points in motion.
6. After watching both videos, come together in your groups to discuss your notes. Use the following prompts to guide your discussion:
   - **a.** What are the main forces acting on a roller coaster or ball at different points in a loop?
   - **b.** How does energy conservation play a role in designing safe loop-the-loops?
   - **c.** What factors can affect the design of a loop-the-loop (e.g., speed, height, radius)?

d. Can you think of real-life examples of roller coasters or similar systems that effectively use these principles?

7. Each group should prepare to share one key insight or interesting fact they learned from both videos with the class.

8. Discuss how these concepts apply to real-world scenarios and why they are significant in understanding physics.

Activity 5.21 Derive the mathematical relationship between the tension, mass, gravity, velocity and radius for the top and bottom of the circular path

What to do

1. Organise yourselves into groups of no more than five.
2. Draw a diagram showing an object tied to a string with the body at the bottom of the circle such that the angle between the vertical and the string is zero.
3. Show the forces acting on the body (i.e. the weight, centripetal force and the tension) when the object is at the bottom of the circle.
4. Write down an equation that shows the relationship between the tension, the centripetal force and the weight
5. Make the tension the subject of the equation i.e. tension at the bottom
6. Show the forces acting on the body (i.e. the weight, centripetal force and the tension) when the object is at the top of the circle.
7. Write down an equation that shows the relationship between the tension, the centripetal force and the weight
8. Make the tension the subject of the equation i.e. tension at the top
9. From the two tension equations, take note of the maximum and minimum tension.

Activity 5.22 Investigating the tension for objects moving in vertical circles using a simulation

Objective: Use an online simulation to explore how tension varies for an object moving in vertical circles, examining the effects of speed, radius, and position on tension.

Materials Needed

1. Access to a computer or tablet with internet access
2. Paper and pens for notes
3. Access to the simulation: Vertical Circle Simulation

What to do

1. Organise yourselves into groups of no more than five. Each group will work together to explore the simulation.
2. Click on the provided link to access the Vertical Circle Simulation. Click on "Launch Interactive". Once the simulation loads, familiarise yourself with the interface and available controls.
3. Start initial exploration with the default settings of the simulation. Take note of the initial values for mass, radius, and speed displayed.
4. **Investigate Tension at Different Positions**
   a. At the Top of the Circle
      i. Observe the tension when the object is at the top of its vertical path.
      ii. Record the value of tension and note how it relates to gravitational force.

   b. At the Bottom of the Circle
      i. Move the object to the bottom of its vertical path and observe the tension again.
      ii. Record this value and compare it with the tension at the top.

c. At Intermediate Positions

i. Move the object to various points between the top and bottom (e.g., halfway up) and observe how tension changes.

ii. Take notes on how tension varies with position in relation to speed and gravitational force.

5. Adjust Variables

a. Change Mass

i. Adjust the mass of the object and observe how this affects tension at different positions.

ii. Record your observations regarding how mass influences tension.

b. Change Speed

i. Modify the speed of the object in circular motion.

ii. Note how increasing or decreasing speed affects tension at various points in the circle.

6. Create a table in your notes to summarise your findings:

a. Record different values of tension at various positions (top, bottom, intermediate) for different masses and speeds. Note any patterns or relationships observed between these variables.

7. After exploring various settings in the simulation, come together as a group to discuss your findings. Use these prompts to guide your discussion:

a. What patterns did you notice between position, mass, speed, and tension?

b. How does changing one variable affect others in terms of motion dynamics?

c. What practical applications can you think of that relate to vertical circular motion (e.g., amusement park rides, pendulums)?

Activity 5.23 Calculating Maximum and minimum tension in a string

Study the worked examples carefully below before attempting the example questions that follow

Worked Example 1

A roller coaster car of mass 500 kg moves through a vertical loop of radius 10 m. At the top of the loop, the car has a speed of 12 m/s.

a. Calculate the tension in the track at the top of the loop.

b. If the car's speed at the bottom of the loop is 18 m/s, calculate the tension in the track at the bottom.

Solution

Step 1 Identify the given variables

v (top) = 12 m/s, v (bottom) = 118 m/s, m = 500 kg, r = 10 m, g = 9.8 m/s^2

Step 2 Identify the appropriate formula for tension at the top

$$T_{top} = \frac{mv^2}{r} - mg$$

Step 3: Substitute the given values into the formula

$$T_{top} = \frac{500 \times 12^2}{10} - (500 \times 9.8)$$

Step 4: Calculate to obtain the tension at the top

$$T_{top} = 7200 - 4900 = 2300\ N$$

Step 5: Identify the appropriate formula for tension at the bottom

$$T_{bottom} = \frac{mv^2}{r} + mg$$

Step 6: Substitute the given values into the formula

$$T_{bottom} = \frac{(500) \times 15^2}{10} + 500 \times 9.8$$

Step 7: Calculate to obtain the tension at the bottom

$$T_{bottom} = 11250 + 4900 = 16150\ \text{N}$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A 2-kg ball is attached to a string and whirled in a vertical circle of radius 1.5 m. At the bottom of the circle, the ball has a speed of 5 m/s. Calculate the tension in the string at the bottom of the circle. (g= 9.8 ms^{-2}).
2. A 0.5-kg stone is tied to a string and swung in a vertical circle of radius 0.8 m. At the top of the circle, the stone moves at a speed of 3 m/s. Calculate the tension in the string at the top of the circle. (g= 9.8 ms^{-2}).

Conical Pendulum

A **conical pendulum** is a type of pendulum in which the bob moves in a horizontal circular path while the string traces out a conical shape. This motion results from the combination of gravitational force, tension in the string, and the centripetal force required to maintain the circular motion.

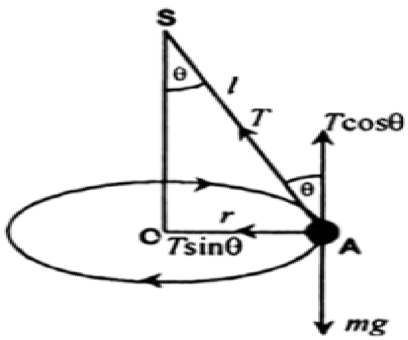


Figure 5.9: Schematic diagram of Conical pendulum

In the diagram above, body A has weight mg which acts vertically downward. The tension T in the string which makes an angle θ with the vertical has components T sin θ which is directed towards the and T cos θ which balances the weight mg of the body.

$T \cos \theta = mg$ ------------------eqn (1)

Since the component of the tension directed towards the centre is T sinθ

$T \sin \theta = \frac{mv^2}{r}$, ------------------eqn (2),

$\frac{mv^2}{r}$ is the centripetal force

eqn (2) ÷ eqn (1)

$$\frac{T\,sin\theta}{T\,cos} = \frac{m\,v^2}{r} \quad \div \text{ mg}$$

$$\tan\theta = \frac{v^2}{rg}$$

Activity 5.24 Investigating conical pendulums using a simulation.

Objective: Use an online simulation to explore the dynamics of conical pendulums, examining how variables such as string length, and angular velocity affect the motion.

Materials Needed

1. Access to a computer or tablet with internet access
2. Paper and pens for notes
3. Access to the simulation: Conical Pendulum Simulation on GeoGebra

What to do

1. Organise yourselves into groups of not more than five.
2. Click on the provided link to access the GeoGebra conical pendulum simulation. Once the simulation loads, familiarise yourself with the interface and available controls.
3. Start initial exploration with the default settings of the simulation. Take note of the initial values for string length, mass, and angular velocity displayed.
4. **Investigate Variables**
   a. **Change String Length**
      i. Adjust the length of the string using the slider.
      ii. Observe how changing the string length affects the angle of the pendulum and its circular motion.
      iii. Take notes on your observations regarding how it influences radius and speed.

b. **Change Angular Velocity**

i. Adjust the angular velocity and observe how it impacts the angle of inclination and speed of circular motion.

ii. Take notes on how increasing or decreasing angular velocity affects centripetal force and motion stability.

5. Create a table in your notes to summarise your findings:

a. Record different combinations of string length, mass, angular velocity, angle of inclination, and any observed effects on motion.

b. Note any patterns or relationships you observe between these variables.

6. After exploring various settings in the simulation, come together as a group to discuss your findings. Use these prompts to guide your discussion:

a. What patterns did you notice between string length, mass, angular velocity, and motion?

b. How does changing one variable affect others in terms of motion dynamics?

c. What practical applications can you think of that relate to conical pendulums (e.g., amusement park rides, planetary motion)?

EXTENDED READING

1. Asiedu, P., & Baah-Yeboah, H. A. (n.d.). Physics for senior high schools (4th ed.). Aki-Ola Publications.
2. Abbott, A. F. (n.d.). Ordinary level physics (5th ed.). Longman.
3. Serway, R. A., & Faughn, J. S. (n.d). College physics (Edition). Cengage Learning.
4. Nelkon, M., & Parker, P. (n.d.). Advanced level physics (Ed.). Heinemann.
5. Abbott, A. F. (n.d.). *Principles of Physics* (5th ed., pp. 53-59, 184, 204-212, 472-483). Longman.

REVIEW QUESTIONS

Review Questions 5.1

1. Name four examples of projectile motion in any area of life.
2. For a given initial velocity, State the factor that determines the maximum range of a projectile and state its numerical value.
3. Define the following terms:
   a. Time of flight
   b. Maximum height
   c. Range of a projectile
4. A projectile is launched with an initial velocity of 40 m/s at an angle of 45 ° to the horizontal.
   a. Find the horizontal range of the projectile.
   b. Calculate the maximum height reached by the projectile.
5. You are in a debate with your colleagues about the optimal angle to kick a football to achieve the maximum horizontal distance. Your colleagues suggest angles of 30^0, 50^0 and 70^0. Given that the initial velocity of the football is 25 ms^{-1} and acceleration due to gravity g =10 ms^{-2}, use the principles of projectile motion to demonstrate that 45^0 is the optimal angle for achieving maximum range.

Review Questions 5.2

1. Define friction.
2. Name the two types of friction
3. Explain why it is necessary to lubricate moving parts of a machine with oil.
4. A girl can push a block of wood easily in a horizontal direction. When her brother decided to press vertically on the block, she could no longer move it as easily as before. Explain why this is so and what the girl needs to do to move the block.

5. A force of 3 N can move a bucket full of water horizontally on a tiled floor. To prevent children from pushing the bucket easily, a woman decided to put a block on it. What is the minimum mass of a block needed for this purpose? [$g=10ms^2$, coefficient of static friction is 0.01, mass of bucket and water = 5 kg]

Review Questions 5.3

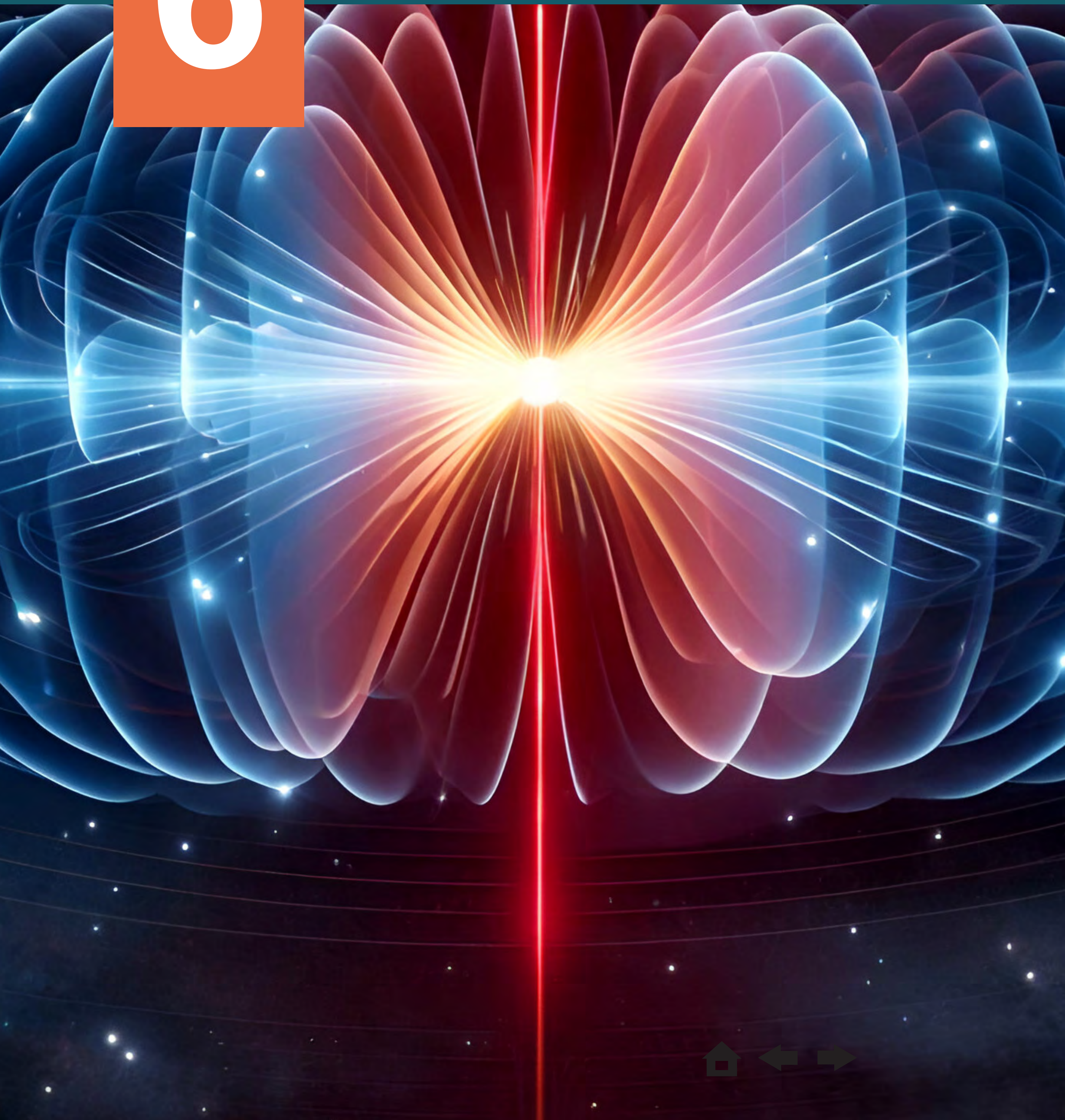
1. State two examples of circular motion
2. A car tyre with a radius of 0.5 m rotates at an angular velocity of 10 rad/s. Determine:
   a. The linear velocity of a point on the edge of the tyre.
   b. The angular displacement of the tyre in 5 seconds.
3. A fan completes 120 revolutions in 1 minute. Calculate its angular velocity in radians per second.

Review Questions 5.4

1. At what point in the motion of an object moving in a vertical circular path (attached to a string) is the tension in the string at its maximum: at the top of the circle, at the bottom, or elsewhere? Explain your reasoning.
2. a. A curve on a road is banked at an angle of 10°, and a car is moving at a speed of 15 m/s. a. What is the radius of the curve for the car to move safely without friction?
   b. Assuming the road is a four-lane road and the radius given measures up to the outer lane, do you think a car in the inner lane can safely negotiate the curve at the same speed as the car in the outer lane? Explain.

SECTION

6 ELECTROMAGNETISM



ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Electromagnetism

INTRODUCTION

This section explores the fascinating interaction between electric currents and magnetic fields. You will examine the force exerted on a current-carrying conductor in a magnetic field and the factors influencing its magnitude.

The section introduces Fleming's left-hand rule to predict the direction of magnetic forces. Forces acting between parallel conductors carrying current are analysed, leading to an understanding of torque in a rectangular current-carrying coil. The principles behind essential devices, such as electric motors, moving coil galvanometers, and electromagnetic switches, are explained.

Additionally, the behaviour of a charged particle in a magnetic field is studied, with real-world applications highlighted. This exploration provides a solid foundation for understanding electromagnetic interactions and their practical uses in technology and industry.

KEY IDEAS

- When a conductor carrying an electric current is placed in a magnetic field, it experiences a force due to the interaction between the magnetic field and the moving charges (electrons) in the conductor. The force exerted on the conductor is known as the magnetic force and is described mathematically by the formula:

  $F = B \cdot I \cdot L\, sin\theta$
- Fleming's left hand rule states that if the forefinger, the thumb and the second finger of the left hand are placed mutually at right angles to each other, then the forefinger points in the direction of magnetic field; the thumb points in the direction of motion of the conductor and the second finger points in the direction of current.

- Torque on a rectangular current-carrying coil in a magnetic field is the working principle behind electric motors and galvanometers.
- Electromagnets can be used in various useful applications such as electromagnetic relays, which are devices that allow users to interact with safe, low-voltage circuits that will in turn complete more dangerous, higher voltage circuits.
- Individual charges moving in magnetic fields also experience a magnetic force, which is described mathematically by the formula:

  $F = B \cdot q \cdot v \sin\theta$

FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD

Magnetic materials have magnetic fields around them. Other magnetic materials which enter this field will experience a force.

Current-carrying conductors also have magnetic fields; we say that they have induced magnetism. The shape and direction of a magnetic field (which points from the North Pole to the South Pole) produced by an electric current depend on the configuration of the conductor:

Straight conductor: The magnetic field around a straight current-carrying conductor forms concentric circles centred on the conductor. For example, overhead power lines generate magnetic fields around each wire as they carry current.

Fleming's Right Hand 'grip' rule gives us the direction of the magnetic field.

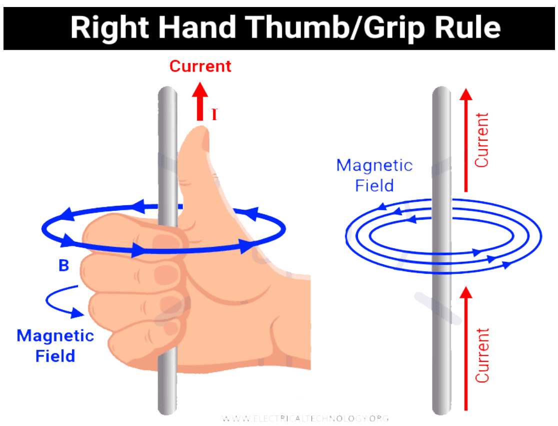


Figure 6.1: Fleming's Right Hand grip rule

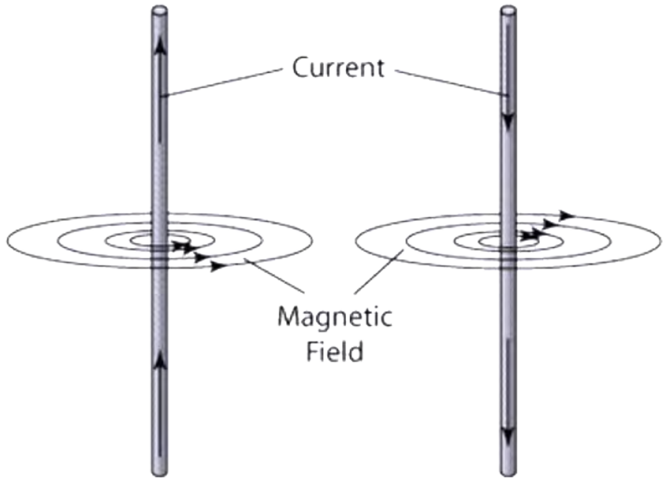
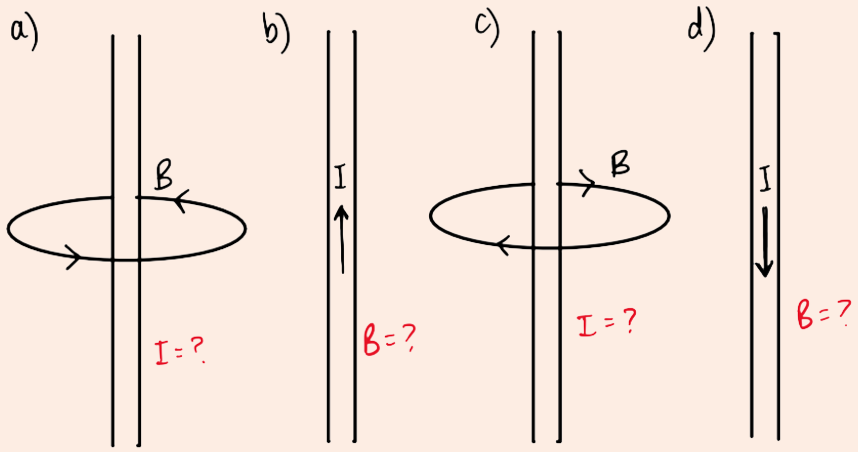


Figure 6.2: Magnetic field around a straight current-carrying conductor

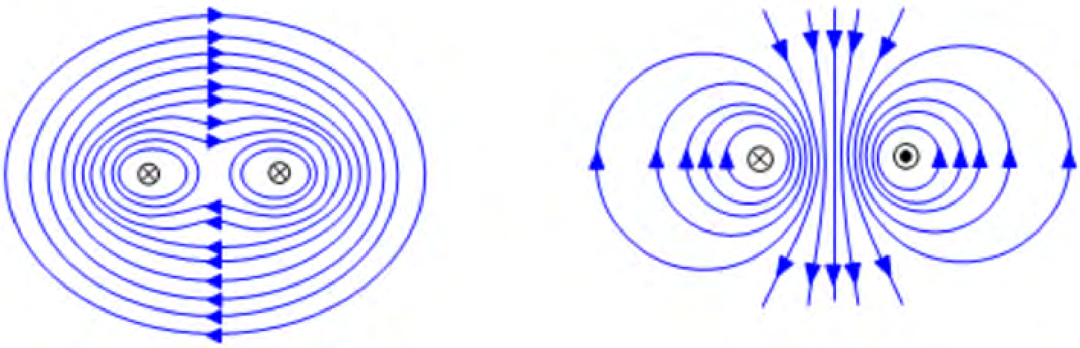
Activity 6.1 Using Fleming's Right-Hand Grip Rule

Analyse the images below to find the missing magnetic field or current directions.



Parallel conductors with currents in the same direction: When two parallel conductors carry current in the same direction, the magnetic fields around each conductor interact. The magnetic field lines between the conductors are in opposite directions and cancel each other out, while the field lines outside the conductors add up, resulting in an attractive force between the conductors. This can be seen in the wires in a multi-core cable carrying currents in the same direction, where they experience attractive forces due to their interacting magnetic fields (see Figure 6.3a).

Parallel conductors with currents in opposite directions: For parallel conductors with currents flowing in opposite directions, the magnetic fields between the conductors add up, while the fields outside the conductors cancel out, resulting in a repulsive force between the conductors. An example of this is transmission lines in a power distribution network, which often have currents flowing in opposite directions, resulting in repulsive forces between the lines (see Figure 6.3b).



6.3 a

6.2b

Figure 6.3: Magnetic field around Parallel conductors with currents in the same direction and opposite direction

Narrow Circular Coil: When current flows through a narrow circular coil, the magnetic field lines inside the coil are nearly parallel and uniform, while outside the coil, the field lines spread out and form loops.

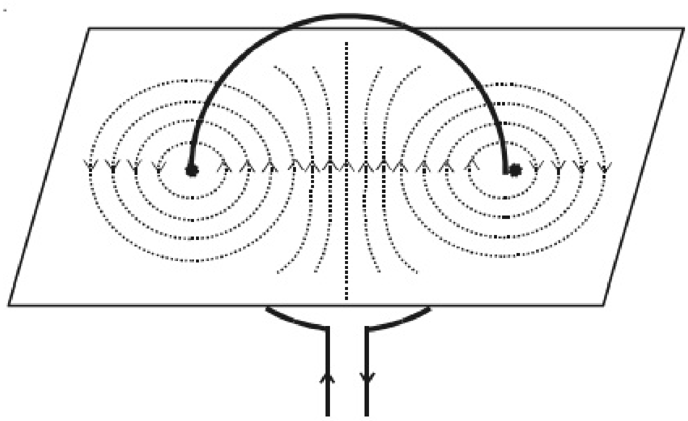


Figure 6.4: Magnetic field around a narrow circular coil

Solenoid: A solenoid is a long coil of wire with many turns. When current flows through a solenoid, the magnetic field inside is strong and uniform, like that of a bar magnet, with distinct north and south poles. The field outside the solenoid is weak and spreads out. The strength of the magnetic field inside a solenoid can be increased by increasing the number of turns per unit length, the current, or by inserting a ferromagnetic core. Solenoids are used in various devices, such as electromagnetic locks, solenoid valves, and MRI machines, where a strong, controlled magnetic field is needed.

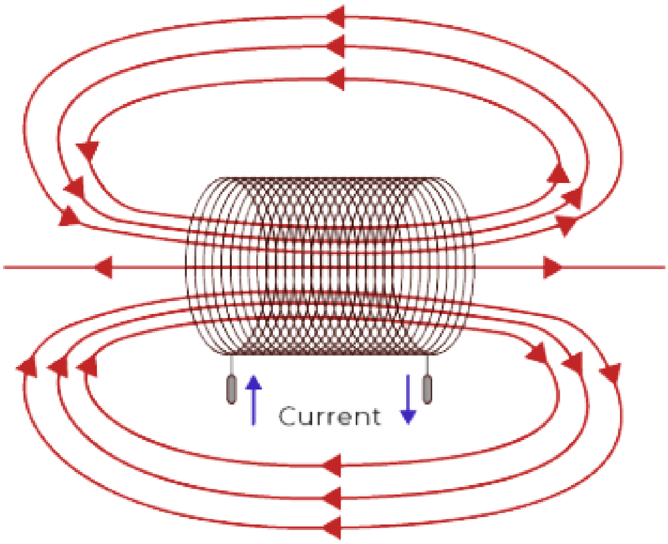


Figure 6.5: Magnetic field in a Solenoid

Activity 6.2 Investigating Magnetic Fields with a Single Wire

Objective: To construct an experimental setup and investigate the magnetic field of a wire that can carry current.

Note: in the absence of practical materials the simulation linked below can be used instead.

https://javalab.org/en/magnetic_field_around_a_wire_en/

Materials Needed

1. One long copper wire (approximately 1 metre)
2. A power source (e.g., batteries)
3. Connecting wires (with alligator/crocodile clips or similar connectors)
4. Small plotting compass (for visualisation)

5. Paper or cardboard.

What to do

1. **Set Up Your Experiment**
   - **a.** Secure some paper of cardboard to work on.
   - **b.** Thread the copper wire through a hole made in the paper/cardboard.
2. **Connect the Wires**
   - **a.** Connect the wire to the power source using connecting wires. Connect the switch in series with the wire for safety.
3. **Visualise the Magnetic Fields**
   - **a. Using the Small Plotting Compass**
     - **i.** Place the plotting compass flat on the paper approximately one centimetre from the copper wire. Note the direction of the needle whilst the switch is open and again whilst it is closed.
     - **ii.** Repeat the experiment in multiple positions around the copper wire.
4. **Experiment with Current Directions**
   - **a.** Next, reverse the connections of the wire so that it carries current in the **opposite direction**. Again, observe and record any changes in field patterns.
5. **Extension**
   - **a.** Explore the magnetic fields around wires further by passing a current down second wire in the same direction as the first. Hold both wires straight and parallel. Can you feel a force between them?
   - **b.** Repeat 5a, but with the currents in opposite directions.
6. In your notebook, write down your observations regarding:
   - **i.** The patterns formed by the compass.
   - **ii.** How changing current directions affected these patterns.
   - **iii.** Why you think that iron filings would be inappropriate to use to visualise the field.

Fleming's Left-Hand Rule

When a conductor carrying an electric current is placed in a magnetic field, it experiences a force due to the interaction between the magnetic field and the moving charges (electrons) in the conductor.

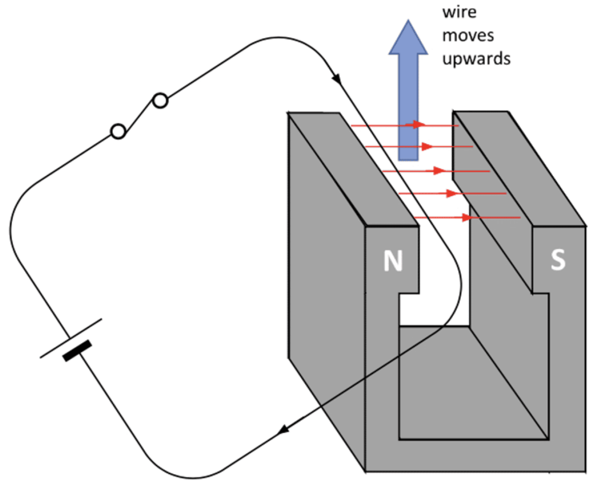


Figure 6.6: The force on a current-carrying conductor placed into a magnetic field

This phenomenon is a fundamental principle of electromagnetism and is the basis for the operation of electric motors, loudspeakers, and other electromagnetic devices.

Fleming's Left-Hand Rule is a simple mnemonic used to determine the direction of the magnetic force acting on a current-carrying conductor in a magnetic field.

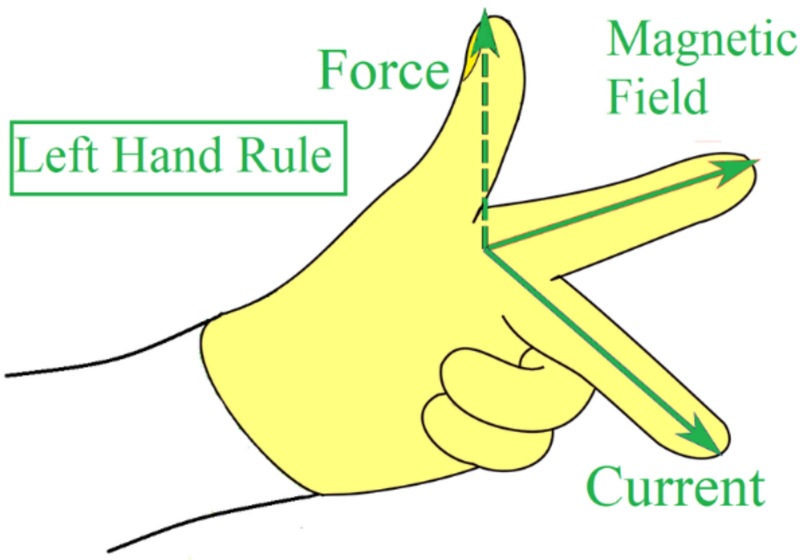


Figure 6.7: Fleming's Left-Hand Rule

Thumb: Represents the direction of the Force (motion of the conductor).

Fore Finger: Represents the direction of the Magnetic Field (from North to South).

Second Finger: Represents the direction of the Current (conventional current from positive to negative).

Fleming's Left-Hand Rule states that "if the forefinger, the thumb and the second finger of the left hand are placed mutually at right angles to each other, then the forefinger points in the direction of the magnetic field; the thumb points in the direction of motion of the conductor and the second finger points in the direction of the current."

Activity 6.3 Experimenting with Fleming's Left-Hand Rule Using a Straight Wire and a Magnet

Objective: To experiment with a straight wire placed between the poles of a horse-shoe magnet to observe the effects of magnetic fields on the wire.

Materials Needed

1. Horseshoe magnet
2. Straight copper wire (approximately 30 cm long)
3. Power source
4. Switch
5. Connecting wires
6. Ammeter
7. Ruler
8. Notebook and pen/pencil

What to do

1. Place the horseshoe magnet on a stable surface with its poles facing upwards.
2. Ensure that the magnet is securely positioned so that it does not move during the experiment.
3. Take the straight copper wire and strip about 1 cm of insulation from both ends if necessary, so that you have exposed metal to make connections.
4. Connect one end of the copper wire to one terminal of the power source (battery).
5. Connect the switch in series with the battery and wire.

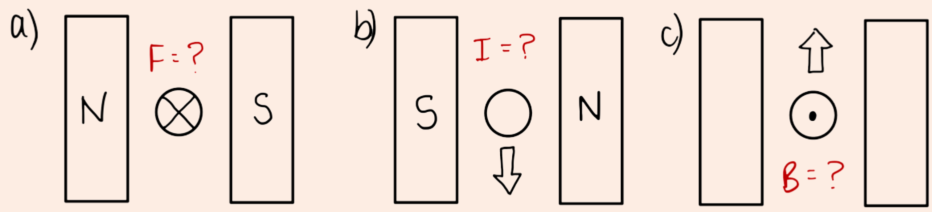
6. Connect the other end of the copper wire to an ammeter and then to the other terminal of the power source.
7. Place the straight wire horizontally between the poles of the horseshoe magnet. Ensure that it is centred and parallel to the magnetic field lines, which run from one pole of the magnet to the other.
8. Turn the switch on to allow current to flow through the wire.
9. Observe what happens to the wire when current flows through it. You should notice that it experiences a force and may move in a specific direction.
10. Verify Fleming's Left-Hand Rule by comparing the direction of motion to that of the current and of the magnetic field:
    a. **Thumb:** Represents the direction of force (motion).
    b. **First Finger:** Represents the direction of the magnetic field (from north to south).
    c. **Second Finger:** Represents the direction of current (from positive to negative).

    Position your left hand according to these guidelines while observing which direction your wire moves.
11. To further investigate, switch the connections on your power source to reverse the current direction.
12. Observe how this change affects the direction in which the wire moves. Record your findings.
13. After conducting your experiments, discuss your findings with your group members. Consider questions such as:

    d. How did changing the current's direction affect motion?
    e. How does this experiment demonstrate Fleming's Left-Hand Rule?

Activity 6.4 Applying Fleming's Left-Hand Rule

Analyse the diagrams below to find the missing direction of the field/current/force. Note that you are seeing the cross section of the wire in the field, and that a CROSS indicates that the current is pointing into the screen and a DOT indicated that the current is pointing out of the screen. The arrow indicated the direction of the force, and the magnetic field points from north to south.



The force exerted on the conductor is known as the magnetic force and is described mathematically by the formula:

$F = B \cdot I \cdot L\ sin\theta$

Where:

- F is the magnetic force (in Newtons, N)
- B is the magnetic flux density (in Teslas, T)
- I is the current in the conductor (in Amperes, A)
- L is the length of the conductor in the magnetic field (in metres, m)
- θ is the angle between the direction of the current and the magnetic field.

The force is always perpendicular to both the direction of the current and the magnetic field.

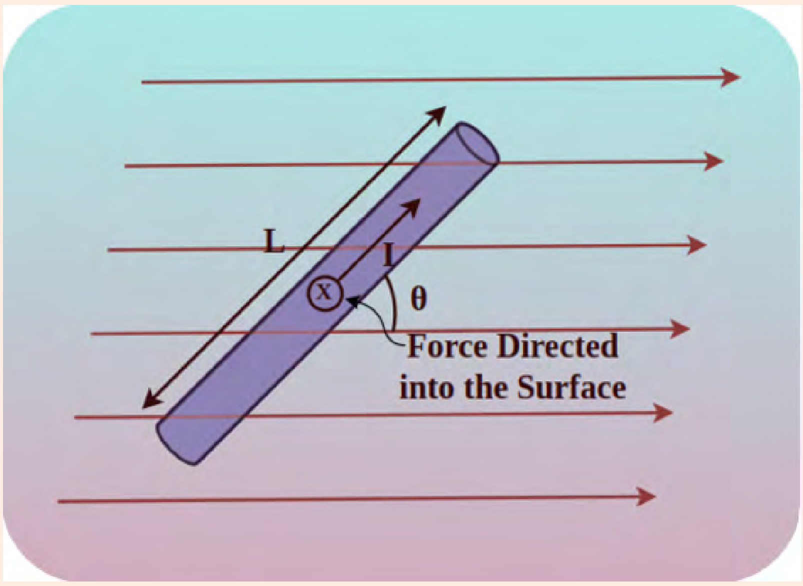


Figure 6.8: Force on a current-carrying conductor in a magnetic field

Factors Affecting the Magnitude of the Magnetic Force

1. Magnetic Flux Density (B): The strength of the magnetic field directly affects the force. A stronger field (B) results in a larger force.
2. Current (I): The magnitude of the electric current in the conductor influences the force. A higher current increases the magnetic force.
3. Length of the Conductor (L): The portion of the conductor exposed to the magnetic field determines the force. A longer conductor experiences a greater force.
4. Angle between current and Magnetic Field (θ): The force depends on the *sine* of the angle (sin θ) between the current's direction and the magnetic field. The force is maximum ($F = BIL$, B and I are perpendicular) when $\theta = 90°$ and zero when $\theta = 0°$ (parallel alignment of B and I).

Activity 6.5 Think-Pair-Share

Procedure:

1. Think silently about ways in which the current and magnetic field strength could be varied in practice.
2. In pairs, discuss your insights. r.
3. Take part in a class discussion to share your ideas.

Activity 6.6 Calculating Force on a Current-Carrying Conductor

Study the worked example below before attempting the example questions that follow.

Worked Example

A straight conductor of length 0.5 m is placed in a magnetic field of 0.2 T. If a current of 5 A flows through the conductor and the conductor makes an angle of 90° with the field, find the magnetic force acting on it.

Step-by-Step Solution

Step 1: Identify the given values

- $B = 0.2$ T

- $I = 5$ A
- $L = 0.5$ m
- $\theta = 90°$ ($\sin(90°) = 1$)

Step 2: Introduce the magnetic force formula

$$F = B \cdot I \cdot L \sin\theta$$

Step 3: Substitute the given values:

$$F = 0.2 \times 5 \times 0.5 \times \sin(90°)$$

$$F = 0.2 \times 5 \times 0.5 \times 1$$

Step 4: Calculate to obtain the answer

$$F = 0.5 \text{ N}$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. A wire 1 m long carries a current of 3 A in a uniform magnetic field of strength 0.1 T. If the wire makes an angle of 30° with the magnetic field, find the magnetic force acting on it.
2. A conductor of length 2 m carrying a current of 4 A is oriented at an angle of 45° to a magnetic field of strength 0.3 T. Find the magnetic force acting on the conductor.

Activity 6.7 Simulating the Effect of Varying Current and Magnetic Field Strength

Use the simulation linked below to observe the effect of changing variables on the magnitude of the force felt by the wires (indicated by the length of the arrow). click here

MAGNETIC FIELD AROUND A CURRENT-CARRYING CONDUCTOR AND TORQUE ON A RECTANGULAR CURRENT-CARRYING COIL IN A MAGNETIC FIELD

Torque on a rectangular current-carrying coil in a magnetic field

A rectangular coil carrying current in a magnetic field experiences a torque due to the interaction of the magnetic field with the current.

Mechanism

The sides of the coil parallel to the magnetic field do not experience force, but the sides perpendicular to the field do. These forces act in opposite directions, creating a couple.

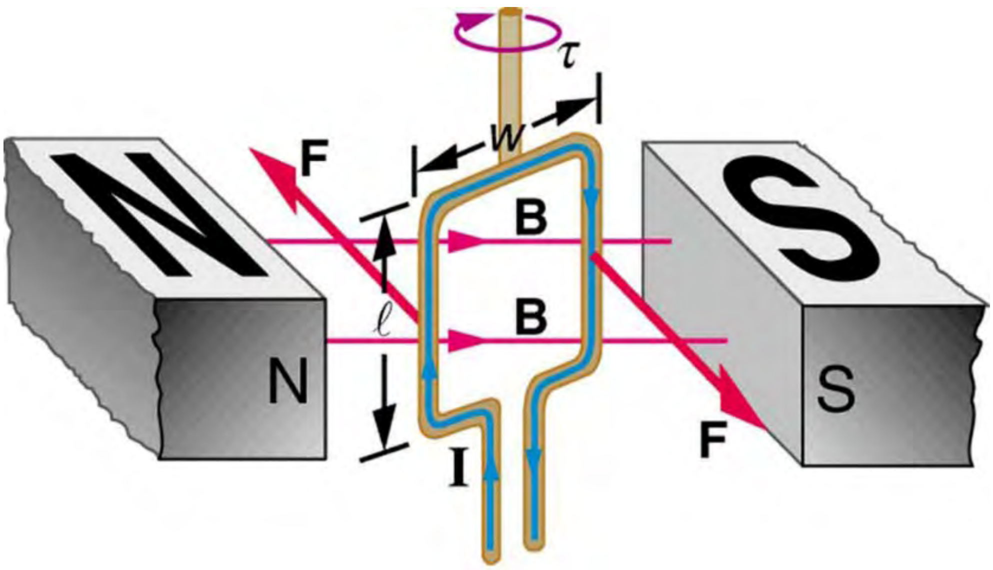


Figure 6.9: Torque on a current loop

Structure and working principle of an electric motor

A motor works on the principle that a current-carrying conductor placed in a magnetic field experiences a force due to the interaction between the magnetic field and the current.

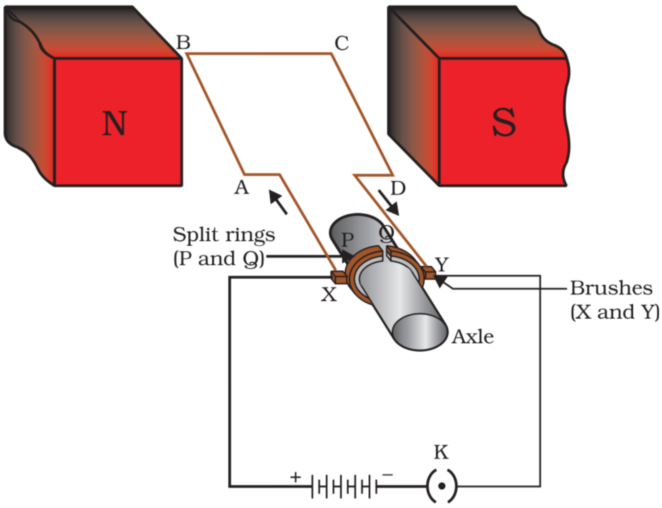


Figure 6.10: Working principle of electric motor

1. The electric current flowing through the windings/coil of the motor generates a magnetic field that interacts with the other magnetic field.
2. This interaction creates a force that acts in opposite directions for each side of the coil (the direction on each side can be found using Fleming's Left Hand rule) causing it to rotate.
3. The split-ring commutator is used to reverse the direction of the current through the coil every half-turn. This ensures that the motor continues to spin in one continuous direction.

Activity 6.8 Constructing a Basic Electric Motor

Objective: To construct a simple electric motor using wire coils, magnets, and a battery.

Materials Needed

1. Insulated copper wire (about 1 metre)
2. A small permanent magnet (e.g., a bar magnet)
3. D-cell battery (1.5V)
4. Two large paper clips or metal sewing needles (with large eyes)
5. Modelling clay or tape
6. Electrical tape
7. Scissors or a hobby knife (to strip wire insulation)
8. Ruler

What to do

1. **Watch the video** linked here to visualise the method:
   https://www.youtube.com/watch?v=WI0pGk0MMhg

2. **Prepare the Wire Coil**
   - **a.** Start by taking the insulated copper wire and wrapping it around a cylindrical object (like a marker or a small bottle) about 30 times to create a coil. Ensure the coils are tightly wound and evenly spaced.
   - **b.** Carefully slide the coil off the cylindrical object.
   - **c.** Leave about 10 cm of wire free at each end and wrap the ends around the coil a few times to hold it together. This will create your armature.

3. **Strip the Wire Ends**
   - **a.** Use scissors or a hobby knife to carefully strip about 1 cm of insulation from each end of the wire. Make sure to do this safely and ask for help if needed.

4. **Set Up the Battery**
   - **a.** Lay the D-cell battery on its side on a flat surface.
   - **b.** Use modelling clay to secure the battery in place so it doesn't roll.

5. **Create Supports for the Coil**
   - **a.** Take the two paper clips or sewing needles and straighten them out slightly, leaving a loop at one end.
   - **b.** Insert the pointed ends of the paper clips or needles into the modelling clay on either side of the battery, ensuring they touch the terminals of the battery. The loops should be positioned so that they can cradle the coil.

6. **Position the Magnet**
   - **a.** Place the small permanent magnet on the side of the battery, centred underneath where the coil will hang. This magnet will create a magnetic field that interacts with your coil.

7. **Connect the Coil**
   - **a.** Position your wire coil above the battery so that it hangs freely between the paper clips or needles.

   b. Ensure that each stripped end of the wire touches one of the paper clips or needles, creating an electrical connection to complete the circuit.

8. Test Your Motor

   a. Give your coil a gentle spin to start it moving. If everything is set up correctly, once you give it an initial push, it should continue to spin.

   b. Observe how changing the position of the magnet or adjusting how securely your coil is connected can affect its operation.

9. In your group, discuss how this setup demonstrates electromagnetic principles:

   a. Explain how current flowing through the coil generates a magnetic field.

   b. Discuss how this magnetic field interacts with that of the permanent magnet to produce motion.

   c. Discuss the reason that the stripped ends of the wire are placed in contact with the paper clips/needles rather than using one continuous piece of wire (note that this models the split-ring commutator in a real motor).

Structure and working principle of a galvanometer (current-measuring device)

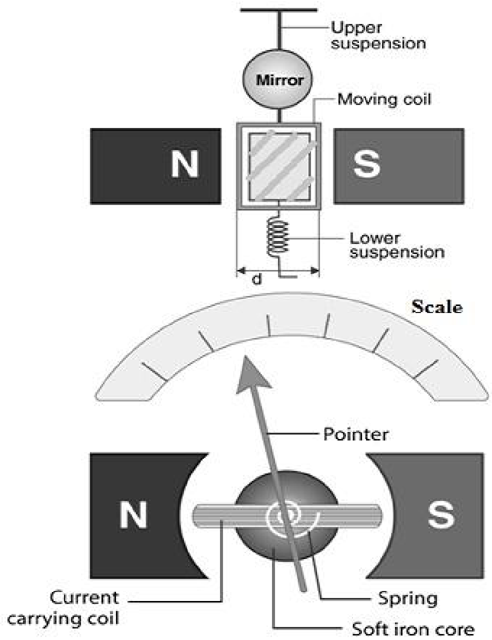


Figure 6.11: Diagram of a moving coil galvanometer

A galvanometer is made up of the following components:

1. **Coil**: A rectangular coil of fine copper wire with many turns wound around a metallic frame. The coil is free to rotate around a fixed axis.
2. **Magnet**: A permanent magnet with hemispherical poles that produce a radial magnetic field.
3. **Pointer**: A thin pointer attached to the coil that moves across a calibrated scale.
4. **Spring**: A small torsion spring that pulls the coil and pointer back to zero when there's no current.
5. **Iron core**: A soft, cylindrical iron core placed inside the coil to strengthen the magnetic field and make it radial.
6. **Suspension**: A phosphor-bronze strip that suspends the coil in the magnetic field.
7. **Mirror**: A small plane mirror attached to the suspension wire that measures the coil's deflection.

A galvanometer works on the principle that a current-carrying coil experiences a torque when placed in a magnetic field:

1. The torque acting on the coil is directly proportional to the magnitude of the electric current flowing through it.
2. The deflection of the coil is directly proportional to the amount of current passed through the coil. The greater the amount of current, the greater the torque and the deflection.
3. The coil is connected to a pointer, which calibrates the pointer and shows correct deflection on a scale.
4. A spring provides a counter torque that balances the magnetic torque, resulting in a steady angular deflection.

Activity 6.9 Exploring the Principle of a Moving Coil Galvanometer

Objective: Learn about the principle of a moving coil galvanometer by constructing a simple demonstration using a small coil and a magnet.

Materials Needed

1. Small coil of insulated copper wire (approximately 50-100 turns)
2. Permanent magnet (e.g., horseshoe magnet)
3. Power source (e.g., battery)

4. Connecting wires (with alligator clips or similar connectors)

5. Switch

6. Paper and pen/pencil (for drawing and labelling)

What to do

1. Set Up Your Equipment

a. Secure the permanent magnet on a stable surface with its poles facing upwards.

b. Ensure that the magnet is positioned so that the magnetic field lines are directed vertically.

2. Prepare the Coil

a. Take the insulated copper wire and form it into a coil with approximately 50-100 turns. Make sure the coils are tightly wound and evenly spaced.

b. Leave enough wire at both ends for making electrical connections.

3. Connect the Circuit

a. Connect one end of the coil to one terminal of the power source (battery) using connecting wires.

b. Connect the other end of the coil to the other terminal of the power source. If using a switch, connect it in series with one of the wires for safety.

4. Place the coil horizontally between the poles of the magnet, ensuring that it is centred and can freely rotate. The plane of the coil should be parallel to the magnetic field lines produced by the magnet.

5. Turn On the Current

a. Turn the switch on to allow current to flow through the coil.

b. Observe what happens to the coil when current flows through it. You should notice that it experiences a torque due to the interaction between the magnetic field and current in the coil, causing it to deflect.

6. Draw and Label Your Device

a. On a piece of paper, draw your setup including:

i. The coil

ii. The permanent magnet

iii. The power source

iv. Connecting wires

b. Label each part clearly (e.g., "Coil," "Magnet," "Power Source," "Current Direction").

7. In your group, discuss how this setup demonstrates the principle of a moving coil galvanometer:

a. Explain how current flowing through the coil generates a magnetic field.

b. Discuss how this magnetic field interacts with the external magnetic field from the magnet.

c. Describe how this interaction produces torque that causes rotation of the coil.

d. Discuss how the galvanometer could be made more sensitive to small currents. Have a go at implementing some of these suggestions to your own galvanometer.

Expression for Torque

The torque (τ) is given by:

$$\tau = n\, I\, B\, A\, sin(\theta)$$

where n is the number of turns, I is the current, B is the magnetic flux density, A is the area of the coil, and θ is the angle between the plane of the coil and the magnetic field.

This torque is the working principle behind electric motors and galvanometers.

Activity 6.10 Calculating Force on a current carrying conductor

Study the worked example below before attempting the example questions that follow.

Worked Example

A rectangular coil of wire with dimensions 0.20 m by 0.30 m and carrying a current of 2.0 A is placed in a uniform magnetic field of 0.50 T. The plane of the coil makes an angle of 30° with the direction of the magnetic field. Calculate the magnitude of the torque on the coil.

Step by step

Step 1: Identify the given values

$n = 1\ turn$

$I = 2.0\ A$

$A = 0.20\ m \times 0.30\ m$

$\theta = 30°$

Step 2. Introduce the formula for torque

$\tau = n\ I\ B\ A\ sin(\theta)$

Step 3: Substitute the given values:

$\tau = (1\ turn)(2.0\ A)(0.20\ m \times 0.30\ m)\ (0.50\ T)\ sin(30°) = 0.030\ N\ m$

Step 4: Calculate to obtain the answer

$\tau = 0.030\ N\ m$

Practice Problems

Now, using the worked example as a guide, solve the following problem individually or in groups.

1. A rectangular coil of wire with dimensions 0.15 m by 0.25 m and 200 turns is placed in a uniform magnetic field of 0.40 T. The coil is initially aligned with its plane parallel to the magnetic field. A current of 3.0 A is passed through the coil. What is the magnitude of the torque on the coil when it has rotated 45° from its initial position?

ELECTROMAGNETIC SWITCHES AND THEIR APPLICATIONS

Electromagnetic switches such as electromagnetic relays are devices that utilise electromagnetic principles to control the flow of electricity in high-current circuits using a smaller control current. They are integral components in various applications across multiple industries due to their efficiency, reliability, and quick response times.

Figure 6.12: Image of electromagnetic relay

Working Principle

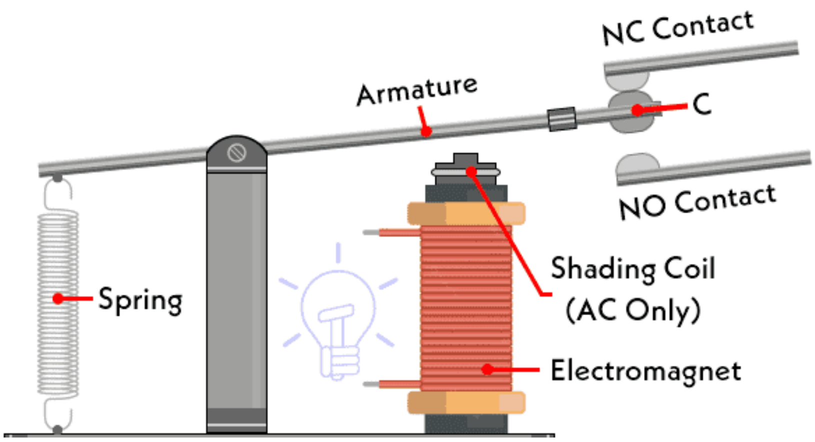


Figure 6.13: Diagram of an electromagnetic relay

Electromagnetic switches operate by using an electromagnet to mechanically move a switch contact. When an electrical current passes through the coil of the electromagnet, it generates a magnetic field that attracts or repels a movable armature. This action opens or closes the circuit, allowing or interrupting the flow of electricity. The rapid activation and deactivation capabilities of these switches make them suitable for applications requiring quick response times, often within milliseconds.

Activity 6.11 Video on Electromagnetic Relays

Watch the video linked below to help to visualise the working principles of a relay. Click here

Electromagnetic relays are used in a wide range of applications due to their versatility and reliability.

1. **Power System Protection:** In power systems, relays are used to detect faults and initiate protective measures such as circuit breakers.
2. **Automotive Industry**: Relays control various functions in vehicles, including lighting, wipers, and heating systems.
3. **Industrial Automation**: They are integral to automation systems, controlling motors, sensors, and other equipment.
4. **Home Appliances**: Common household devices like refrigerators, air conditioners, and washing machines rely on relays for their operation.
5. **Telecommunications**: Relays are used to switch signals in telecommunication equipment, ensuring reliable communication.

The adaptability of electromagnetic relays to different voltage and current levels makes them ideal for these varied applications, providing dependable performance in each scenario.

Activity 6.12 Designing a Relay or Solenoid for a Specific Application

Objective: Work in groups to design a relay or solenoid for a specific application.

Materials Needed

1. Access to research materials (books, articles, internet)
2. Paper and pencils for sketching designs
3. Markers or coloured pencils for presentations
4. Presentation materials (poster board, slides, etc.)

5. Access to safety guidelines related to electrical devices (provided or available online)

What to do

1. Organise yourselves into small groups.
2. As a group, decide on a specific application for your relay or solenoid. Consider applications such as:
   - **a.** Door locking mechanisms
   - **b.** Automated irrigation systems
   - **c.** Remote-controlled devices
   - **d.** Industrial machinery controls
   - **e.** Home automation systems
3. Use available resources to research how relays and solenoids work. Focus on:
   - **a.** The main components of relays and solenoids.
   - **b.** How they operate when current flows through them.
   - **c.** The advantages and disadvantages of using relays versus solenoids in your chosen application.
4. Sketch your design on paper or cardboard. Include:
   - **a.** A labelled diagram of your relay or solenoid.
   - **b.** An explanation of how it functions within the chosen application.
   - **c.** Any additional components needed (e.g., switches, power sources).
5. Identify and discuss the safety precautions necessary when using your relay or solenoid design. Consider factors such as:
   - **a.** Electrical hazards (overcurrent, short circuits)
   - **b.** Heat generation
   - **c.** Proper insulation and housing for components
   - **d.** Safe handling procedures
6. Organise your findings and design into a presentation format. Be sure to cover:
   - **a.** The problem you are solving with your design.
   - **b.** How you applied theoretical knowledge to develop your solution.
   - **c.** The collaboration process within your group.
   - **d.** The safety precautions associated with your device.

7. Take turns presenting your designs to the class. Use visual aids such as diagrams or posters to enhance your presentation.

Activity 6.13 Constructing and Investigating an Electromagnet

Objective: Work in small groups to construct an electromagnet and investigate how its strength varies with either the current flowing through it or the number of turns of wire around the core.

Materials Needed

1. Iron nail or iron rod (core for the electromagnet)
2. Insulated copper wire (about 1-2 meters)
3. Power source (e.g., 1.5V or 9V battery)
4. Paperclips
5. Switch
6. Electrical tape
7. Ammeter
8. Wire stripper
9. Ruler
10. Notebook and pen/pencil

What to do

1. Organise yourselves into small groups of 3-4 students.
2. **Construct Your Electromagnet**
   a. Take the iron nail or rod and wrap the insulated copper wire around it tightly. Make sure to leave some free lengths of the wire at both ends for connections.
   b. The more turns of wire you make around the nail, the stronger your electromagnet will be.
   c. Connect one end of the wire to the positive terminal of your battery and the other end to a switch (if using). Connect the other terminal of the switch to the negative terminal of the battery.

3. **Measure Electromagnet Strength**
   a. Once your electromagnet is constructed, test its strength by counting how many paper clips it can hold when powered on.
   b. Start with a specific number of turns (e.g., 10 turns) or a specific current setting if you are varying current.
   c. Turn on your electromagnet and gradually add paper clips until it can no longer hold any more. Count and record the total number of paper clips held.

4. **Varying Current or Number of Turns**
   a. **If investigating current:** Change the current by using different battery voltages (e.g., 1.5 V vs. 9 V) or by adding resistors in series to limit current flow. Measure how many paper clips your electromagnet can hold at each current setting.
   b. **If investigating the number of turns:** Construct additional electromagnets with different numbers of turns (e.g., 5, 10, 15, 20). Measure how many paper clips each configuration can hold.

5. Create a table in your notebook to organise your findings:

Number of Turns	Paperclips Held

Or

Current (A)	Paperclips Held

6. After completing your measurements, analyse your data to determine how either current or number of turns affects the strength of your electromagnet. Consider questions such as:
   a. How does increasing current affect the number of paperclips held?
   b. How does increasing the number of turns influence electromagnet strength?
   c. What patterns do you observe in your results?

7. Discuss as a group what you learned from this investigation and prepare a brief summary of your findings.

Activity 6.14 Group Discussion on Electromagnetic Devices

Objective: Work in groups to discuss various questions related to electromagnetic devices, such as relays and solenoids. This activity will encourage collaboration, enhance understanding, and allow all group members to contribute based on their confidence levels.

Materials Needed

1. Notebook and pen/pencil (for taking notes)
2. Whiteboard or large paper (optional, for summarising group discussions)
3. Access to the list of discussion questions provided in this activity

What to do

1. Organise yourselves into small groups.
2. As a group, look at the list of discussion questions provided below. Take a few minutes to read through the questions together and discuss any terms or concepts you may not understand.
3. If desired, assign roles within your group to help facilitate discussion. For example:
   a. **Facilitator:** Keeps the discussion on track.
   b. **Note-taker:** Records key points and ideas.
   c. **Presenter:** Summarises the group›s findings for the class.
4. Begin discussing the questions as a group. Encourage everyone to share their thoughts, ideas, and experiences related to each question. Use the following questions to guide your discussion:

   Discussion Questions

   a. What are the main parts of a relay and how do they work?
   b. Can you think of any devices that use solenoids? What are their functions?
   c. How does an electromagnet differ from a permanent magnet?
   d. What role do relays play in electrical circuits?
   e. Can you describe how a solenoid operates when current flows through it?

f. What are some everyday applications of electromagnets?
g. How can varying the current affect the strength of an electromagnet?
h. Why might someone choose to use a relay instead of a switch in a circuit?
i. What safety considerations should be taken into account when working with electrical devices like relays and solenoids?
j. How do you think technology has changed the use of electromagnetic devices in recent years?

5. Make sure all group members have an opportunity to contribute, especially those who may feel less confident. If someone is hesitant to speak up, encourage them by asking specific questions or inviting them to share their thoughts.
6. After discussing all the questions, take some time to summarise your group's key points and insights. Write down your main findings for reference.
7. Take turns and present your key points and insights to the class.

FORCE ON A CHARGE PARTICLE

Force on a charge moving in a magnetic field

A charged particle moving through a uniform magnetic field experiences a force determined by its velocity, the magnitude of its charge, the magnetic flux density, and the direction of its motion. This fundamental principle of electromagnetism forms the basis for technologies such as cyclotrons, mass spectrometers, and electric motors.

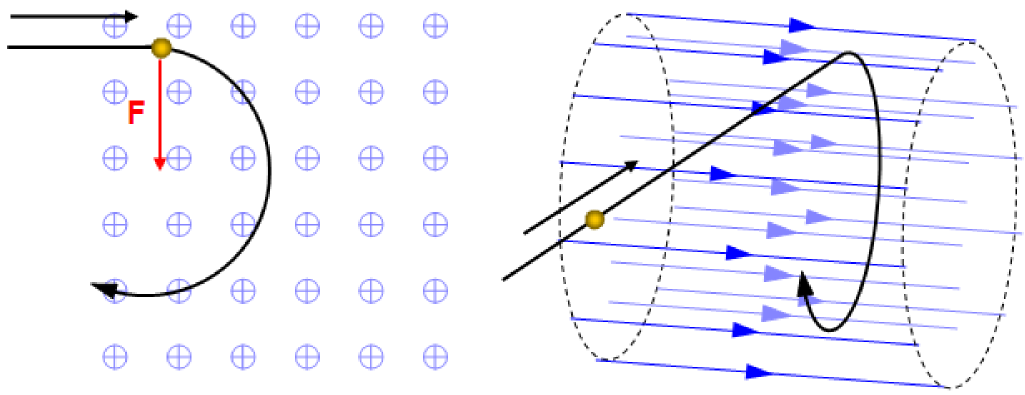


Figure 6.14: Force on a charged particle due to a magnetic field

The force F experienced by a charge is such that

$F \propto B$ --------------------- 1

$F \propto v$ ---------------------- 2

$F \propto q$ --------------------- 3

$F \propto \sin\theta$ ------------------ 4

Combining all 4 proportionalities, $F \propto Bvq \sin\theta$

where

- B = magnetic flux density,
- v = velocity of the charge,
- q = magnitude of the charge,
- θ = the angle between the direction of motion of the charge and the direction of the magnetic field.

Introducing a constant of proportionality k

$F = kBvqsin\theta$, k = 1

$F = Bvqsin\theta$

The force on the charge is maximum when the charge moves perpendicular to the magnetic field, i. e. $\theta = 90^o$.

$F = Bvq\ sin90 = Bvq$

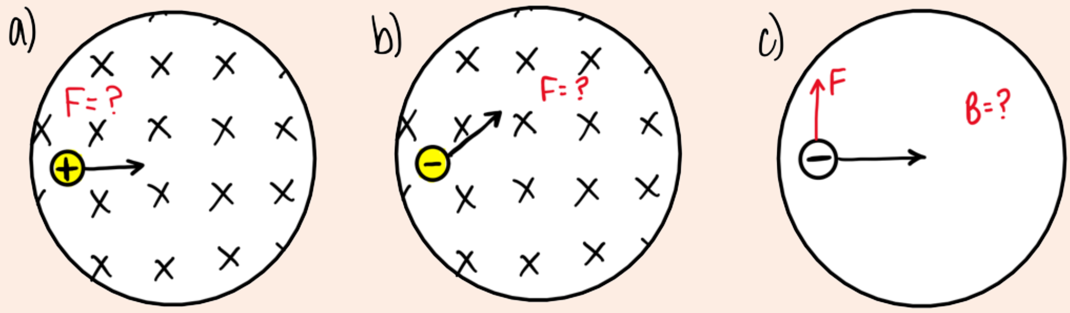
Direction of the force

The direction of this force can once again be found using Fleming's Left-Hand Rule. If the particle is positive, the direction of the current is the same as the direction of motion of the particle. If the particle is negative, the direction of the current is in the opposite direction to the direction of motion of the particle.

As the force acting on the particle is always at right angles to its motion, it travels in a circular path.

Activity 6.15 Magnetic Force on a Charged Particle – Applying Fleming's Left-Hand Rule

Analyse the diagrams below to find the missing force or magnetic field direction.



Force on a charge moving in an electric field

When a charged particle enters an electric field, it experiences a force that is directly proportional to the electric field strength (field intensity) and the magnitude of the charge. This force can either accelerate the particle from rest or decelerate it to rest if it is already in motion.

The force depends solely on the charge and the strength of the electric field, irrespective of the particle's velocity. For a positive charge, the force acts in the direction of the electric field, while for a negative charge, it acts opposite to the field's direction.

The force on a charge in an electric field

$F = Eq$

Where;

E = electric field strength,

q = charge

Note that electric fields point from positive to negative.

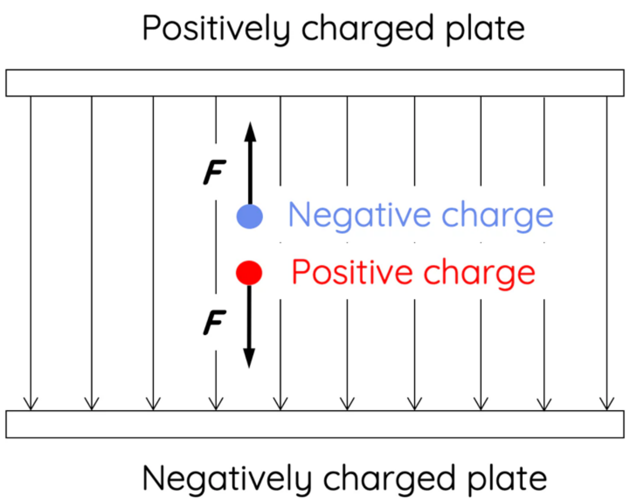
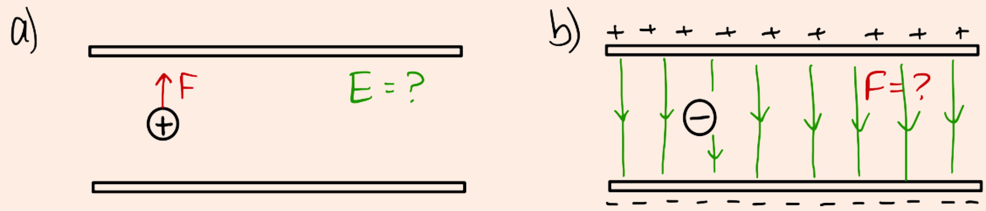


Figure 6.15: Force on a charged particle due to an electric field

Activity 6.16 Electric Force on a Charged Particle

Analyse the diagrams below to find the missing force or electric field direction.



Force on a charge moving in a crossed field

A crossed field is a field in which there are two forces. One of the forces is due to a magnetic field and the other force is due to an electric field. These two forces are equal in magnitude but opposite in direction.

Force F due to the magnetic field = Bvq,

Where;

- B = magnetic flux density,
- v = velocity, q = charge

Force F due to the electric field = Eq

where

- E = electric field strength/intensity,
- q = charge

$Bvq = Eq,$

$Bv = E,$

$v = \frac{E}{B}$

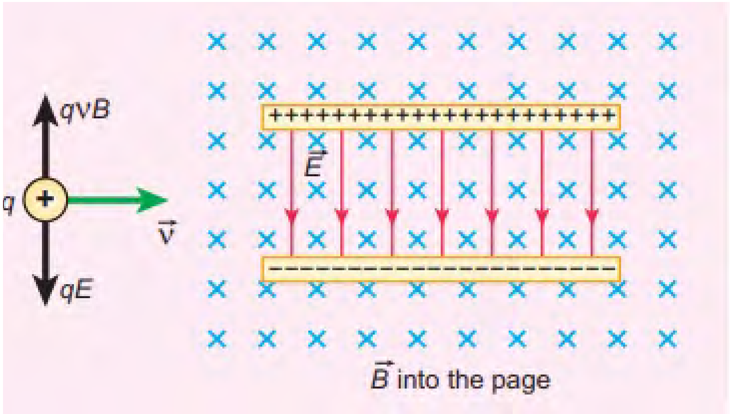


Figure 6.16: A charge in a crossed field

Activity 6.17 Magnetic and Electric Fields Simulation

Use the simulation linked below to observe the effect of a magnetic and an electric field on a beam of electrons. Click here

Activity 6.18 Calculating force on a charged particle

Study the worked examples below before attempting the example questions that follow.

Worked Example 1

A proton with charge $q = 1.6 \times 10^{-19}$ C moves at a velocity of 2.0×10^{6} m/s perpendicular to a uniform magnetic field of flux density $B = 0.05$ T. Assume the mass of the proton is 1.67×10^{-27} kg

i. Calculate the magnitude of the magnetic force acting on the proton.

ii. If the proton moves in a circular path due to the magnetic force, determine the radius of its trajectory.

Step-by-Step Solution

Step 1: identify the given variables

$q = 1.6 \times 10^{-19}$ C, $v = 2.0 \times 10^{6}$ m/s, $B = 0.05$ T, $\theta = 90^{o}$, $F = ?$,
$m = 1.67 \times 10^{-27}$ kg

Step 2: identify the appropriate formula for force on a charged particle in a magnetic field

$F = Bvq$

Step 3: Substitution given values into formula and calculate to obtain the magnetic force

$F = 0.05\ T \times 2.0 \times 10^{6}\ m/s \times 1.6 \times 10^{-19}\ C = 0.16 \times 10^{-13} N$

Step 4: if the proton moves in a circle the force should provide the centripetal force, recall the formula for centripetal force

$$F_c = \frac{mv^2}{r}$$

Step 5: Equate the force on the charge to the centripetal force

$F_C = F$

$$F = m\frac{v^2}{r}$$

Step 6: Substitute given values and calculate values

$$0.16\ x\ 10^{-13} N = \frac{1.67 \times 10^{-27} kg \times (2.0 \times 10^{6} m/s)^2}{r}$$

Step 7: Make r the subject and calculate to obtain the radius

$$0.16\ x\ 10^{-13} N = \frac{3.34 \times 10^{-21}}{r}$$

$$r = \frac{3.34 \times 10^{-21}}{0.16 \times 10^{-13}}$$

$$r = 20.9 \times 10^{-8}\ m,$$

Worked Example 2

A proton with a charge of $+1.6 \times 10^{-19}$ C enters a uniform electric field with a strength of 5×10^{3} N/C.

a. Calculate the electric force acting on the proton.

b. If the proton is initially at rest, what will its acceleration be due to this force? (Assume the mass of the proton is 1.67×10^{-27} kg).

Step-by-Step Solution

Step 1: Identify given variables

$q = 1.6 \times 10^{-19}$ C, $E = 5 \times 10^{3}$ N/C, $F = ?$

Step 2: Identify the formula for force on a charge in an electric field

$F = Eq$

Step 3: Substitute given values and calculate to obtain the force

$\text{F} = 5 \times 10^{3}\ \text{N/C} \times 1.6 \times 10^{-19}\ \text{C} = 8 \times 10^{-16}\ \text{N}$

Step 3: To determine the acceleration, recall the formula for force

F = ma,

where m = mass, a = acceleration

Step 4: Substitute calculate values and given values and make acceleration the subject

$8 \times 10^{-16}\ \text{N} = 1.67 \times 10^{-27}\text{kg x a}$

$$a = \frac{8\ x\ 10^{-16}\ N}{1.67 \times 10^{-27}\ kg}$$

Step 5: Calculate to obtain your answer

$\text{a} = 4.79 \times 10^{11}\text{m/s}^2$

Worked Example 3

An electron moves through a region where there is a magnetic field of B=0.2 T and an electric field of E=500 N/C. Determine the velocity at which the electron will pass through the fields without deflection.

Step-by-Step Solution

Step 1: Identify given variables

Magnetic flux density B = 0.2 T, electric field strength E = 500 N/C, velocity v =?

Step 2 Identify the formula for a charge moving in a cross-field

$$v = \frac{E}{B}$$

Step 3 Substitute given values and calculate

$$v = \frac{500}{0.2} = 2500 \text{ m/s}$$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. An oil drop weighing 3.0×10^{-5} N and carrying a charge of 4×10^{-6} C is found to remain at rest in a vertical uniform electric field. Calculate the magnitude of the electric field.
2. Calculate the velocity of an ion moving undeflected in a crossed field. The electric and magnetic field strengths are 5.2 N/C and 0.1 T respectively.

Activity 6.19 Research and Presentation on Applications of Forces on Charged Particles

Objective: Work in groups to research and present topics related to the applications of forces on charged particles. You will create either an essay or a poster that includes detailed explanations, relevant formulas, diagrams, and real-world applications.

Materials Needed

1. Access to research materials (books, articles, internet)
2. Paper or poster board (for creating posters)
3. Markers, coloured pencils, or crayons (for illustrations)
4. Notebook and pen/pencil (for taking notes)
5. Access to a computer (optional, for digital presentations)

What to do

1. Organise yourselves into small groups. As a group, select one topic from the suggested list below or propose another topic related to the applications of forces on charged particles.
   a. **The Role of Electric Fields in Particle Accelerators**: How charged particles are accelerated and manipulated using electric fields.
   b. **Magnetic Fields and Charged Particle Motion**: The effects of magnetic fields on the trajectory of charged particles in devices like cyclotrons. A good example of these is the Large Hadron Collider at CERN in Switzerland.
   c. **Applications of Electromagnets**: How forces on charged particles are used in devices such as MRI machines and electric motors.
   d. **Electrostatic Forces in Everyday Life**: The application of forces on charged particles in devices like photocopiers and laser printers.
   e. **Cosmic Rays and Earth's Magnetic Field**: How charged cosmic rays are affected by the Earth's magnetic field and their implications for technology and health.
   f. **The Use of Charged Particles in Radiation Therapy**: How forces on charged particles are applied in medical treatments for cancer.
   g. **The Physics of Mass Spectrometry**: How charged particles are separated based on their mass-to-charge ratio using electric and magnetic fields.

2. Conduct Research by using the following resources to gather information about your chosen topic:
   i. Online articles and educational websites
   ii. Textbooks covering electromagnetism and particle physics
   iii. Scientific journals or papers relevant to your topic

   Take notes on key concepts, formulas, diagrams, and real-world applications related to your topic.

3. Decide whether your group will create an essay or a poster.
   a. If creating a poster:
      i. Include headings for each section (e.g., Introduction, Key Concepts, and Applications).
      ii. Use diagrams to illustrate concepts visually.
      iii. Ensure your poster is colourful and engaging.

b. If writing an essay:

   i. Structure your essay with clear sections (Introduction, Body, and Conclusion).

   ii. Include relevant formulas and explanations.

   iii. Provide citations for any sources used.

4. Organise your findings into a cohesive presentation format.

5. Take turns as a group and present your research to the class for discussion and feedback.

6. After all presentations are complete, write down any new insights regarding the applications of forces on charged particles.

ADDITIONAL READING MATERIALS

1. Griffiths, D. J. (2020). *Introduction to electrodynamics* (4th ed.). Cambridge University Press.
2. Halliday, D., Resnick, R., & Walker, J. (2020). *Fundamentals of physics* (11th ed.). Wiley.
3. Hughes, E., Smith, I. M., Hiley, J., & Brown, K. (2023). *Electrical and electronic technology* (13th ed.). Pearson Education.
4. Tipler, P. A., & Mosca, G. (2019). *Physics for scientists and engineers with modern physics* (7th ed.). W. H. Freeman.
5. Byju's. (n.d.). *Magnetic field in a solenoid*. Retrieved from https://www.geeksforgeeks.org/magnetic-field-in-a-solenoid

REVIEW QUESTIONS

Review Questions 6.1

1. State Fleming's Left-Hand Rule.
2. A straight conductor of length 0.5 m is placed in a uniform magnetic field of strength 2 T. If the conductor carries a current of 3 A, and is oriented perpendicular to the magnetic field, calculate the force experienced by the conductor.

Review Questions 6.2

1. What is the working principle of a motor?
2. A rectangular loop of dimensions 20 cm by 10 cm carries a current of 5 A. The loop is placed in a uniform magnetic field of 0.3 T such that the plane of the loop makes an angle of 30° with the magnetic field.
   a. Calculate the torque acting on the loop.
   b. If the angle between the plane of the loop and the magnetic field is reduced to 0°, what will the torque be?

Review Questions 6.3

1. Write the formula for the magnetic force acting on a charged particle and define each term.
2. In a velocity selector, an ion with a charge of $+1.6 \times 10^{-19}$ C and a mass of 1.67×10^{-27} kg passes through undeflected. The electric field is 300 N/C and the magnetic field is 0.01 T
   a. Calculate the velocity of the ion.
   b. Determine the radius of the ion's circular path if the magnetic field is increased to 0.02 T after leaving the velocity selector.
3. A proton is moving through a crossed-field setup where the electric field is 500 N/C and the magnetic field is 0.05 T. Calculate the velocity of the proton if it passes through the fields undeflected.

SECTION

7 WAVES

ENERGY

Waves

INTRODUCTION

This section explores wave characteristics, classifications (e.g., longitudinal, transverse, electromagnetic, and mechanical), and properties like reflection, refraction, and diffraction. Practical applications include determining wave parameters, such as amplitude, frequency, and wavelength, and deriving the wave equation. Sound waves, a key focus, are studied in terms of their production, nature, classification, and applications like echo measurement and resonance, helping you connect theoretical concepts to real-world phenomena.

KEY IDEAS

- A wave is a disturbance which transfers energy between places without the transfer of matter.
- Properties of wave include reflection, refraction, diffraction, interference, polarisation
- Sound is produced by vibrations. Sound is a longitudinal wave. Sound requires a medium to travel, such as air, water, or solids.

WAVE MOTION

Remember the days you went swimming with your friends? When the first person jumped into the pool, what did you observe about the surface of the water? A disturbance was created at the point of impact, and this disturbance spread even to the banks of the pool, even though the water at the origin of the disturbance did not travel to the banks. This indicates that it is possible to transfer energy from place to place through matter without matter accompanying the transfer. This phenomenon describes wave motion.

Definition: A wave is a disturbance which transfers energy between places without the transfer of matter.

Examples of waves include sound, light, water waves, seismic waves, etc.

Figure 7.1: Ripples form during swimming

Activity 7.1 Creating a Concept Map on Waves

Objective: To recall and discuss your prior knowledge of waves.

Materials Needed

1. Large sheets of paper or poster board (for creating the concept map)
2. Markers, coloured pencils, or crayons (for drawing and labelling)
3. Sticky notes (optional, for organising ideas)
4. Reference materials (textbooks or notes on waves, if needed)

Keywords to Prompt Discussion

1. Wave
2. Amplitude
3. Wavelength
4. Frequency
5. Speed
6. Reflection
7. Refraction

8. Diffraction
9. Sound Waves
10. Light Waves
11. Electromagnetic Waves
12. Medium
13. Energy Transfer

What to do

1. Organise yourselves into small groups of not more than five.
2. Begin by discussing what you already know about waves. Use the keywords provided above to prompt your discussion.
3. Share any definitions, examples, or concepts related to waves that you can remember.

Organise Your Ideas

a. As you discuss, write down important terms and concepts that come up during your conversation.

b. Consider how these concepts are related to each other. For example, think about how amplitude relates to energy transfer or how frequency relates to wavelength.

On your large sheet of paper or poster board, start creating your concept map

a. Write the main topic "Waves" in the centre of the page.

b. Branch out from the main topic with key concepts you discussed (e.g., Amplitude, Wavelength).

c. Draw lines between related concepts and label those lines with descriptions of their relationships (e.g., "affects," "is a type of," "depends on").

d. Use different colours or shapes to differentiate between types of waves (e.g., sound waves vs. electromagnetic waves).

Figure 7.2: Example of concept map

Collaborate and Revise

a. Work together as a group to ensure that everyone's ideas are included in the concept map.

b. Revise and refine your map as needed, adding any additional connections or concepts that arise during your discussion.

Prepare to Share

a. Once your concept map is complete, prepare to present it to the class.

b. Decide who will explain each part of the map and what key points you want to highlight during your presentation.

Present Your Concept Map

a. Each group will take turns presenting their concept maps to the class.

b. Explain the connections between different concepts and share any insights gained during your discussions.

Properties of Waves

When a wave is travelling through a medium, it interacts with the particles of the medium and exhibits certain characteristics, which we refer to as wave properties.

Waves interact with the medium's particles, leading to observable phenomena like reflection, refraction, diffraction, and interference. These properties help us understand how waves transfer energy and interact with their surroundings.

Reflection

Reflection is the bouncing back of a wave into its original medium after encountering a boundary or obstacle. In this process:

a. The frequency, wavelength, and velocity of the wave remain unchanged, as long as the wave stays in the same medium. Only the direction of the wave changes.

b. The amplitude may change depending on the nature of the boundary (e.g., energy loss at the boundary).

While reflection is often associated with light rays, all types of waves—such as sound waves, water waves, and seismic waves—undergo reflection as well.

For example,

1. **Reflection of Light:** You can see yourself and the environment behind you in a mirror because light waves reflect off the mirror's surface. This is one of the most common experiences of wave reflection.
2. **Reflection of Sound:** Echoes in large, empty halls and reverberations in empty rooms occur because sound waves reflect off hard surfaces like walls, ceilings, and floors. These reflections can enhance or distort the original sound.

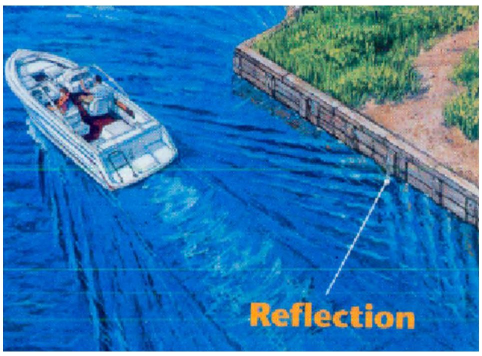


Figure 7.3a: Reflection of water waves against a wall

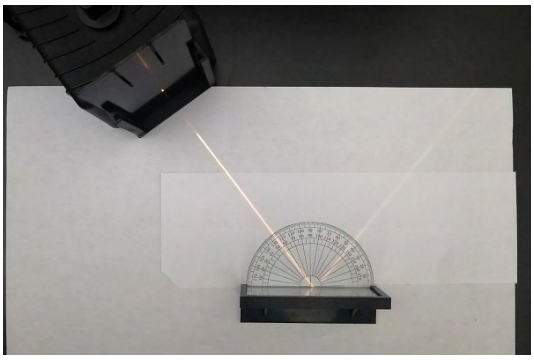


Figure 7.3b: Reflection of light in a lab experiment

Activity 7.2 Demonstrations of reflection

Try one or more of the following activities to see reflection in action:

1. Shine a laser pointer along a flat surface directed towards a mirror. Observe the path of the light after it meets the mirror. Experiment with different angles at which the light meets the surface of the mirror.
2. Take a tray or oven dish and fill it with water until it is around 1cm deep. Put the tray on a flat surface, and then gently lift and drop one end. Observe the wave that is produced and notice what happens when it hits the other end of the tray.
3. Look at yourself in a mirror, and compare the image to that which you see in a photograph of yourself. Are they the same? In what ways are they different?

Refraction

Refraction, like reflection, occurs at a boundary. However, in this case, the boundary is permeable to the wave, allowing it to enter the next medium. When a wave passes from one medium to another with a different (optical, in the case of light) density, it changes direction (bends), speed, and wavelength. Importantly, the frequency remains unchanged.

Definition: *Refraction is the change in the speed and direction (bending) of a wave when it moves from one medium to another of a different density.*

A few daily phenomena resulting from the refraction of waves include:

1. **Shallow Appearance of Water:** A pool of water appears shallower than it actually is because light rays bend (refract) when they travel from water to air, creating a misleading perception of depth.
2. **Fish in a Pond:** Fish appear closer to the surface of a pond than they really are due to the refraction of light as it passes from water to air, altering the perceived position of the fish.
3. **Sound Intensity Variation:** The intensity of sound varies during the day because sound waves refract when passing through layers of air at different temperatures, causing changes in their direction and concentration.

Figure 7.4 a: Light refracting through a rectangular prism

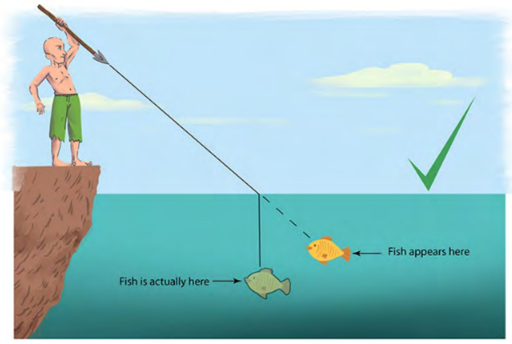


Figure 7.4 b: Real and apparent positions of a fish in water

Activity 7.3 Demonstrations of refraction

Try one or more of the following activities to see refraction in action:

1. Shine a laser pointer along a piece of paper, directed towards a glass block lying flat on the paper. Observe the path of the light as it enters the glass. Experiment by changing the angle at which the light hits the surface of the glass.
2. Place a penny into a transparent container, like a drinking glass, and observe the penny from the top. How does its apparent depth compare with true depth?

Diffraction

Diffraction is the spreading out of waves when they pass through small openings (apertures) or the bending of waves around obstacles.

It is a common phenomenon observed with all types of waves, such as light, sound, and water waves.

Key points about diffraction

1. The degree of diffraction depends on the wavelength of the wave and the size of the aperture or obstacle.
2. Waves with longer wavelengths (e.g., low-frequency sounds) diffract more effectively.
3. If the wavelength is significantly smaller than the gap or obstacle, little to no diffraction occurs, and the wave passes straight through as if in free space.

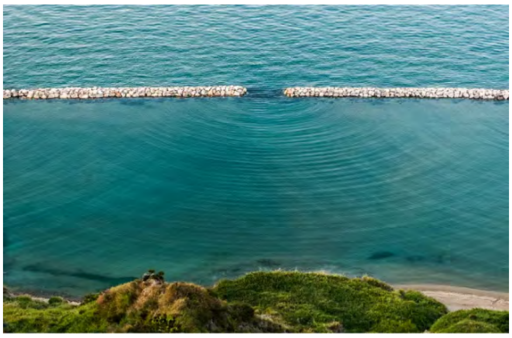


Figure 7.5a: Diffraction of water waves through an opening in a wall

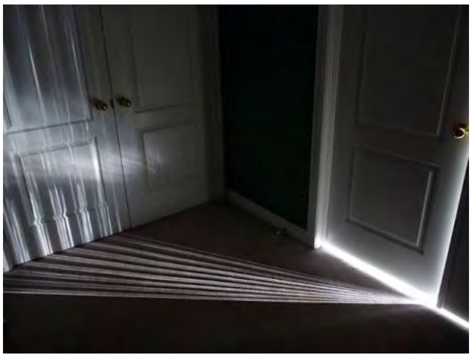


Figure 7.5b: Diffraction of light through a slightly ajar door

Examples of Diffraction in Daily Life

1. **Sound Diffraction**: Low-frequency sounds (bass) diffract around buildings and through small gaps, allowing them to be heard in areas not directly exposed to the sound source.
2. **Light Diffraction**: Light rays diffract through small gaps between leaves in a forest canopy, scattering to light up the forest floor.
3. **Water Waves**: When ocean waves pass through a narrow harbour entrance or around a breakwater, they spread out and form circular wave patterns beyond the gap.
4. **Radio Waves**: Radio signals, especially those in the AM frequency range (longer wavelengths), can bend around hills, buildings, and other obstacles, allowing reception in areas not in direct line-of-sight of the transmitter.
5. **Shadow Edges**: The edges of shadows are not perfectly sharp because light diffracts slightly around the edges of objects, causing a gradual transition from light to shadow.

Activity 7.4 Demonstrations of diffraction

Try one or more of the following activities to see diffraction in action:

1. Shine a laser pointer at a diffraction grating so that the pattern emerging can be seen on the wall opposite. Describe the pattern that you see. Experiment by changing the distance to the wall.
2. As in activity 7.2, create a water wave in a tray. This time, place an object in the centre of the tray. How does the wave behave as it passes the object?
3. As above, but this time create a barrier in the middle of the try with a small gap in the centre. How does the wave behave as it passes through the gap?

Interference of Waves

Interference occurs when two or more waves meet, overlap, and combine as they travel through the same medium. This phenomenon can happen with any type of wave—such as sound, light, water, or even electromagnetic waves.

The resulting wave pattern depends on how the individual waves interact. This interaction is governed by the principle of superposition, which states: ***the resultant displacement at any point is the algebraic sum of the displacements of the individual waves at that point.***

Types of Interference

Constructive Interference: Occurs when waves meet in phase (their crests and troughs align). The amplitudes of the waves add up, creating a wave with a greater amplitude.

Example: Louder sound at certain points in a room when sound waves from multiple sources reinforce each other.

Destructive Interference: Occurs when waves meet out of phase (a crest aligns with a trough). The amplitudes cancel each other out, reducing or completely nullifying the resultant wave.

Example: Noise-cancelling headphones use destructive interference to reduce unwanted sound.

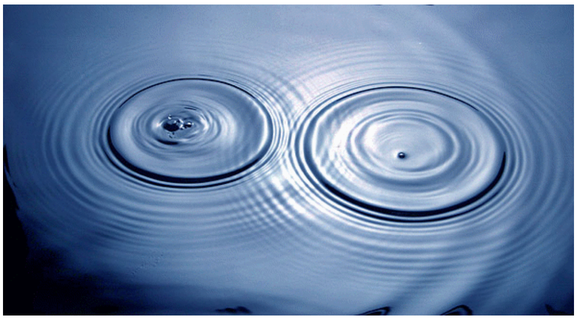


Figure 7.6a: Interference of two water waves

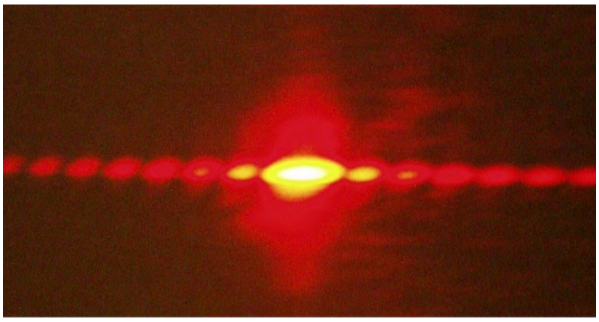


Figure 7.6b: Interference pattern observed in a double slit experiment on light.

Applications and Examples

1. **Light Interference**: Thin-film interference creates colourful patterns on soap bubbles or oil spills due to the overlapping of light waves reflected from different layers of the film.

2. **Sound Interference**: When sound waves overlap, they can create regions of louder (constructive interference) and quieter (destructive interference) sound, like beats in musical tuning.
3. **Water Wave Interference**: When two stones are dropped into a pond, the ripples overlap, creating constructive and destructive interference patterns visible as areas of higher or lower wave heights.

Interference explains how waves interact to create complex wave patterns, whether amplifying or cancelling each other out. This principle is fundamental to understanding many natural and technological phenomena.

Polarisation

In the next discussion, you will learn about a type of wave called a transverse wave. In transverse waves, the direction of the medium's displacement is perpendicular to the direction in which the wave travels. A common example of transverse waves is electromagnetic waves.

Electromagnetic waves consist of oscillating electric and magnetic fields that are perpendicular to each other and the direction of wave propagation. These fields typically oscillate in multiple planes. Through a process called polarisation, it is possible to filter or restrict these oscillations to a single plane, allowing only waves in that plane to propagate while blocking others.

This filtering process is essential in various applications, such as reducing glare in sunglasses or enhancing signal clarity in communication systems.

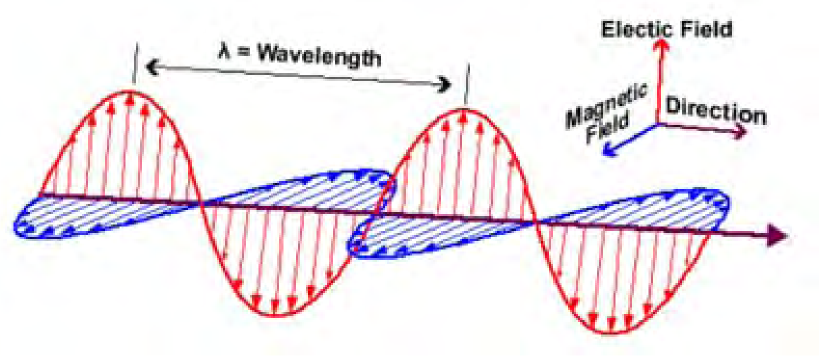


Figure 7.7: magnetic (blue and horizontal) and electric (red and vertical) fields propagating in the same direction but perpendicular in orientation.

Activity 7.5 Demonstrations of polarisation

Try the following activity to see polarisation in action:

Go out into the street on a sunny day and look at the windscreen of a car. Now look again, but this time with polarising sunglasses on. How are the two images different?

Classification of waves

1. **Based on the Medium**
   a. Mechanical Waves: Require a medium (solid, liquid, or gas) to propagate and cannot travel through a vacuum. Examples include sound waves and water waves.
   b. Electromagnetic Waves: Do not require a medium and can propagate through a vacuum. However, they interact with matter when travelling through a medium, such as air or water. Examples include light, X-rays, and microwaves.
2. **Based on the Direction of Propagation Relative to Medium Particles**
   a. **Longitudinal Waves:** The wave propagates parallel to the displacement of particles in the medium (e.g., sound waves).
   b. **Transverse Waves:** The wave propagates perpendicular to the displacement of particles in the medium (e.g., electromagnetic waves).

Note: Water waves are surface waves with both transverse and longitudinal components.

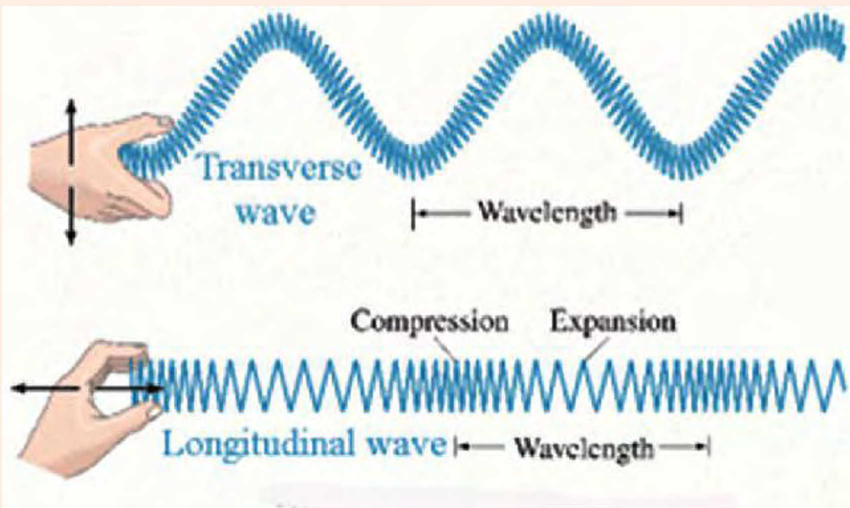


Figure 7.8: using a slinky to demonstrate transverse and longitudinal waves

3. **Based on Energy Transfer**
   a. **Progressive Waves:** Transfer energy through a medium without permanently displacing the medium's particles. Examples include electromagnetic waves and surface water waves.
   b. **Standing Waves**: Confine energy between fixed points where incident and reflected waves superimpose, creating nodes (no motion) and antinodes (maximum motion). These waves do not transport energy over long distances, as seen in vibrating guitar strings.

Activity 7.6 Modelling Transverse and Longitudinal Waves

In groups of 10-20 students, follow the instructions below in order to model the behaviour of transverse and longitudinal waves.

1. Half of the group (group A) should stand in a line, shoulder to shoulder. The rest of the group (group B) should observe.
2. The person on the far left of group A should act as the source of a longitudinal wave (e.g., sound). To do this, they should begin by vibrating side-to-side.
3. They should gently collide with their neighbour, causing them to also vibrate from side to side.
4. This process should continue until the final person, on the far right hand side, is vibrating. The wave has been transferred longitudinally, with the oscillations parallel to the transfer of energy.
5. Group B should now take their turn and stand side by side, observed by group A.
6. The person on the far left hand side of group A should perform a 'Mexican Wave', moving up and down with exaggerated movements.
7. After a second, the person next to them should also being moving in the same way.
8. This process should continue until the final person, on the far right hand side, is moving. The wave has been transferred transversely, with the oscillation perpendicular to the transfer of energy.

Activity 7.7 Exploring Wave Properties Through Demonstrations

Objective: Explore different types of waves by conducting hands-on demonstrations using a rope, a slinky, and a vibrating guitar string.

Materials Needed

1. Long rope or string (approximately 3-5 metres)
2. Slinky spring
3. Guitar (or any instrument with a vibrating string)
4. Flat surface (for the slinky demonstration)
5. Paper and pen/pencil (for taking notes and creating classification charts)

What to do

Part A: Rope Wave Demonstration

1. Organise yourselves into small groups.
2. Stretch the long rope or string between two fixed points (e.g., two chairs or trees) so that it is taut.
3. One member of your group should quickly move one end of the rope up and down to create waves. Observe how the wave travels along the rope.
4. After the demonstration, discuss as a group:
   a. What type of wave was created?
   b. How did the wave travel through the rope?

Part B: Slinky Wave Demonstration

4. Stretch the slinky across a flat surface.
5. One member of your group should hold one end of the slinky stationary while another member quickly pushes and pulls the other end to create waves.
6. Next, while one end of the slinky is held stationary, have another member move the other end up and down or side-to-side to create a different type of wave.
7. After each type of wave demonstration with the slinky, discuss as a group:
   a. What characteristics did you observe for each type of wave?
   b. How did each wave behave differently?
   c. What do you think distinguishes these types of waves?

Part C: Guitar String Wave Demonstration

8. Use a guitar or similar instrument to demonstrate waves.
9. Pluck a string to create vibrations and observe how these vibrations produce sound waves.
10. Discuss as a group:
    a. What characteristics did you notice about the sound waves produced by the vibrating guitar string?
    b. How does this wave differ from those created with the rope and slinky?
    c. What properties did you observe?

Part D: Classification Discussion

9. On a piece of paper, create a classification chart with columns for:
    a. Longitudinal Waves
    b. Transverse Waves
    c. Electromagnetic Waves
    d. Mechanical Waves
    e. Progressive Waves
    f. Stationary Waves
10. Based on your observations from each demonstration, categorise each type of wave into the appropriate columns in your classification chart.
11. Discuss as a group why you classified each wave in that way.

Activity 7.8 Classifying Waves Based on Definitions

Objective: work in pairs or small groups to classify different types of waves based on their definitions. You will discuss the characteristics of each wave type and categorise them accordingly.

Materials Needed

1. Lists of definitions (provided below)
2. Lists of different types of waves (provided below)
3. Paper and pen/pencil
4. Whiteboard or large paper (optional, for organising your classifications)

Definitions List

1. **Transverse Wave**: A wave in which the particle's displacement is perpendicular to the direction of wave propagation.
2. **Longitudinal Wave**: A wave in which the particle's displacement is parallel to the direction of wave propagation.
3. **Progressive Wave**: A wave that travels through a medium, transferring energy from one point to another.
4. **Stationary Wave**: A wave that remains in a constant position, formed by the interference of two waves traveling in opposite directions.
5. **Mechanical Wave**: A wave that requires a medium (solid, liquid, or gas) to travel through.
6. **Electromagnetic Wave**: A wave that does not require a medium and can travel through a vacuum; it consists of oscillating electric and magnetic fields.

Types of Waves List

1. Sound Wave
2. Light Wave
3. Water Wave
4. Seismic Wave
5. Radio Wave
6. Microwaves
7. String Wave (e.g., on a guitar string)
8. Ultrasound Wave

What to do

1. Organise yourselves into groups of no more than five.
2. **Review Definitions**
   a. Each group should read through the definitions list carefully.
   b. Discuss the meaning of each term and ensure that everyone understands the differences between transverse waves, longitudinal waves, progressive waves, stationary waves, mechanical waves, and electromagnetic waves.

3. **Review Types of Waves**
   - **a.** Next, review the list of different types of waves provided.
   - **b.** Discuss each type and consider its characteristics.
4. **Classify the Waves**
   - **a.** As a group, classify each type of wave from the "Types of Waves" list into appropriate categories based on the definitions:
     - **i.** Identify which waves are transverse and which are longitudinal.
     - **ii.** Determine which are mechanical and which are electromagnetic.
     - **iii.** Discuss whether they are progressive or stationary.
   - **b.** You can create a table or chart to organise your classifications.
5. Write down your classifications on paper or use a whiteboard to visually represent your findings.
6. **Present Your Classifications**
   - **a.** Each group will take turns presenting their classifications to the class.
   - **b.** Explain how you categorised each type of wave based on its definition and characteristics.

Activity 7.9 Exploring Wave Types Using PhET Simulations

Objective: Use the PhET wave simulation tools to explore different types of waves.

Materials Needed

1. Computer or tablet with internet access
2. Access to PhET simulations, specifically:
   a. Wave on a String
   b. Sound
   c. Fourier: Making Waves
   d. Wave Interference
3. Paper and pen/pencil (for taking notes and classifying waves)

What to do

1. Open your web browser and navigate to the PhET website. Choose one of the wave simulations from the list above.
2. **Explore Different Types of Waves**
   a. **Sound Simulation**
      i. Click on "Play" to generate sound waves.
      ii. Observe how the waves propagate through the medium.
      iii. Take notes on the characteristics you observe, such as patterns, movement, and behaviours.

b. **Wave on a String Simulation**
   i. Use the controls to create waves by moving one end of a string up and down.
   ii. Observe how the wave travels along the string.
   iii. Note any characteristics such as shape, amplitude, and speed.

c. **Fourier: Making Waves Simulation**
   i. Experiment with creating different waveforms using sine waves.
   ii. Observe how these combinations can produce various wave shapes.
   iii. Take note of how different parameters affect wave behaviour.

d. **Wave Interference Simulation**
   i. Set up two sources of waves (e.g., point sources) and observe how they interact.
   ii. Note how the waves combine and create patterns.
   iii. Discuss any observations about how these interactions occur.

3. After exploring each simulation, create a table in your notebook to organize your observations:

Wave Type	Characteristics Observed	Classification
Example Wave 1	Describe shape, direction, amplitude, etc.	
Example Wave 2	Describe shape, direction, amplitude, etc.	
Example Wave 3	Describe shape, direction, amplitude, etc.	

4. **Discuss Findings with Peers**
   a. After completing your exploration and classification, discuss your findings with classmates in small groups.
   b. Share insights about how you categorised each type of wave based on your observations.

WAVE MOTION 2

Wave Terminology and Representation

Representation of Waves

In Figure 7.9, a longitudinal wave and a transverse wave are compared.

All waves, whether transverse or longitudinal, can be represented graphically in the form of a transverse wave when displacement is plotted against time or position. This graphical representation produces a sinusoidal (trigonometric) curve, regardless of the wave type.

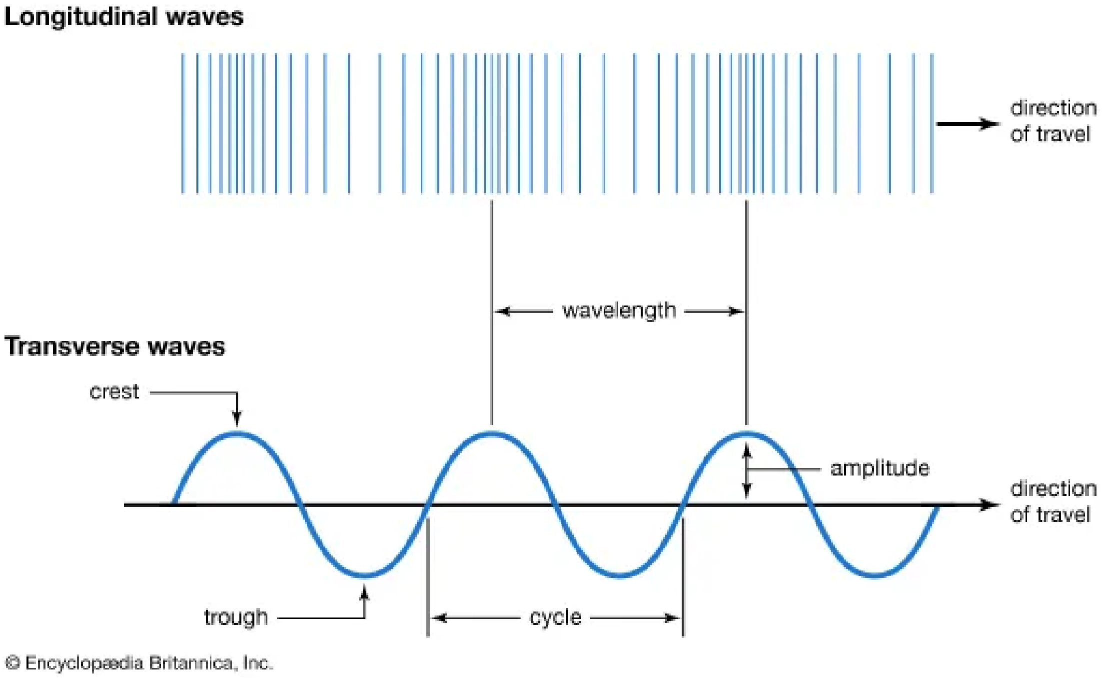


Figure 7.9: relating longitudinal and transverse waves.

Key Terms in Wave Properties

1. **Crest:** The highest point of a transverse wave above the equilibrium position. It alternates with troughs as the wave propagates.
2. **Trough:** The lowest point of a transverse wave below the equilibrium position. Troughs alternate with crests throughout the wave's motion.
3. **Compression:** A region in a longitudinal wave where particles of the medium are closely packed, resulting in high pressure. It is analogous to the crest of a transverse wave.

4. **Rarefaction:** A region in a longitudinal wave where particles of the medium are spread out, resulting in low pressure. It alternates with compressions and is analogous to the trough of a transverse wave.
5. **Displacement (y):** The distance moved by a particle of the medium from its equilibrium position at any time due to wave propagation. Displacement can occur in any direction, depending on the wave type.
6. **Amplitude (a):** The maximum displacement of a particle from its equilibrium position. It indicates the wave's energy and is measured in metres (m).
7. **Wavelength (λ):** The distance between two successive points in phase on a wave, such as two crests, two troughs, or two compressions. It is measured in metres (m).
8. **Period (T):** The time taken for one complete oscillation or cycle of a wave. It is measured in seconds (s).

Activity 7.10 Identifying the feature from a graph

From the images below, match up the correct feature with the letter from the image. Note that one letter will not be needed.

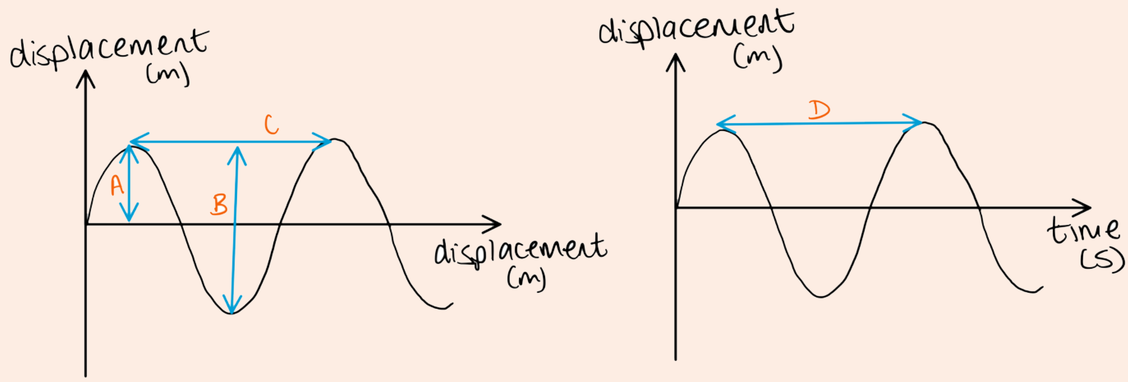


Figure 7.10: Features of a wave

Feature	Letter
Wavelength	
Time period	
Amplitude	

Activity 7.11 Drawing Wave Profiles on Graph Paper

Objective: Create wave profiles on graph paper by specifying amplitudes and wavelengths.

Materials Needed

1. Graph paper (sheets or a notebook)
2. Ruler
3. Pencil or pen
4. Eraser (optional)
5. Coloured pencils or markers (optional, for added detail)

What to do

1. Before you start drawing, familiarise yourself with the key parameters of a wave:
   a. **Amplitude (A)**: The maximum height of the wave from the rest position (baseline).
   b. **Wavelength (λ)**: The distance between two consecutive points in phase on the wave (e.g., crest to crest or trough to trough).
2. Choose Your Parameters. Decide on the amplitude and wavelength for your wave profile. For example:
   c. Amplitude = 3 units
   d. Wavelength = 6 units
3. **Set Up Your Graph Paper:**
   a. Place your graph paper on a flat surface.
   b. Choose a baseline (horizontal line) to represent the rest position of the wave. This will be your starting point.
4. **Draw the Wave Profile:**
   a. Start at the left edge of the graph paper and mark your baseline.
   b. Using your ruler, measure and mark points for one complete wavelength:
      i. From the starting point, move right by the wavelength distance (e.g., 6 units).

c. Now, draw the wave:

i. From the baseline, move up to represent the crest of the wave at an amplitude of 3 units.

ii. Move back down to the baseline, then down to represent the trough at -3 units (if using a vertical scale).

iii. Return to the baseline and complete one full cycle by moving back up to create another crest.

d. Repeat this process to draw multiple wavelengths across your graph paper.

3. Clearly label your wave profile with:

i. Amplitude (e.g., "Amplitude = 3 units")

ii. Wavelength (e.g., "Wavelength = 6 units")

iii. Any other relevant information (e.g., "Wave Profile").

4. Use coloured pencils or markers to differentiate between crests and troughs, or to highlight specific features of your wave profile.

The key terms describing waves that we have met so far can all be directly measured. However, there are also some properties of waves which can be calculated, such as their velocity or frequency.

Activity 7.12 Deriving the Wave Equation from the Definition of Speed

Objective: mathematically derive the wave equation using the definition of speed as distance divided by time.

Definitions

1. **Speed (v)**: The distance travelled per unit of time.
2. **Wavelength (λ)**: The distance between two consecutive points in phase on a wave (e.g., crest to crest or trough to trough).
3. **Frequency (f)**: The number of complete wave cycles that pass a point in one second (measured in Hertz, Hz).
4. **Period (T)**: The time taken for one complete cycle of the wave to pass a point.

What to do

1. Recall the formula for speed (v) which is given by:

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

2. Consider a Wave

a. For a wave, the distance travelled in one complete cycle is equal to the wavelength (λ).

b. Therefore, when one complete wave cycle travels past a point, it covers a distance of λ.

3. Relate Time to Frequency

a. The frequency (f) is defined as the number of cycles per second. If T is the period (the time for one complete cycle), then:

$$f = \frac{1}{T}$$

b. This means that if you know the frequency, you can determine the period:

$$T = \frac{1}{f}$$

4. Substituting into the Speed Formula

a. When one complete cycle passes a point, it takes a time equal to the period (T).

b. Therefore, substituting λ for distance and T for time in the speed formula gives:

$$v = \frac{\lambda}{T}$$

5. Expressing Period in Terms of Frequency

a. Now substitute $T = \frac{1}{f}$ into the equation:

$$v = \frac{\lambda}{\frac{1}{f}}$$

6. Rearranging gives you the wave equation:

$$v = f\lambda$$

More Key Terms in Wave Properties

1. **Frequency (f):** The number of complete oscillations made by a particle per second or the number of wavelengths passing through a point per second. Frequency is measured in hertz (Hz) or s^{-1}.

   $f = \frac{1}{T}$

2. **Velocity (v):** The distance travelled by a wave in one second. Velocity is measured in metres per second (m/s).

   $v = \lambda f$

Finding the displacement of a particle at any given time

The motion of a wave follows the form of a simple harmonic motion. As such, the general wave equation is given as $y = a\sin\theta$,

Where θ is the phase (angle) of the cycle through which the particle has oscillated. θ could also be seen as the angular displacement, if the wave/particle were in a circular motion. As such, $\omega = \theta$=$and\ \theta = \omega t$.

Hence $y = a\sin\omega t$, where ω is the angular frequency; the angle per second through which the particle oscillates, and t is the time that has passed.

For example, a particle at the beginning of an oscillation, in the rest position has a phase angle of 0^0. A particle a quarter of the way through a cycle has a phase angle of 90^0 or $\frac{\pi}{2}$ radians).

Progressive wave equation

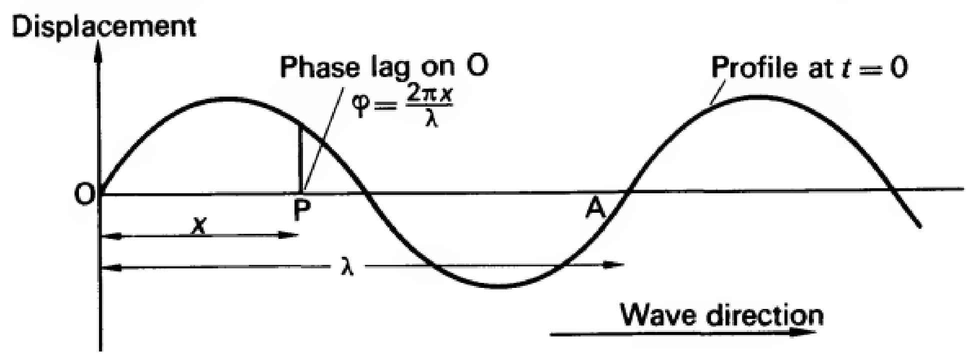


Figure 7.11: Phase lag

Wave Moving Left to Right (Positive x-Direction)

1. **Displacement at Origin (O):** The displacement of the particle at O is given by:

   $y = a \sin \omega t$

   Where:

   - a is the amplitude,
   - ω is the angular frequency,
   - t is the time.

2. **Displacement at a Point P**: A particle P at a distance x from O lags behind O by a phase angle ϕ. Its displacement is given by: $y = a \sin(\omega t - \phi)$,

   The negative sign means that P lags behind O.

Phase Angle and Wavelength Relationship

For a full wavelength λ, *the total phase angle* $\theta = 2\pi$,

At the position x along the wave at , $\theta = \phi$

Therefore, $\frac{\lambda}{x} = \frac{2\pi}{\phi}$

Making ϕ the subject, $\phi = \frac{2\pi x}{\lambda}$

Substituting $\phi = \frac{2\pi x}{\lambda}$ into $y = a \sin(\omega t - \phi)$

$y = a \sin(\omega t - \frac{2\pi x}{\lambda})$

Wave number and frequency

$y = a \sin(\omega t - kx)$

- The **wave number** is defined as $k = \frac{2\pi}{\lambda}$,
- The **velocity (v)** is related to the wavelength (λ) and period (T) by:

$v = \frac{\lambda}{T}$, *where* $T = \frac{\lambda}{v}$

and $\omega = \frac{2\pi}{T}$, $\omega = \frac{2\pi v}{\lambda}$

Substituting ϕ and ω into $y = a \sin(\omega t - \phi)$

$y = a \sin(\frac{2\pi vt}{\lambda} \pm \frac{2\pi x}{\lambda})$ OR $y = a \sin(2\pi ft \pm \frac{2\pi x}{\lambda})$

The progressive wave equation

1. For a left-to-right motion (positive x-direction): of the wave,

$$y = a\,sin\left(\frac{2\pi vt}{\lambda} - \frac{2\pi x}{\lambda}\right) = a\,sin\left(2\pi ft - \frac{2\pi x}{\lambda}\right)$$

2. For a right-to-left motion (negative x-direction):

$$y = a\,sin\left(\frac{2\pi vt}{\lambda} + \frac{2\pi x}{\lambda}\right) = a\,sin\left(2\pi ft + \frac{2\pi x}{\lambda}\right)$$

Parameters

- y: Displacement of the particle.
- a: Amplitude of the wave.
- v: Wave velocity.
- f: Frequency of vibration ($f = \frac{1}{T}$).
- x: Distance of the particle from the origin.
- λ: Wavelength of the wave.
- k: Wave number ($k = \frac{2\pi}{\lambda}$).
- ω: Angular frequency ($\omega = 2\pi f$).

Activity 7.13 Exploring Wave Properties Using PhET Simulation

Objective: use the PhET wave simulation to obtain the frequency, amplitude, and wavelength of sinusoidal waves.

Materials Needed

1. Computer or tablet with internet access
2. Access to the PhET wave simulation tool (e.g., PhET Waves Simulation)
3. Paper and pen/pencil (for recording measurements and calculations)
4. Calculator (optional, for calculations)

What to do

1. **Access the Simulation**
   a. Open your web browser and navigate to the PhET wave simulation tool.
   b. Familiarise yourself with the interface and controls of the simulation.

2. **Generate Sinusoidal Waves**
   a. Use the simulation to create sinusoidal waves by adjusting parameters such as amplitude, frequency, and wavelength.
   b. Start with a default setting and observe how changing these parameters affects the wave.

3. **Measure Wave Properties**
   a. **Amplitude** (**A**): Use the simulation's tools to measure the maximum height of the wave from its rest position. Record this value.
   b. **Frequency** (**f**): Determine how many complete cycles of the wave pass a point in one second. Record this value in Hertz (Hz).
   c. **Wavelength** (**λ**): Measure the distance between two consecutive crests (or troughs) of the wave. Record this value in meters (m).
   d. **Period** (**T**): Calculate the period of the wave using the formula:
   $T = \frac{1}{f}$
   where f is the frequency you measured.

4. Create a table in your notes to organize your measurements:

Wave Setting	Amplitude (*A*)	Frequency (*f*)	Wavelength (λ)	Period (*T*)
1				
2				
3				

5. Use the recorded frequency and wavelength to calculate wave velocity (vv) using the formula:
   $v = f\lambda$
   Record your calculated values in your table.

6. Based on your measurements, write down the general progressive wave equation by substituting the measurements in the progressive wave equation below:
   $y = a \sin\left(2\pi ft \mp \frac{2\pi x}{\lambda}\right)$

Activity 7.14 Calculating amplitude, velocity, frequency, period, wavelength of a wave

Study the worked examples below carefully before attempting the example questions that follow.

Worked Example 1

A wave travelling along a string is described by the equation:

$y(x, t) = 0.04sin\ (8\pi t - 4\pi x)$, where y is in meters, t is in seconds, and x is in meters.

a. Determine the following:

b. Amplitude (a)

c. Angular frequency ω

d. Frequency f

e. Wavelength λ

f. Wave speed v

g. Wave number k

h. The direction of wave propagation

i. The displacement (y) of a particle at x = 0.5 m and t = 0.25 s.

Solution:

Wave Setting	Amplitude (A)	Frequency (f)	Wavelength (λ)	Period (T)
1				
2				
3				

Step 1: Write down the general wave equation and the given wave equation

$$y(x, t) = \text{a}\sin(\omega t - kx)$$

$$y(x, t) = 0.04sin(8\pi t - 4\pi x),$$

Step 2: compare the equations, extract the necessary data and use it to calculate the parameters as follows:

a. Amplitude $a = 0.04\,m$

b. Angular Frequency $\omega = 8\pi = 25.13\, rad/s$

c. Frequency $2\pi f = 8\pi, f = \frac{8\pi}{2\pi} = 4.0\, Hz$

d. Wavelength $k = \frac{2\pi}{\lambda} = 4\pi, \lambda = \frac{2\pi}{4\pi} = 0.5\, m$

e. Wave Speed $v = \lambda f = 0.5 \times 4 = 2.0\, m/s$

f. Wave Number $k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.5} = 12.57\, rad/m$

g. Displacement at x= 0.5 m and t = 0.25 s

$y(x,t) = 0.04sin(8\pi t - 4\pi x),$

$y(x,t) = 0.04sin(8\pi(0.25) - 4\pi(0.5)),$

$y(x,t) = 0.0\ m$

Worked Example 2

A sound wave propagating in air is described by the equation:

$y(x,t) = 0.02sin(300t + 0.5x)$

Where y is in meters, t is in seconds, and x is in meters. Determine the following:

a. Amplitude (a)

b. Angular frequency (ω)

c. Frequency (f)

d. Wave number (k)

e. Wavelength (λ)

f. Wave speed (v)

g. The direction of wave propagation

h. The displacement (y) of a particle at x= 2 m and t = 0.01 s.

Solution

Step 1: Write down the general wave equation and the given wave equation

$y(x,t) = a\sin(\omega t - kx)$

$y(x,t) = 0.02sin(300t + 0.5x)$

Step 2: compare the equations, extract the necessary data and use it to calculate the parameters as follows:

a. Amplitude $a = 0.02\, m$

b. Angular Frequency $\omega = 300\, rad/s$

c. Frequency $f = \frac{\omega}{2\pi} = \frac{300}{2\pi} = 47.75\ Hz$

d. Wave Number $k = 0.5\, rad/m$

e. Wavelength $\lambda = \frac{2\pi}{k} = \frac{2\pi}{0.5} = 12.57\, m$

f. Wave Speed $v = \lambda f = 12.57 \times 47.75 = 600.0\, m/s$

g. Since we have a + sign in the brackets, the wave is in the negative x-direction

h. Displacement y at $x = 2\, m, t = 0.01\ s$

$y(2,0.01) = 0.02\sin(300(0.01) + 0.5(2)) = -0.0151\, m$

Practice problems

Now, using the worked example as a guide, solve the following problems individually or in groups.

1. The displacement of a particle in a progressive wave is described by:
$y = 0.05 sin(10\pi t - 2\pi x)$
Where y and x are in metres, t is in seconds.

- **a.** What is the displacement of the particle at $x = 2\ m, t = 0.5\ s$?
- **b.** What is the amplitude of the wave?

2. A wave travelling along a string is represented by the equation: $y = 0.1 sin(50t - 4x)$
Where y and x are in metres, t is in seconds,

- **a.** Find the angular frequency ω and wave number k from the equation.
- **b.** Determine the frequency f of the wave.
- **c.** Calculate the velocity v of the wave.

3. A sound wave has a wavelength of 2 m and a speed of 340 m/s.

- **a.** Calculate the frequency of the wave.
- **b.** Determine the angular frequency.

4. The displacement-time graph of a particle vibrating in a wave is sinusoidal, with a maximum displacement of 0.08 m and a period of 0.02 s.

- **a.** What is the amplitude of the wave?
- **b.** Calculate the angular frequency (ω) and frequency (f).

5. A snapshot of a wave travelling in the positive x-direction shows the following characteristics: The crest is located at $x = 2\ m$ with a maximum displacement of 0.05 m, the wavelength is 4 m, and the wave moves at a speed of 20 m/s.
   a. Write the wave equation.
   b. Determine the displacement of a particle at $x = 1\ m\ and\ t = 0.1\ s$.
6. A progressive wave is described by: $y = 0.03sin(5t + 3x)$, y and x are in metres, t is in seconds
   a. What is the wave's amplitude?
   b. What is the direction of propagation of the wave?
   c. Find the angular frequency (ω) and wave number (k).
   d. Calculate the frequency and velocity of the wave.

SOUND WAVES

Production, Nature, and Transmission of Sound

Production of Sound

1. Sound is produced by vibrations.
2. When an object vibrates, it creates a disturbance in the surrounding medium (usually air).
3. This disturbance travels outwards in the form of waves, which we perceive as sound.

Examples:

1. Musical Instruments: In a guitar, plucking a string causes it to vibrate. The vibrations transfer to the air, producing sound waves that we hear as music.
2. Voice Production: In humans, the vocal cords vibrate as air passes through them, producing sound waves that form speech and singing.
3. Speakers: In a loudspeaker, an electrical signal causes a diaphragm to vibrate, creating sound waves that propagate through the air.
4. Vibrating tuning fork producing sound waves

Nature of Sound

1. Sound is a longitudinal wave.

2. In a longitudinal wave, the particles of the medium vibrate parallel to the direction of wave propagation.

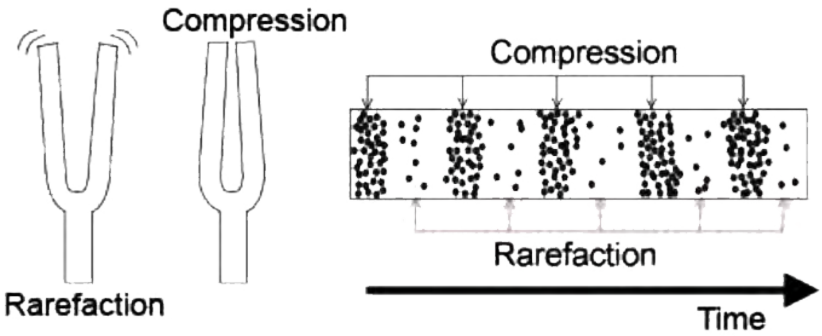


Figure 7.12a: Vibrating tuning fork producing sound waves

3. Sound waves consist of compressions (regions of high pressure) and rarefactions (regions of low pressure).

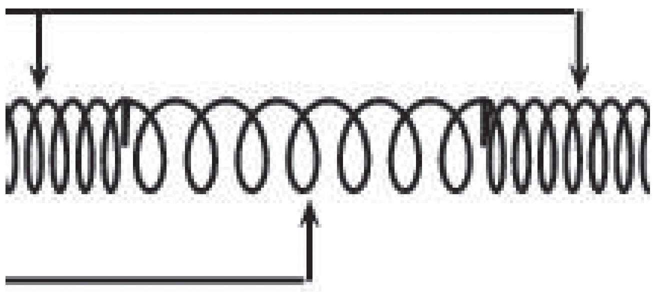


Figure 7.12b: Longitudinal wave showing compressions and rarefactions

Transmission of Sound

1. Sound requires a medium to travel, such as air, water, or solids.
2. It cannot travel through a vacuum.
3. The speed of sound varies in different media. It is generally faster in solids than in liquids and gases.

Activity 7.15 Exploring the Speed of Sound in Different States of Matter

Objective: engage in a group discussion to compare the speed of sound in solids, liquids, and gases.

Materials Needed

1. Access to textbooks or online resources about sound and its properties (if available)
2. Paper and pens/pencils (for taking notes)

3. Whiteboard or large paper (optional, for recording key points during discussions)

What to do

1. Divide yourselves into small groups of 4-5 students. Each group will choose one state of matter from the states of matter below:
   - a. Solids
   - b. Liquids
   - c. Gases
2. Each group should spend 10-15 minutes researching and discussing the following points about their assigned state:
   - d. What is the approximate speed of sound in your assigned state of matter? (For reference, consider general values: approximately 5000 m/s for solids, 1500 m/s for liquids, and 343 m/s for gases.)
   - e. Why does sound travel faster in your assigned state compared to the others?
   - f. Discuss how molecular arrangement, density, and elasticity affect the speed of sound.
   - g. Think of real-world examples where the speed of sound is important in your assigned state (e.g., underwater communication for liquids, musical instruments for solids).
3. As a group, summarise your findings in a few key points. Write these down on paper.
4. After your discussion time is up, each group should share their findings with the class. One member from each group should present the key points you prepared.
5. After all groups have presented, engage in a class-wide discussion:
   - h. Compare and contrast the findings from each group.
   - i. Discuss how molecular structure and material properties influence the speed of sound.
   - j. Explore any questions or interesting insights that arose during your discussions.
6. Summarise the main points discussed regarding how sound behaves differently in solids, liquids, and gases. Highlight why understanding these

differences is important in various fields such as engineering, acoustics, and environmental science.

Activity 7.16 Exploring Sound Transmission with a Tuning Fork

Objective: Investigate how sound travels through different materials by using a tuning fork.

Materials Needed

1. Tuning fork
2. Rubber mallet (for striking the tuning fork)
3. Container filled with water (enough to submerge the tuning fork)
4. Metal object (e.g., a metal rod or a piece of metal sheet)
5. Paper and pen/pencil (for taking notes)

What to do

1. **Strike the Tuning Fork**
   - **a.** Hold the tuning fork by its handle.
   - **b.** Use the rubber mallet to strike the tuning fork gently. Observe how the tines of the fork vibrate and produce sound.
2. **Listen to Sound in Air**
   - **a.** Stand a few feet away from the tuning fork after striking it and listen to the sound produced in air. Pay attention to how loud or clear the sound is.
3. **Observe Vibrations**
   - **a.** While holding the struck tuning fork, place your fingers lightly on the tines of the fork. Feel the vibrations as they resonate through your fingers.
4. **Test Sound Transmission in Water**
   - **a.** Carefully submerge the tines of the tuning fork into the container of water while keeping the handle above water.
   - **b.** Strike the tuning fork again while it is submerged and listen closely to how the sound changes compared to when it was in air.
   - **c.** Note how the vibrations feel through your fingers when they are submerged in water.

5. **Test Sound Transmission in Metal**
   a. Next, strike the tuning fork again and then gently place one tine against a solid metal object (e.g., a metal rod or sheet).
   b. Listen carefully for any differences in sound transmission through the metal compared to air and water.
   c. You may also try placing your ear against the metal object while holding the tuning fork against it to hear how sound travels through solid materials.

6. **Record Your Observations:**
   a. Create a table in your notes to summarise your observations about sound transmission through each medium:

Medium	Sound Quality/Characteristics	Observations on Vibrations
Air		
Water		
Metal		

7. After completing your observations, discuss with your classmates what you noticed about how sound travelled through different materials. Consider questions such as:
   a. How did the sound differ between air, water, and metal?
   b. What do you think causes these differences in sound transmission?

Classification of Sound

Sound waves can be classified based on their frequency:

1. **Infrasonic** (Infrasound) **Sound:** Sound waves with frequencies below 20 Hz. Humans cannot hear these sounds. Infrasound. They can be produced by natural phenomena such as earthquakes, volcanic eruptions, and ocean waves, as well as by some animals for communication.
2. **Audio sonic Sound:** Sound waves with frequencies between 20 Hz and 20,000 Hz. Humans can hear these sounds.
3. **Ultrasonic Sound:** Sound waves with frequencies above 20,000 Hz. Humans cannot hear these sounds. Ultrasound is used in various applications, including medical imaging (ultrasound scans), cleaning, and non-destructive

testing. Some animals, like bats and dolphins, use ultrasound for navigation and communication.

Activity 7.17 Frequency and detection of sound using a frequency generator or video

Follow the link below to a video. In this video the frequency of a sound is slowly increased. When the video starts you should put your hand in the air and keep it raised until you can no longer hear the sound. Click here

Discuss with your neighbour the factors which might affect peoples' hearing and their ability to hear high pitched sounds.

Echo and Depth Determination

1. An echo is a reflected sound wave.
2. When a sound wave hits a hard surface, it bounces back and reaches our ears as an echo.
3. The time taken for the sound to travel to the surface and back can be used to determine the distance to the surface.

For an echo to be perceived as distinct from the original sound, there needs to be a minimum time delay, typically around 0.1 seconds. This corresponds to a minimum distance of about 17 meters (56 feet) between the source and the reflecting surface. If the distance is shorter, the reflected sound may blend with the original sound, making the echo indistinguishable.

Formula for calculating distance:

$$Distance = \frac{speed\ of\ sound \times time\ delay}{2}$$

Activity 7.18 Creating and Measuring Echoes

Objective: create an echo by clapping your hands or using a whistle near a wall or in a large open space. You will listen for the reflected sound and use the speed of sound in air to calculate the distance to the reflecting surface.

Materials Needed

1. Open space with a wall or large flat surface (e.g., gymnasium, playground)
2. Stopwatch (or a timer on your phone)
3. Whistle (optional, if you prefer not to clap)
4. Paper and pen/pencil (for recording measurements and calculations)

What to do

1. Locate an open space where you can safely make sounds without disturbing others. Ensure there is a wall or large flat surface nearby to create an echo.
2. Stand at a distance of about 10-15 meters from the wall. Clap your hands loudly or blow the whistle towards the wall. Make sure to face the wall while doing this.
3. After making the sound, listen carefully for the echo. The echo is the sound that reflects off the wall and returns to you.
4. Use a stopwatch or timer to measure the time it takes from when you make the sound until you hear the echo. Start the timer when you clap or whistle and stop it as soon as you hear the echo. Record this time in seconds.
5. Use the formula for calculating distance based on the speed of sound:

   $$Distance = speed \times time$$

   - The average speed of sound in air is approximately 343 meters per second (m/s). However, since the sound travels to the wall and back, you need to divide your recorded time by 2 before using it in your calculation:

     $$Distance\ to\ wall = \frac{speed\ of\ sound \times time\ delay}{2}$$

6. Substitute your values into the formula. If your recorded time is t seconds:

   $$Distance\ to\ wall = \frac{342\ m/s \times t}{2}$$

7. Create a table in your notes to organise your measurements:

Trial	Time Recorded (s)	Distance to Wall (m)
1		
2		
3		

8. Repeat steps 2-6 for increasing distances to get different time recordings.
9. After completing your calculations, discuss with classmates what you observed about echoes. Consider questions such as:
   a. How did changing your distance from the wall affect the echo?
   b. Were there any differences in clarity or timing based on how loudly you clapped or whistled?

Activity 7.19 Exploring Echolocation and Its Applications

Objective: watch a video of a blind person using echolocation to navigate their environment and engage in a group discussion about how echolocation works, its applications in nature, and its relation to ultrasound, audio sound, and infrasound.

Materials Needed

1. Access to a computer or device with internet access
2. Access to the video: Human Echolocation - Daniel Kish (3:41 minutes)
3. Paper and pens/pencils (for taking notes)
4. Reference materials (textbooks or online resources) for definitions of ultrasound, audio sound, and infrasound (optional)

What to do

1. Gather your group and watch the video titled "Human Echolocation - Daniel Kish." Pay close attention to how Daniel uses echolocation to navigate his surroundings.
2. After watching the video, discuss the following questions with your group:
   a. How does echolocation work? What sounds does Daniel make, and how do they help him "see" his environment?
   b. What are some other applications of echolocation that you know of? Can you think of any animals that use echolocation?
   c. Discuss whether humans can hear the sounds made by animals that use echolocation.

3. Research and share examples of animals that use echolocation, such as bats, dolphins, and certain species of birds.
4. Discuss how these animals utilise echolocation for navigation and hunting.
5. As a group, research the following terms:
   a. **Ultrasound:** Sound waves with frequencies above the audible range for humans (above 20 kHz).
   b. **Audio Sound:** Sound waves within the audible range for humans (approximately 20 Hz to 20 kHz).
   c. **Infrasound:** Sound waves with frequencies below the audible range for humans (below 20 Hz).
6. Discuss how these types of sound relate to echolocation and how they are used in various technologies (e.g., medical imaging with ultrasound).
7. Take notes during your discussion, recording key points about how echolocation works, its applications, and the definitions of ultrasound, audio sound, and infrasound.
8. Summarise your findings as a group. Reflect on what you learned about echolocation and its significance in both nature and technology.

Resonance and Speed of Sound

Resonance occurs when an object vibrates at its natural frequency due to an external force. This phenomenon can be used to determine the speed of sound in air.

Activity 7.20 Exploring Sound Vibrations Through Humming

Objective: To explore how sound vibrations are produced in the body by humming or making simple sounds. You will feel the vibrations in your throat and discuss how changes in pitch and volume affect these vibrations.

What to do

1. Sit or stand comfortably, ensuring you have enough space around you to focus on this activity.
2. Gently place your hands on your neck, specifically over your throat (oesophagus area). Make sure your fingers are lightly touching the skin.

3. Take a deep breath and hum or produce a simple sound like "ah" or "oo." Focus on the sensation of the vibrations as you make the sound.
4. Experiment by changing the pitch of your hum (higher or lower) while keeping your hands on your throat. Notice how the vibrations feel different.
5. Next, change the volume of your sound (louder or softer) and observe any changes in the intensity of the vibrations you feel.
6. After you have experimented with different sounds, take a moment to reflect on what you felt during the activity.
7. Gather with your classmates to discuss your observations. Consider the following questions:
   a. **What did you notice about the vibrations when you changed the sound?**
      i. Discuss how different pitches and volumes affected the intensity and quality of the vibrations you felt.
   b. **How do you think this relates to how we produce different sounds when speaking or singing?**
      i. Explore how our vocal cords and throat contribute to producing various sounds and how changes in pitch and volume occur.
8. As a group, summarise what you learned about sound vibrations and their relationship to speech and singing.

$$Distance = speed \times time$$

$$Distance\ to\ wall = \frac{speed\ of\ sound \times time\ delay}{2}$$

$$Distance\ to\ wall = \frac{342\ m/s \times t}{2}$$

Activity 7.21 Measuring the Speed of Sound in Air Using a Resonance Tube or Video

Objective: Determine the speed of sound in air using a resonance tube experiment.

Materials Needed

If using a Resonance Tube

1. Resonance tube
2. Water (to fill the resonance tube)

3. Tuning forks of known frequencies (e.g., 256 Hz, 512 Hz)
4. Meter stick or measuring tape
5. Rubber pad (optional, for stability)

If using a Video

6. Access to a computer or device with internet access
7. Video demonstrating the speed of sound using a resonance tube (e.g., Speed of Sound Experiment)

What to do

Option 1: Using a Resonance Tube

1. Set up the resonance tube**.** Ensure the resonance tube is vertical and stable. Fill it partially with water, leaving enough air space at the top.

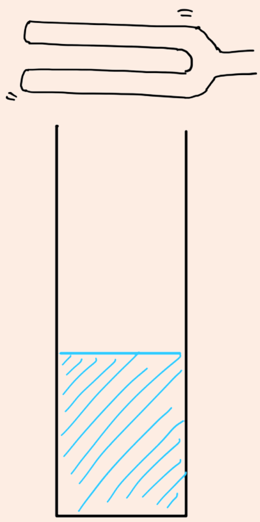


Figure 7.13: Experimental set up

2. **Strike the Tuning Fork**
   - **a.** Take one of the tuning forks and strike it against a rubber pad or hard surface to produce sound.
   - **b.** Hold the vibrating tuning fork just above the open end of the resonance tube.
3. **Find Resonance**
   - **a.** Slowly adjust the water level in the tube by adding or removing water until you hear the loudest sound (resonance). This indicates that the length of air column corresponds to a resonant frequency.

b. Measure and record the length of the air column at resonance (let's call this l_1).

4. Repeat steps 2 and 3 for different tuning forks to find additional resonance lengths (l_2, l_3, etc.).

5. For each tuning fork, calculate the wavelength (λ) using:

$$v = 4l_n$$

where l_n is the length of the air column at resonance.

6. **Calculate Speed of Sound**

a. Use the formula:

$$v = f\lambda$$

where f is the frequency of the tuning fork and v is the speed of sound.

b. Record your calculations in a table:

Tuning Fork Frequency (Hz)	Length of Air Column (m)	Wavelength (m)	Speed of Sound (m/s)

Option 2: Watching a Video

1. **Watch the Video**

a. Find and watch a video demonstrating how to measure the speed of sound using a resonance tube.

b. Pay attention to how they set up the experiment, find resonance, and measure distances.

2. While watching, take notes on key steps shown in the video, including how they calculate wavelength and speed.

3. **Calculate Speed of Sound Based on Observations**

a. If specific frequencies and lengths are mentioned in the video, use those values to calculate speed using:

$$v = f\lambda$$

Activity 7.22 Exploring Sound Production with Musical Instruments

Objective: Explore how sound is produced using various local musical instruments.

Materials Needed

1. Access to local musical instruments (e.g., drums, percussion instruments, flutes, horns, stringed instruments) available within your community or at home
2. Paper and pens/pencils (for taking notes)
3. Space to play the instruments comfortably

What to do

1. Organise yourselves into groups of no more than five. Discuss among your group members and select a variety of local musical instruments available. Each group should aim to include at least one of each type: percussion (e.g., drums), wind (e.g., flute, horns), and stringed instruments.
2. Each group should take turns exploring how each one produces sound. For each instrument, consider the following:
   - **a. Drums/Percussion**
     - **i.** How is sound produced? (e.g., by striking the surface)
     - **ii.** What happens to the drumhead when it is hit?
   - **b. Flute/Horns**
     - **i.** How is sound produced? (e.g., by blowing air through the instrument)
     - **ii.** How does changing your breath or finger placement affect the pitch?
   - **c. Stringed Instruments**
     - **i.** How is sound produced? (e.g., by plucking or bowing the strings)
     - **ii.** How does tension or length of the string affect the sound?
3. Each group member should take turns demonstrating how their chosen instrument produces sound. Pay attention to how the instrument works and what changes occur when you modify your playing technique.

4. After each demonstration, discuss as a group:
   a. What mechanisms are involved in producing sound for each type of instrument?
   b. How do different materials and shapes of the instruments influence the sound quality?
5. As a group, discuss how sound travels as a longitudinal wave:
   a. In longitudinal waves, particles of the medium move parallel to the direction of wave propagation.
   b. Discuss how this relates to sound traveling through air (or other media) when instruments are played.
   c. Explore examples of how sound waves compress and rarefy as they travel.
6. Take notes on your findings regarding how different instruments produce sound and how this relates to the nature of sound waves.

ADDITIONAL READING MATERIALS

1. Halliday, D., Resnick, R., & Walker, J. (2018). *Fundamentals of Physics* (11th ed.). Wiley. Comprehensive resource on wave motion and sound.
2. Serway, R. A., & Jewett, J. W. (2019). *Physics for Scientists and Engineers with Modern Physics* (10th ed.). Cengage Learning. Detailed explanation of wave properties and equations.
3. Tipler, P. A., & Mosca, G. (2022). *Physics for Scientists and Engineers* (7th ed.). Macmillan. Insights on sound waves and resonance phenomena.
4. Hecht, E. (2016). *Optics* (5th ed.). Pearson. Explores wave behavior like diffraction, reflection, and interference.
5. Giancoli, D. C. (2015). *Physics: Principles with Applications* (7th ed.). Pearson. Simplified explanations suitable for introductory wave concepts.
6. Young, H. D., & Freedman, R. A. (2020). *University Physics with Modern Physics* (15th ed.). Pearson. Advanced wave mechanics and sound wave applications.
7. Walker, J. S. (2019). *Physics* (6th ed.). Pearson. Discussion on wave propagation and sound properties.

REVIEW QUESTIONS

Review questions 7.1

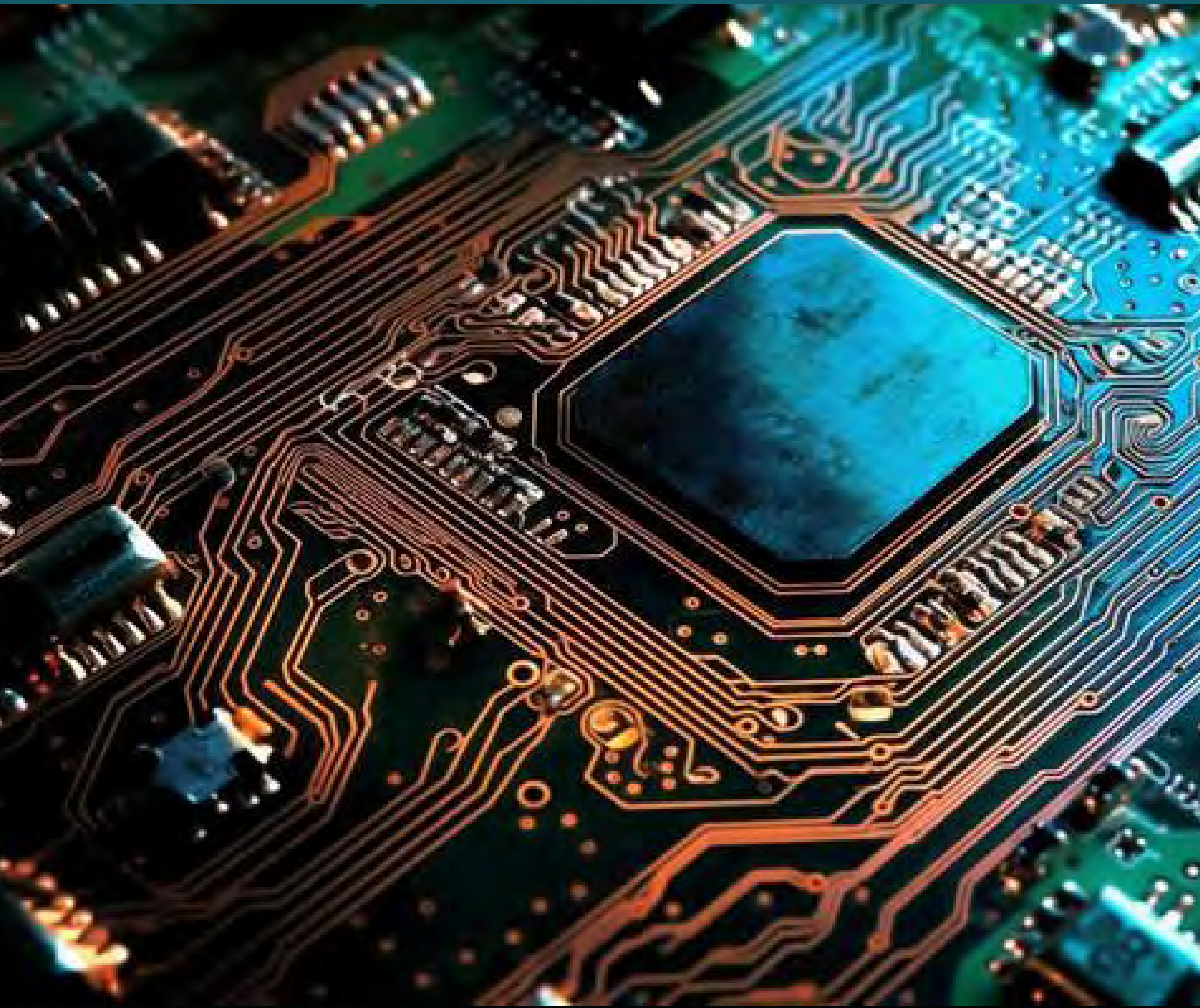
1. Define the following terms:
   a. Amplitude
   b. Frequency
   c. Period
   d. Wavelength
2. A wave is described by the equation: $y(x,t) = 0.05sin(400t - 2x)$. Using this equation, determine the following parameters of the wave:
   a. The amplitude of the wave.
   b. Angular frequency (ω).
   c. Wave number (k).
   d. Wavelength (λ).
   e. Frequency (f).
   f. Period (T).
   g. Wave velocity (v).
   h. The direction of wave propagation.
3. The amplitude of a transverse wave on a string is 0.02 m, and its frequency is 50 Hz. The speed of the wave is 10 m/s.
   a. Find the wavelength of the wave.
   b. Write the wave equation.
   c. Calculate the displacement at $x = 3\ m\ and\ t = 0.2\ s$.
   d. Sketch the waveform on a
      i. displacement-time graph
      ii. displacement-position graph

Review questions 7.2

1. State the range of frequencies for infrasound, audible sound, and ultrasound.
   a. Infrasound
   b. Audible sound
   c. Ultrasound
2. Define resonance in the context of sound waves.
3. Why can sound not travel through a vacuum?
4. In what way does the resonance method provide an accurate determination of the speed of sound in air?

SECTION

8 ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS



ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Digital Electronics

INTRODUCTION

This section explores the foundational principles of digital electronics, emphasising the distinction between analogue and digital signals. You will examine the characteristics, advantages, and limitations of each signal type, along with the processes of analogue-to-digital (ADC) and digital-to-analogue (DAC) conversion. Practical applications of these processes are highlighted to bridge theoretical concepts with real-world usage. The section further introduces binary systems and logic gates, which form the backbone of digital circuit design, guiding you in creating truth tables and deriving Boolean expressions. The structure, operation, and applications of 7-segment displays are also discussed. Hands-on activities focus on the design and construction of digital circuits using combinational logic and microcontrollers like Arduino, equipping you with the skills to address community challenges. This holistic approach integrates theory, problem-solving, and practical implementation to deepen understanding and foster innovation in digital electronics.

KEY IDEAS

1. **Analogue and Digital Signals**:
   - Analogue signals are continuous and vary smoothly over time.
   - Digital signals are discrete, making them less prone to noise.
2. **Signal Conversion**:
   - **ADC (Analogue-to-Digital Conversion)** involves sampling, quantisation, and encoding to convert analogue data into a digital format.
   - **DAC (Digital-to-Analogue Conversion)** reverses the process, reconstructing a continuous signal from digital data.

3. **Binary Systems and Logic Gates**:
   - Binary systems use 0s and 1s to perform operations.
   - Logic gates like AND, OR, and NOT perform specific operations based on binary inputs and outputs.
4. **7-Segment Displays**:
   - Composed of 7 LEDs (segments) arranged to form numbers or simple characters.
   - Used in devices like clocks and calculators to display numeric data.
5. **Boolean Notation**:
   - Boolean expressions represent logical operations.
   - Truth tables help derive these expressions and simplify circuit designs.
6. **Combinational Circuits and Microcontrollers**:
   - Combinational circuits use logic gates to produce outputs based only on current inputs.
   - Microcontrollers like Arduino integrate computing functions to control embedded systems for tasks like automation.

ANALOGUE AND DIGITAL SIGNALS

Communication occurs in various ways between humans. Similarly, in electronic and other systems, information is exchanged between different components to ensure the system operates effectively. This exchange of information is carried out through entities known as signals, which can represent various forms of data, such as voltage, current, or other physical quantities.

Signals can be classified as ‘analogue’ or ‘digital’:

Analogue Signals

Analogue signals are continuous and vary smoothly over time. They represent all possible values between two defined boundaries or extremes. For example, consider an analogue weighing scale with its pointer at 5 kg. As you add a little more mass, the pointer moves to, say, 7 kg. During this movement, the pointer would pass through countless intermediate values, regardless of how quickly or slowly it moved. This demonstrates the continuous range of masses from 5 kg to

7 kg. An analogue signal is a continuous signal that varies smoothly over time, representing information through variations in amplitude, frequency, or phase.

Characteristics

Continuous Nature: Analogue signals have an infinite number of possible values within a range.

Examples: Sound waves, light intensity, temperature variations, electric current and voltage.

Representation: Analogue signals are represented as a smooth waveform, such as a sine wave.

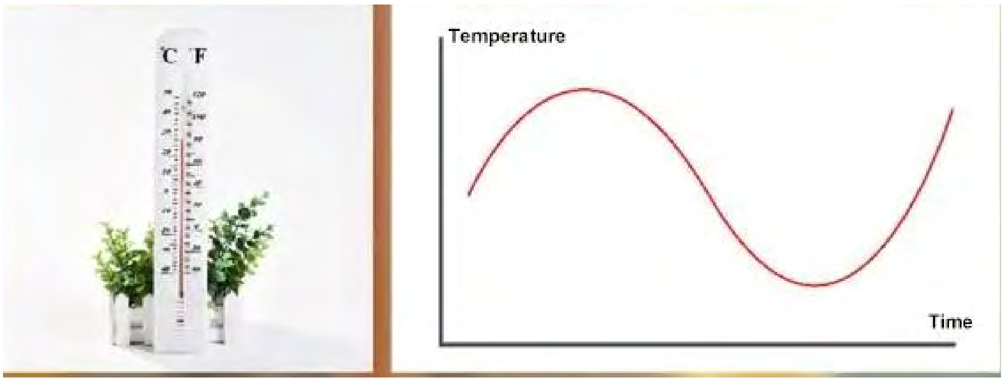


Figure 8.1: The continuous curve of temperature to time

Devices that operate using analogue signals include liquid thermometers, voltmeters, ammeters, energy meters, weighing scales, etc.

Newer versions of the devices mentioned above operate on digital signals. Let's now consider what digital signals are.

Digital Signals

Digital signals are represented in the form of digits, specifically zeros (0) and ones (1). These digits correspond to the off and on states of the signal, respectively, without any intermediate values. Digital signals are described as discrete, meaning they transition between specific states, ignoring all intermediate possibilities.

For example, on a digital weighing scale calibrated to the nearest whole number, the mass of a substance in the scenario above would increase directly from 5 kg to 6 kg, and then to 7 kg. The scale would not display any intermediate values between 5 and 6 or between 6 and 7 kg, highlighting the discrete nature of digital signals.

Characteristics

Discrete Nature: Digital signals have distinct levels, typically two (high and low or 1 and 0).

Examples: Computer data, digital audio, and video files.

Representation: A square waveform that alternates between discrete levels.

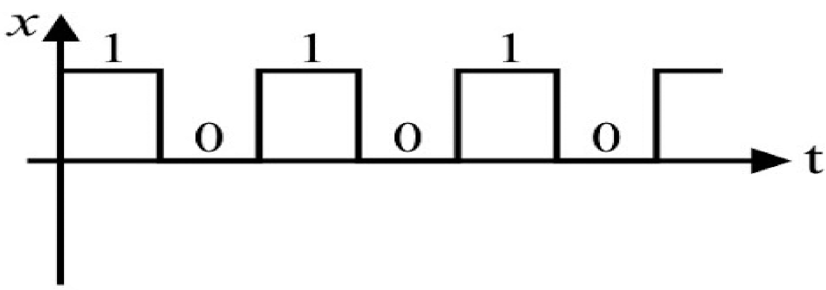


Figure 8.2: A digitised signal which can take the value of 0 or 1

Devices that operate on digital signals are computers, smartphones, and modern television sets. Digital signals are less affected by noise and can be transmitted over long distances with minimal degradation.

Activity 8.1 Video about Analogue and Digital Signals

Watch the video linked below to learn more about the difference between analogue and digital signals. Click here

Activity 8.2 Think-Pair-Share on Analogue and Digital Signals

Objective: Analyse the advantages and disadvantages of analogue and digital signals by discussing specific prompts in pairs and sharing insights with the class.

Materials Needed

Paper and pens for notes

What to do

1. Form pairs with a partner. Each pair will discuss the prompts together.
2. Each pair should use the following discussion prompts:
   a. **Storage:** Compare how analogue and digital signals are stored.
   b. **Noise:** Discuss how each type of signal is affected by noise during transmission.
   c. **Bandwidth:** Evaluate the bandwidth requirements for both analogue and digital signals.
3. Individually, take a few minutes to think about each prompt. Write down your initial thoughts regarding the advantages and disadvantages of both signal types related to the prompts.
4. Discuss your thoughts with your partner. Make sure to cover:
   d. What advantages does each type of signal have regarding the prompt?
   e. What disadvantages does each type of signal face?
5. Take notes on key points from your discussion that you find most compelling or interesting.
6. After discussing in pairs, come together as a larger group. Each pair will share one key insight or conclusion from their discussion regarding each prompt.
7. As pairs share, take notes on different perspectives and insights provided by others.

Binary Number Systems and Conversion

Number systems are ways of representing and working with numbers. The features that define how a particular number system works include:

1. **Digits**: the unique symbols used in the number system.
2. **Place value:** It is the position of a digit in a number, which determines its value in the number.
3. **Maximum numbers**: The highest quantity you can represent with a given number of digits.

Radix or Base of a Number System

This is the number of unique symbols/digits used in a particular number system, e.g., Base 10, base 2, etc.

Decimal system: The popular decimal system we use every day has a base of 10 because it uses 10 digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9.

In the decimal system, numbers greater than 9 are written by combining digits.

For example: After 9 comes 10 (adding a second digit).

The sequence continues (10, 11, 12…19) until the second digit changes to 2 (20, 21, etc.).

This process repeats for higher numbers, such as moving from 99 to 100.

Binary system: The binary system has a base of 2 because it uses only 2 digits: 0 and 1.

In the binary system, the same principle applies, but with only 0 and 1:

After 1 comes 10, then 11, followed by 100, 101, and so on.

For example, the first 16 binary numbers are:

0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, 1111.

After 1111 comes 10000, which has 5 digits.

Place Values

The place value of a digit depends on its position.

Decimal system: In the decimal system, the place values are powers of 10: $10^0, 10^1, 10^2$, and so on.

For example: In decimal, the number 123 means $(1\times10^2)+(2\times10^1)+(3\times10^0)$

Binary system: In the binary system, the place values are powers of 2: 2^0, 2^1, 2^2, and so on.

In binary, the number 101 means $(1\times2^2)+(0\times2^1)+(1\times2^0)$

The number of unique combinations you can create depends on the number of digits.

For example: 4 binary digits can create $2^4=16$ unique numbers, from 0 to 1111. Generally, n binary digits can generate a maximum of 2^n possible binary numbers.

Activity 8.3 Converting between decimal and binary number systems

Study the worked examples below before attempting the example questions that follow.

Worked Example 1

Convert 27 to a binary number.

Solution

Step 1: Divide the base 10 number (here it's 27) by 2, recording the quotient and the remainder.

Repeat the division with the quotient until it becomes 0.

$\frac{27}{2} = 13$, *remainder* 1

$\frac{13}{2} = 6$, *remainder* 1

$\frac{6}{2} = 3$, *remainder* 0

$\frac{3}{2} = 1$, *remainder* 1

$\frac{1}{2} = 0$, *remainder* 1

Step 2: Write the remainders from bottom to top to get the binary representation.

11011

Worked Example 2

Convert 35 to binary

Solution

Step 1: divide 35 by 2 repeatedly, keeping the remainders, until the last quotient is zero

$\frac{35}{2} = 17$, *remainder* 1

$\frac{17}{2} = 8$, *remainder* 1

$\frac{8}{2} = 4$, *remainder* 0

$\frac{4}{2} = 2$, *remainder* 0

$\frac{2}{2} = 1$, *remainder* 0

$\frac{1}{2} = 0$, *remainder* 1

Step 2: write the remainders from bottom to top

100011

Worked Example 3

Convert 11011_2 to a decimal.

Solution

Step 1: write down the base 2 number.

11011

Step 2: assign powers of 2 to each digit from right to left in a decreasing order.

$1 \times 2^4 \ = \ 161 \times 2^3 \ = \ 80 \times 2^2 \ = \ 01 \times 2^1 \ = \ 21 \times 2^0 \ = \ 1$

Step 3: add the results, and the sum is the base 10 number.

$16 + 8 + 0 + 2 + 1 \ = \ 27$

Worked Example 4

Convert 100011_2 to decimal

Solution

Step 1: write down the base 2 number

100011

Step 2: assign powers of 2 to each digit from right to left in a decreasing order of.

$1 \times 2^5 \ = \ 320 \times 2^4 \ = \ 00 \times 2^3 \ = \ 00 \times 2^2 \ = \ 01 \times 2^1 \ = \ 21 \times 2^0 \ = \ 1$

Step 3: add the results, and the sum is the base 10 number.

$32 + 0 + 0 + 0 + 0 + 2 + 1 \ = \ 35$

Practice Problems

Now, using the worked example as a guide, solve the following problems individually or in groups

1. Convert the following numbers to binary numbers
   a. 12
   b. 25
   c. 33
   d. 46
   e. 57
2. Convert the following binary numbers to decimals
   a. 1101
   b. 10010
   c. 11111
   d. 11000
   e. 101100
   f. 1000101

Signal Conversion

Analogue-to-digital Conversion (ADC)

This process is essential for modern electronics and communication systems. It makes possible the processing and transmission of analogue information in a digital form. ADC involves the three key steps below:

1. **Sampling**

   This is the first step of ADC. It involves measuring the value of an analogue signal at regular time intervals.

   The rate at which the signal is sampled is called the sampling rate or sampling frequency, measured in Hertz (Hz). Sampling a continuous analogue signal yields a series of discrete values.
2. **Quantisation**

   It is the process of matching the sampled signal values to a finite set of discrete levels. Each sampled value is rounded to the nearest available level.

The difference between the actual analogue value and the quantised value is called the quantisation error.

The sampled values are approximated into discrete amplitude levels.

3. **Encoding**

After quantising analogue signals, they must be converted into zeros and ones (0 and 1), also known as the binary code. This process is called encoding.

Each quantised level is assigned a unique binary code, and these codes represent the digital signal which can now be processed, stored or transmitted.

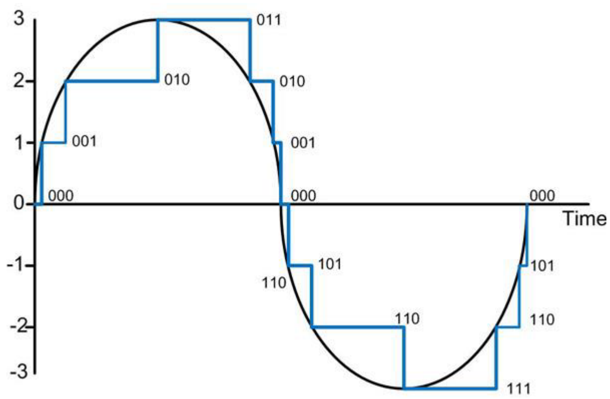


Figure 8.3: Analogue signal being digitised

Applications of ADC:

1. Audio recording and playback (e.g., CDs, MP3s)
2. Digital communication (e.g., mobile phones, the Internet)
3. Signal processing in electronic devices (e.g., sensors, microcontrollers)

Digital-to-analogue Conversion (DAC)

It is necessary to convert digital signals back to analogue signals in many practical applications because most real-world systems and devices operate in the analogue domain.

The three key steps involved in DAC are reconstruction, filtering, and amplification:

1. **Reconstruction**

Here, the digital signal, represented by discrete binary values (0 and 1), is converted into a sequence of pulses or steps.

The binary values from the digital signal are used to generate corresponding voltage levels or currents. Each level corresponds to a specific digital value.

2. **Filtering (Smoothing)**

   The output in steps or levels from the reconstruction phase is smoothed to create a continuous analogue waveform. This is achieved using a low-pass filter. Low pass means the filter allows low frequencies to pass through while blocking high-frequency components introduced by the discrete nature of the digital signal.

   After this step, the new analogue signal closely resembles the original signal before digitisation.

3. **Amplification (Optional)**

   In some instances, the reconstructed analogue signal may require boosting / intensification to achieve the desired strength for output or further processing. The amplitude of the new analogue signal is then adjusted accordingly to match the requirements of the connected analogue system (e.g., speakers, and displays).

Comparison of Analogue and Digital Signals

	Analogue Signal	Digital Signal
Nature	Continuous	Discrete
Representation	Smooth waveforms	Square waveforms
Noise Susceptibility	High	Low
Storage & Processing	Complex	Easy
Transmission Quality	Degrades with distance	Maintains quality
Examples	Radio waves, sound waves	Computer data, digital TV

Example: Suppose you are playing an MP3 file on a digital music player:

1. The binary data from the MP3 file is sent to a DAC.
2. The DAC generates a stepped analogue voltage corresponding to the binary values.
3. A low-pass filter smoothens the stepped voltage into a continuous analogue audio signal.
4. An amplifier boosts the signal strength before sending it to the speakers.

Applications:

a. Audio recording and playback (e.g., CDs, MP3s)

b. Digital communication (e.g., mobile phones, the Internet)

c. Signal processing in electronic devices (e.g., sensors, microcontrollers)

Activity 8.4 Video of a Microphone Signal Being Converted

Watch the video below to understand more about how analogue signals, such as those from microphones, are converted to digital signals. Click here

If possible, use a real microphone an oscilloscope or audio editing software to show the waveform produced when a person whistles into the microphone. Complete activity 8.5 in order to understand how this signal could be digitised.

Activity 8.5 Sampling on a Simulation

Exploring Sampling and Quantisation Using Digital Simulations

Objective: Work in small groups to explore how analogue signals are sampled and quantised into digital signals using digital simulation tools.

Materials Needed

1. Access to Computers or Devices (computers, tablets, or smartphones).

2. Digital Simulation Resources (The Input Devices and Music Interaction Laboratory (IDMIL) Digital Audio Workbench (DAWb)) - Scan this QR Code:

3. Paper and Pens/Pencils

What to do

1. Organise yourselves into small groups of 3–5.
2. As a group, decide on the specific aspects of sampling and quantisation you want to investigate. Consider:
   a. Definitions and importance of sampling rate and bit depth.
   b. Effects of changing the sampling rate (e.g., 8 kHz, 22 kHz, 44 kHz, and higher).
   c. Effects of changing bit depth (e.g., 8-bit, 16-bit, 24-bit) on the quality of digital signals.
3. Divide the research tasks clearly amongst your group. For example, one member may research definitions and functions of sampling and quantisation, while another investigates how the sampling rate affects the quality of the digital signal, and one explores the impact of bit depth changes on digital signal quality, others may identify real-world applications where sampling and quantisation are essential.
4. Use the provided simulation tools to gather information about sampling and quantisation. Adjust parameters such as sampling rate and bit depth, noting the observed changes. Take detailed notes on your observations, including visual diagrams or screenshots from the simulation.
5. Organise the information gathered into clear sections for your presentation:
   a. Title slide with group members' names.
   b. Overview and definitions of sampling and quantisation.
   c. Effects of sampling rate on signal quality (with examples from simulations).
   d. Effects of bit depth on signal quality (with examples from simulations).
   e. Real-world examples/applications of sampling and quantisation.
   f. Conclusion summarising your findings and recommendations.
6. Use diagrams or screenshots from the simulations to illustrate how sampling and quantisation affect analogue-to-digital signal conversion.
7. Present your group's findings to the class using the format described above for discussion and feedback.

Activity 8.6 Investigating Sampling and Quantisation Using Musical Instruments

Objective: Work in small groups to practically explore how sampling rate and bit depth affect analogue-to-digital conversion using musical instruments and audio editing software.

Materials Needed

1. Musical Instruments: Guitar, keyboard, drum, flute, or other available instruments.
2. Recording Device: Smartphones, tablets, or laptops capable of recording audio.
3. Audio Editing Software: Audacity (free audio editing software)
4. Paper and Pens/Pencils

What to do

1. Organise yourselves into small groups of 3-5.
2. As a group, select one musical instrument you will use for your demonstration. Consider the following for your investigation:
   a. How sampling rate affects audio quality (clarity, fidelity, and distortion).
   b. How bit depth influences the quality and noise level of the digital signal.
   c. Practical examples demonstrating the differences.
3. Divide tasks clearly in your group. For example.
   a. One member may record a short music clip (10–15 seconds) using the chosen instrument.
   b. Another member may use Audacity to investigate the effects of changing sampling rates (44,100 Hz, 22,050 Hz, 11,025 Hz, 8,000 Hz).
   c. While one member examines how changing bit depths (8-bit, 16-bit, 24-bit) affects audio quality.
   d. Additional members may document observations and findings for presentation.
4. Use Audacity software to modify your recording's sampling rate and bit depth settings. Listen carefully to each resulting clip and document

noticeable changes in audio quality. Include specific examples, observations, and differences noted.

5. Organise the information gathered into the following sections for your group presentation:
   a. Title slide with group members' names.
   b. A brief overview of sampling and quantisation.
   c. Effects of varying sampling rates demonstrated through your recorded audio samples.
   d. Effects of changing bit depths shown through audio examples.
   e. Practical observations about how these digital audio processes relate to real-world music production and listening experiences.
   f. Conclusion summarising your findings.
   g. Use audio examples, screenshots from Audacity, and visual diagrams to illustrate how sampling and quantisation affect audio quality.
6. Present your group's findings to the class, following the structured format above, for feedback and discussion.

Activity 8.7 Sketching Analogue Signals and Converting to Digital Signals

Objective: Sketch an analogue signal onto graph paper, convert it into a digital signal using a specified sampling rate and coding method, and collaborate with peers to enhance your understanding of the conversion process.

Materials Needed

1. Graph Paper
2. Pencils or Pens
3. Ruler
4. Sample Analogue Signal Data below

Sample Analogue Signal Data (Voltage in Volts)

Time (s)	Voltage (V)
0	0.0
1	1.0
2	2.5
3	4.0
4	3.5
5	2.0
6	1.0
7	0.5
8	1.5
9	3.0
10	4.5

What to do

1. Take a piece of graph paper and set up your axes:

a. Label the x-axis from **0 to 10 seconds**.

b. Label the y-axis from **0 to 5V**.

2. Using the sample data provided, plot the voltage values against time on the graph paper.

3. Connect the points smoothly to illustrate the continuous nature of an analogue signal.

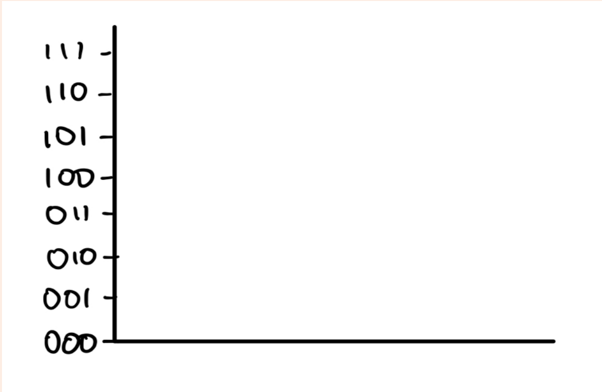
4. Once you have sketched your analogue signal, swap your graph with a friend in your group.

4. You will convert your friend's analogue signal into a digital one using a sampling rate of **2 Hz**. This means you will take samples of the analogue signal twice every second.

5. Mark the points on your friend's analogue signal at each second (0s, 0.5s, 1s, 1.5s ..., up to 10s).

6. Use **3-bit coding for your digital representation. This means you can represent values from 0 to 7 (since 2**^{3}=8 possible values). To convert each voltage reading into a digital value:

a. Divide the y-axis into 7 parts, labelling each step 000, 001, 010, 011… 111 as shown below.



b. Estimate which of these levels is closest to the y-value for each of the points that you have marked on your friend's signal.

7. Create a table showing:

a. Time (seconds)

b. Analogue Voltage (V)

c. Digital Value (3-bit binary)

Time (s)	Analogue Voltage (V)	Digital Value (3-bit)
0	0	000
0.5		
1		
1.5		
2		
2.5		
etc		

9. After completing the conversion, gather as a group to discuss:

a. What challenges did you face while sketching or converting the signals?

b. How did you determine the digital values from the analogue readings?

c. Why is it important to understand both analogue and digital signals in technology?

Activity 8.8 Creating a Poster Presentation on Conversion Processes (Analogue to Digital and Digital to Analogue)

Objective: Work in small groups to create a detailed poster presentation that explains the conversion processes between analogue and digital signals.

Materials Needed

1. Poster Board or Large Paper
2. Markers, Coloured Pencils, or Crayons:
3. Ruler:
4. Access to Research Materials:
   a. Textbooks, articles, or online resources on analogue and digital signals.
   b. Websites such as:
      i. Khan Academy: Analog vs. Digital
      ii. Wikipedia: Analog Signal
      iii. Wikipedia: Digital Signal
5. Examples of Analogue and Digital Signals: Images or graphs that illustrate different types of signals (e.g., sound waves for analogue, square waves for digital).

What to do

1. Organise yourselves into groups of no more than five.
2. Use textbooks, articles, and online resources to gather information about:
   a. The characteristics of analogue signals (continuous signals).
   b. The characteristics of digital signals (discrete signals).
   c. The process of converting an analogue signal to a digital signal (sampling, quantisation).
   d. The process of converting a digital signal back to an analogue signal (digital-to-analogue conversion).
   e. Real-world examples of both types of signals (e.g., audio signals, video signals).
3. Draw diagrams that illustrate:
   a. Examples of analogue signals (like sound waves).
   b. Examples of digital signals (like square waves).

   c. The conversion processes with labelled steps.
   d. Use arrows and labels to indicate how the conversion occurs.

4. Organise your findings into clear sections for the poster:
   a. Title
   b. Definitions of analogue and digital signals
   c. Example applications of both, for example analogue wristwatches and digital clocks
   d. Explanation of conversion processes (analogue to digital and vice versa)
   e. Diagrams illustrating the concepts
5. Plan how you want to arrange the information on your poster. Consider sections for each topic and ensure there is a logical flow. Use headings, bullet points, and visuals to make the information easy to read.
6. **Create the Poster:**
   a. Using your poster board or large paper, write out your sections clearly.
   b. Include diagrams and illustrations where appropriate.
   c. Use colours to highlight important points and make your poster visually appealing.
7. Each group will present their poster to the class. Explain each section clearly and engage with your audience by asking if they have any questions.

Activity 8.9 Discussing the Migration from Analogue to Digital Television

Objective: Discuss the real-world applications of analogue and digital signals, focusing on Ghana's migration from analogue to digital terrestrial television.

Materials Needed

1. Access to Research Materials: Articles or online resources about the migration from analogue to digital TV in Ghana, such as:
   - Ghana Migrated To DTT Before Deadline
   - Digital TV Switchover in Ghana: A Tale of Unfulfilled Ministerial Promises
   - Explained: Migrating To Digital TV (Ghana Edition)
2. Paper and Pens/Pencils:

What to do

1. Organise yourselves into groups of no more than five. .
2. As a group, research how Ghana migrated from analogue to digital terrestrial television. Focus on:
   - **a.** The timeline of the migration process.
   - **b.** The technology involved in digital broadcasting.
   - **c.** The benefits of digital over analogue television.
   - **d.** Challenges faced during the migration.
3. Each group member should prepare at least one point or question related to the migration process or the differences between analogue and digital signals. Consider discussing:
   - **a.** How did the migration affect viewers in Ghana?
   - **b.** What technological advancements facilitated this transition?
   - **c.** What were some challenges that consumers faced during the transition?
4. **Engage in Group Discussion**
   - **a.** Start a discussion within your group about your findings. Use your prepared points and questions to guide the conversation.
   - **b.** Encourage each member to share their thoughts and experiences regarding watching television on both analogue and digital devices.
   - **c.** Discuss any personal experiences you have had with transitioning to digital TV:
     - **i.** What differences did you notice in picture quality, sound, or channel availability?
     - **ii.** Did you face any challenges during this transition?
5. Discuss how an analogue television can receive digital TV content:
   - **a.** Explain concepts like digital-to-analogue converters (set-top boxes) that allow older TVs to display digital signals.
   - **b.** Reference information from reliable sources, such as:
     - **i.** Analogue televisions can receive digital television (DTV) signals by using a "Digital-to-Analogue Converter Box" that processes the signal for display on an analogue TV.
     - **ii.** Discuss how these converter boxes sample the incoming digital signal and convert it into an analogue format that can be displayed on older televisions.

PULL-UP AND PULL-DOWN RESISTORS

Digital logic gates are essential components of digital circuits, working with two logic states: high (1) and low (0). These states are represented by voltage levels, typically 0V for low (logic 0) and a higher voltage (e.g., +5V) for high (logic 1).

Unconnected Inputs and the Need for Resistors

When an input pin is left unconnected, it is said to be in a "floating" or high-impedance state. This means the pin does not have a definite logic level, making it susceptible to electrical noise. This noise can cause the input to fluctuate unpredictably between high and low states. Such behaviour can lead to erratic operation of the circuit, as the logic state of the floating input becomes unreliable.

For example, an unconnected pin on a microcontroller might randomly register as high or low, causing unintended or malfunctioning behaviour in the system.

Role of Pull-Up and Pull-Down Resistors

Pull-up and pull-down resistors solve this issue by forcing the floating pin to a defined logic state.

Pull-Up Resistor: Connects the input pin to a high voltage (e.g., +5V), ensuring the logic state is high (1) when the pin is not actively driven.

Pull-Down Resistor: Connects the input pin to 0V, ensuring the logic state is low (0) when the pin is not actively driven.

These resistors are crucial for stable and predictable digital circuit operation, especially when inputs are not directly controlled by another component.

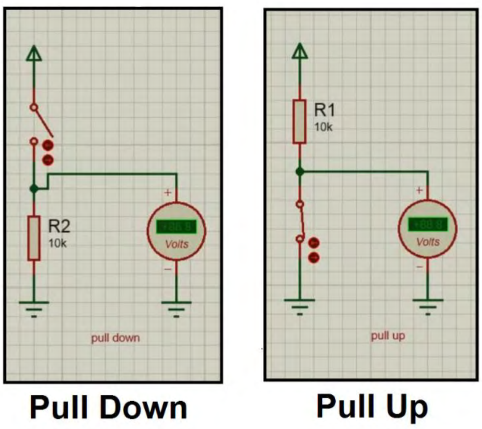


Figure 8.4: diagrams of pull down and pull up resistors

Activity 8.10 Video lesson on pull-up and pull-down resistors.

What to do

1. Form groups of four and carry out the following activities.
2. Use the QR scanner on your device to scan the code above.
3. Watch the video lesson for the first time.
4. Go over the video carefully, pausing and replaying portions to answer the following questions:
   a. Explain how the pull-down resistor functions in the circuit.
   b. Explain how the pull-up resistor functions in the circuit.
   c. Why are the resistors called pull-down or pull-up?
   d. What would happen if the data line is grounded directly without the resistor?
5. Search and watch other lessons on the applications of pull-up and pull-down resistors.
6. In turns, present your notes orally before the entire class, noting down new lessons learnt from other presentations.

Activity 8.11 Practical to build pull up and down resistors on breadboards

Materials Needed

- Breadboard
- Pull-up resistor (typically 10kΩ)
- Jumper wires
- Power supply (e.g., 5V or 3.3V, depending on your circuit)
- Switch or component to connect to the pull-up resistor (e.g., a button)

Instructions

1. **Place the Breadboard:** Set up your breadboard and ensure it is oriented with the power rails (usually marked with "+" and "-") on the sides for easy power connection.
2. **Connect Power**
   a. Connect the positive power rail (+) to your power supply (e.g., 5V).
   b. Connect the negative power rail (-) to your ground (GND).
3. **Place the Resistor**
   a. Insert one end of your 10kΩ resistor into an empty row on the breadboard.
   b. Insert the other end into another row, ensuring it's in a different line than the power and ground rails.
4. **Connect the Resistor to Power:** Use a jumper wire to connect the first end of the resistor (the one not already inserted) to the power rail (+).
5. **Connect the Output:** Insert a jumper wire into the same row as the second leg of the resistor. This will be your output node, where the pull-up will be applied.
6. **Add a Switch (optional):** If you want to use a button or switch to pull the output low, connect one end of the switch to the output node (where the resistor is connected) and the other end to the ground rail (-).
7. **Test the Circuit**
   a. When the switch is open (not pressed), the pull-up resistor will pull the output high (near the power supply voltage).
   b. When the switch is closed (pressed), it will connect the output to ground, pulling it low.
8. **Discussion**
   a. How does changing the resistor value affect the behaviour of the circuit?

The above activity could be performed using an online simulation tool such as the one linked below.

https://everycircuit.com/circuit/4978266532478976/pull-up-and-pull-down-resistors

Activity 8.12 Researching Real-World Applications of Pull-Up and Pull-Down Resistors

Objective: Work in small groups to research the real-world applications of pull-up and pull-down resistors in digital circuits.

Materials Needed

1. Access to Computers or Devices:
2. Research Resources: Articles and websites for information on pull-up and pull-down resistors:
   - Chipsmall: The Uses of Pull-Up and Pull-Down Resistors in Circuits
   - Circuit Digest: What is Pull Up and Pull Down Resistor?
   - Dr. Shashank M Gowda: Understanding Pull-Up and Pull-Down Resistors
   - Robu.in: What are Pull-up and Pull-down Resistors?
   - Andwin PCB: Uses of Pull-Up Resistors
   - Robocraze: Pull-Up vs Pull-Down Resistors
3. Paper and Pens/Pencils:

What to do

1. Organise yourselves into groups of no more than five
2. As a group, decide on specific aspects of pull-up and pull-down resistors you want to focus on. Consider:

- **a.** Definitions and functions of pull-up and pull-down resistors.
- **b.** Common applications in digital circuits (e.g., microcontrollers, I2C communication).
- **c.** How they prevent floating inputs and improve circuit stability.

3. The group members should divide the research tasks among themselves. Each member can focus on different aspects such as:

- **d.** One member researches definitions and basic functions.
- **e.** Another member looks into specific applications in digital circuits.
- **f.** A third member explores examples from real-world devices or systems.

4. Use the provided links to gather information about pull-up and pull-down resistors. Take notes on key points, definitions, examples, and any diagrams that illustrate concepts.

5. Organise the information gathered into clear sections for your presentation:

- Title slide with group members' names.
- Overview of pull-up and pull-down resistors.
- Functions and importance in digital circuits.
- Specific applications with diagrams or examples.
- Conclusion summarising your findings.

6. Use diagrams to illustrate how pull-up and pull-down resistors work in circuits. Include images or schematics from your research to enhance understanding.

7. Each group should present their findings to the class.

Activity 8.13 Pull Up or Pull Down resistor?

Choose the appropriate resistor for each scenario:

Scenario 1: You're designing a system where you have a push-button or switch that, when pressed, should send a LOW signal to the microcontroller (e.g., an Arduino or Raspberry Pi). The system should register a "pressed" state when the button connects the input to ground.

Scenario 2: You have a button or switch that, when pressed, should send a HIGH signal to the microcontroller. When the button is not pressed, the input should be at a default LOW state (grounded).

Scenario 3: You are using a communication protocol such as I2C or a digital bus where multiple devices share a line, and the line is actively pulled low by devices but not driven high. The devices only pull the line low when they need to send data.

Scenario 4: You have an unused input pin on a microcontroller that might float (undefined voltage) if left unconnected. You want to ensure it doesn't pick up stray noise or cause unpredictable behaviour.

Scenario 5: You are detecting the state of a door switch in a security system. The switch closes when the door is open and opens when the door is closed. You want to detect when the door is open by receiving a HIGH signal and when it's closed by receiving a LOW signal.

7-SEGMENT DISPLAY MODULE

A 7-segment display is a widely used electronic component for visualising or displaying numerical data in a straightforward and compact format.

Each segment is actually a Light Emitting Diode (LED), with an optional eighth LED for a decimal point. The seven diodes (segments) are labelled (commonly from 'a' to 'g'), and by selectively powering the appropriate segments, it can represent digits from 0 to 9 and some letters like A, b, C, d, E, and F.

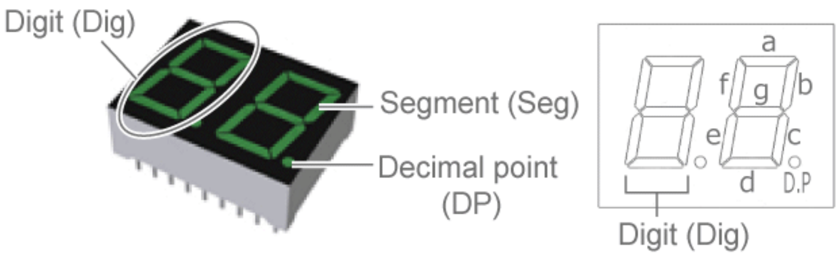


Figure 8.5: Parts of the 7-segment display LED parts

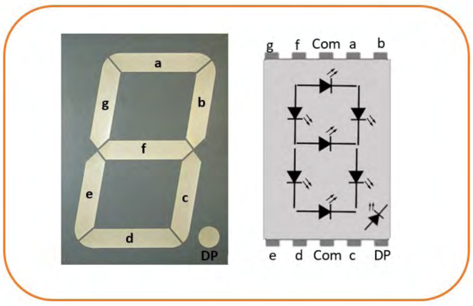


Figure 8.6: 7-Segment display decoder format

There are two types of 7-segment LED digital display:

Common Anode (CA) configuration: All the LEDs' anodes (positive terminals) are joined and connected to a positive supply. To operate a segment, its cathode is connected to ground.

Common Cathode (CC) configuration: Here all the cathodes (negative terminals) of the LEDs are joined. To operate a segment (LED), its anode is connected to a positive voltage supply.

Advantages:

1. Easy to control and use in circuits.
2. Bright and clear display for numerical information.
3. It can display numbers and some alphabetic characters.

Disadvantages:

1. It can only display a limited set of characters.
2. Each segment requires power, which can add up in larger displays.

Applications:

Some common applications include digital clocks, calculators, meters, counters and various household appliances like microwave ovens, washing machines and other appliances which have display settings and timers.

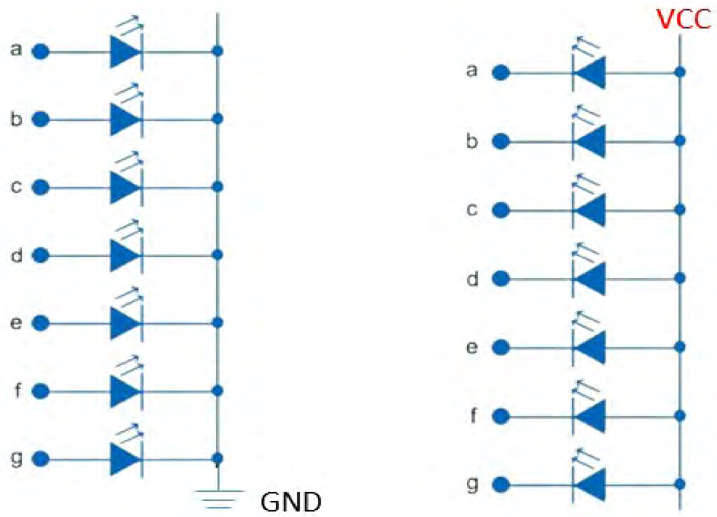


Figure 8.7: common cathode (left), and common anode (right)

Activity 8.14 Practical to build 7-segment display using breadboard

Materials Needed

- 7 LEDs
- 7 resistors (330Ω or 470Ω each)
- 1 Breadboard
- Jumper wires
- 1 Push button (optional, for control)
- 1 Common cathode or common anode wiring setup
- 1 9V battery or 5V power supply

Step 1: Understanding the Layout

A 7-segment display consists of 7 individual LED segments labelled **a, b, c, d, e, f, g** arranged as follows:

```
-- a --
|    |
f    b
|    |
-- g --
|     |
e    c
|    |
-- d --
```

Each LED represents a segment that will light up to form numbers (0-9) or some letters.

Step 2: Placing the LEDs on the Breadboard

1. Arrange 7 LEDs in the pattern shown above.
2. Make sure all the negative (cathode) legs of the LEDs are connected together if using a common cathode setup (connect to GND).
3. If using a common anode setup, all positive (anode) legs should be connected together (connect to +5V or +9V).

Step 3: Connecting Resistors

Each LED should have a 330Ω or 470Ω resistor in series to limit the current:

1. Connect one leg of each resistor to the positive (anode) of the LED if using common cathode.
2. Connect one leg of each resistor to the negative (cathode) if using common anode.
3. The other leg of each resistor connects to a control wire (which will later connect to a microcontroller or switch).

Step 4: Wiring the LEDs

1. Use jumper wires to connect each LED segment to its respective controlling pin.
2. Connect the output of each switch to a specific LED resistor.

Step 5: Testing the Setup

Press each switch to see if the correct LED lights up.

Step 6: Displaying Numbers

To display numbers, turn on the appropriate LEDs based on this truth table:

| Number | Segments ON |

| 0 | a, b, c, d, e, f |

| 1 | b, c |

| 2 | a, b, g, e, d |

| 3 | a, b, g, c, d |

| 4 | f, g, b, c |

| 5 | a, f, g, c, d |

| 6 | a, f, g, e, d, c |

| 7 | a, b, c |

| 8 | a, b, c, d, e, f, g |

| 9 | a, b, c, d

Activity 8.15 Simulation using 7-segment displays

Use the simulation linked below to observe the binary codes produced when different numbers and letters are illuminated using the 7-segment displays.

click here

Activity 8.16 Case Study Analysis of 7-Segment Displays in a Digital Clock

Objective: Analyse the design and implementation of 7-segment displays in a digital clock, discussing their advantages and limitations based on a provided case study.

Materials Needed

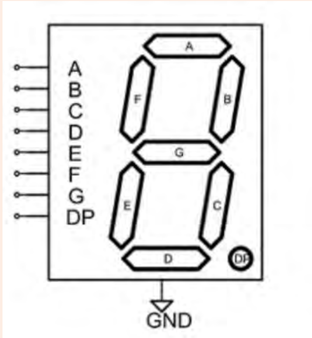
1. Case study document (provided below)
2. Paper and pens for notes
3. Presentation tools (e.g., poster board, markers, or digital presentation software)

Case Study: Digital Clock with 7-Segment Display

Digital clocks commonly use 7-segment displays to show the time. Each digit of the time is represented by a combination of illuminated segments. A typical digital clock displays hours and minutes in a format like HH:MM.

Design Features

1. **Structure of the 7-Segment Display**
   - **a.** Each digit consists of 7 segments arranged in a figure-eight pattern.
   - **b.** The segments are labelled as follows:



c. Each segment can be turned on or off to display the desired number.

2. **Operation**
   a. A microcontroller sends signals to each segment based on the current time.
   b. For example, to display "12:34", segments corresponding to '1', '2', '3', and '4' are activated in sequence.

3. **User Interface**
   a. The clock may include buttons for setting the time, usually located on the back or side.
   b. Some models have additional features like alarms or backlighting.

What to do

1. Organise yourselves into groups of no more than five.
2. Take a few minutes to read through the case study together.
3. In your group, discuss the following questions:
   a. How does the design of the 7-segment display enhance the usability of the digital clock?
   b. What are some specific examples from the case study that illustrate both advantages and limitations? See some suggested answers to this in Annex A.
   c. How might these limitations affect user experience?
4. Prepare Your Findings:
   a. Summarise your discussion points on paper.
   b. Prepare a short presentation that includes:
      iv. Key design features of the digital clock's 7-segment display.
      v. A list of advantages and limitations discussed in your group.
5. Each group should present their findings to the class.

Activity 8.17 Researching and Comparing 7-Segment Displays with Other Display Technologies

Objective: Work in small groups to research and compare 7-segment displays with other display technologies, such as LCDs and OLEDs.

Materials Needed

1. Access to Computers or Devices
2. Research Resources: Articles and websites for information on display technologies:
3. Paper and Pens/Pencils
   - Chipsmall: The Uses of Pull-Up and Pull-Down Resistors in Circuits
   - Circuit Digest: What is Pull Up and Pull Down Resistor?
   - Dr. Shashank M Gowda: Understanding Pull-Up and Pull-Down Resistors
   - Robu.in: What are Pull-up and Pull-down Resistors?
   - Andwin PCB: Uses of Pull-Up Resistors
   - Robocraze: Pull-Up vs Pull-Down Resistors

What to do

1. Organise yourselves into groups of no more than five
2. As a group, decide on specific aspects of 7-segment displays, LCDs, and OLEDs that you want to focus on. Consider:

a. Definitions and basic functions of each display type.
b. Key differences between 7-segment displays, LCDs, and OLEDs.
c. Common applications for each type of display technology.
d. Advantages and disadvantages of using each display type.

3. Use the provided links to gather information about 7-segment displays, LCDs, and OLEDs. Take notes on key points, definitions, examples, advantages, disadvantages, and any diagrams that illustrate concepts.

4. **Compile Your Findings**
   a. Overview of 7-segment displays, including how they work.
   b. Overview of LCD technology, including how it works.
   c. Overview of OLED technology, including how it works.
   d. Comparison table highlighting key differences (e.g., resolution, power consumption, applications).
   e. Situations where 7-segment displays are more suitable than other technologies (e.g., simple numeric displays in clocks or calculators).

5. **Engage in Group Discussion**
   a. Start a discussion within your group about your findings. Use your compiled information to guide the conversation.
   b. Discuss the advantages of using 7-segment displays in specific applications compared to LCDs or OLEDs:
      i. For example, consider scenarios like digital clocks or basic calculators where only numeric output is required.

6. **Explore Real-World Applications**
   a. Discuss real-world examples where each type of display is used:
      i. Where might you find a 7-segment display? (e.g., digital meters, speedometers)
      ii. Where are LCDs commonly used? (e.g., televisions, computer screens)
      iii. What about OLEDs? (e.g., smartphones, high-end TVs)

BASIC LOGIC AND UNIVERSAL GATES

In the previous lesson, you learnt about digitisation and binary numbers. In this lesson and subsequent ones, you will learn how these binary numbers are applied in digital circuits.

Binary Variables and Voltage Levels

In digital systems, binary variables represent two discrete states: **Logic '0'** and **Logic '1'**.

Types of Logic Systems

Positive Logic System: In a positive logic system, the higher voltage level represents logic '1', and the lower voltage level represents logic '0'.

This is the most commonly used logic system in modern electronics.

Negative Logic System: In a negative logic system, the higher voltage level represents logic '0', and the lower voltage level represents logic '1'.

Though less common, negative logic systems are used in some applications for convenience or compatibility.

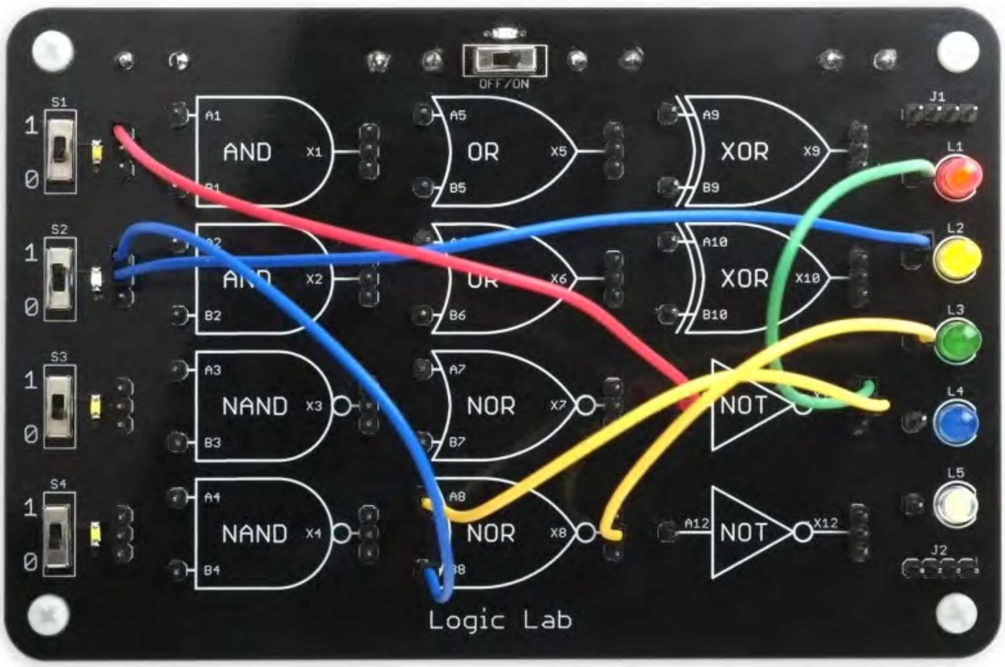


Figure 8.8: A microcontroller with logic gates

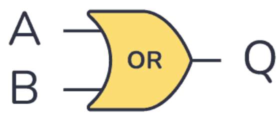
Truth Tables and Logic Gates

A logic gate is an electronic circuit designed to execute a set of instructions called logic. These gates form the basic building blocks of all digital systems, including computers. Each logic gate performs a specific operation based on one or more binary inputs (0s and 1s) to produce a single binary output.

The three fundamental logic gates are the OR gate, the AND gate, and the NOT gate:

- **a.** The OR gate produces a high output (1) if any of its inputs are high.
- **b.** The AND gate produces a high output (1) only if all of its inputs are high.
- **c.** The NOT gate inverts the input, producing the opposite binary state.
- **d.** The NAND gate (NOT AND) produces a high output (1) unless all inputs are high.
- **e.** The NOR gate (NOT OR) produces a high output (1) only when all inputs are low.

To understand how logic gates work, we use a truth table. A truth table is a tabular representation of all possible input combinations (voltage/current levels) and their corresponding outputs based on the logic implemented by the gate. Truth tables provide a clear and systematic way to visualise the behaviour of each gate under different input conditions. In general, for n binary inputs, a truth table will have 2^n rows, representing all possible input combinations.



A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

Figure 8.9: A diagram of the OR logic gate and its truth table

In the figure, A and B are the two inputs, and Q is the output of an OR logic gate. The OR gate operates based on the principle of logical addition, where the output Q is high (logic ‘1’) if either or both inputs are high. The output Q is low if both inputs are low (logic ‘0’).

The behaviour of the OR gate can be described using the equation: $Q=A+B$

The truth table is constructed by evaluating all possible combinations of inputs A and B:

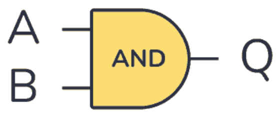
When $A=0$ and $B=0$, $Q=0$.

When $A=0$ and $B=1$, $Q=1$.

When $A=1$ and $B=0$, $Q=1$.

When $A=1$ and $B=1$, $Q=1$.

This demonstrates that the output Q is high whenever at least one of the inputs is high. The truth table shown in the figure provides a clear representation of this logic.



A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

Figure 8.10: A diagram of an AND logic gate and its truth table

In Figure 8.10, A and B are the two inputs, and Q is the output of an AND logic gate. The AND gate operates based on the principle of logical multiplication, where the output Q is high (logic '1') only if both inputs are high. If either or both inputs are low (logic '0'), the output Q will be low.

The behaviour of the AND gate can be described using the equation: $Q=A \cdot B$

The truth table is constructed by evaluating all possible combinations of inputs A and B:

When $A=0$ and $B=0$, $Q=0$.

When $A=0$ and $B=1$, $Q=0$.

When $A=1$ and $B=0$, $Q=0$.

When $A=1$ and $B=1$, $Q=1$.

This demonstrates that the output Q is high only when both inputs are high, which aligns with the logical AND operation. The truth table shown in the figure provides a clear representation of this logic

A	Q
0	1
1	0

Figure 8.11: A diagram of the NOT (inverter) logic gate and its truth table

In Figure, A is the input, and Q is the output of a NOT logic gate. The NOT gate, also known as an inverter, operates by inverting the input signal. If the input A is high (logic ‘1’), the output Q is low (logic ‘0’), and vice versa.

The behaviour of the NOT gate can be described using the equation: $Q = \overline{A}$

Here, the overline represents the logical NOT operation, indicating that the output is the complement of the input.

The truth table is as follows:

When A=0, Q=1.

When A=1, Q=0.

This demonstrates that the NOT gate always outputs the opposite of the input signal, providing a simple yet essential operation in digital logic.

Activity 8.18 Building Basic Digital Circuits with Logic Gates

Objective: use breadboards, logic gate ICs, and other necessary components to build basic digital circuits.

Materials Needed

1. Breadboards
2. Logic Gate ICs:
   - **a.** (NOT Gate)
   - **b.** (AND Gate)

   c. (OR Gate)
   d. (NAND Gate)
   e. (NOR Gate)
3. Resistors (e.g., 1kΩ)
4. LEDs (to visualise outputs)
5. Push buttons or switches (for inputs)
6. Power supply (e.g., 5V DC supply or batteries)
7. Jumper wires
8. Multimeter (optional, for testing)

What to do

1. Organise yourselves into groups of no more than five
2. Connect the power supply to the breadboard:
   a. Connect the positive terminal to the power rail (usually marked with a red line).
   b. Connect the negative terminal to the ground rail (usually marked with a blue line).
3. Follow the instructions below to build each logic gate circuit on the breadboard:
   a. **NOT Gate:** Connect an input switch/button to the input pin of the NOT gate IC and an LED to the output pin.
   b. **AND Gate:** Connect two input switches/buttons to the input pins of the AND gate IC and an LED to the output pin.
   c. **OR Gate:** Connect two input switches/buttons to the input pins of the OR gate IC and an LED to the output pin.
   d. **NAND Gate:** Similar setup as AND but observe that the output LED should be off when both inputs are high.
   e. **NOR Gate:** Similar setup as OR but observe that the output LED should be off when at least one input is high.
4. Test Each Circuit**.** For each circuit:
   a. Apply different combinations of inputs using switches or buttons:
      i. For two-input gates (AND, OR, NAND, NOR), test all combinations:

- Input A = 0, Input B = 0
- Input A = 0, Input B = 1
- Input A = 1, Input B = 0
- Input A = 1, Input B = 1

ii. For the NOT gate, test both input states:

- Input = 0
- Input = 1

b. Observe and record whether the output LED lights up or not.

5. For each logic gate you built, create a truth table based on your observations. The truth table should include all possible input combinations and their corresponding outputs. Here's how to fill them out:

Gate Type	Input A	Input B	Output
NOT	0		
NOT	1		
AND	0	0	
AND	0	1	
AND	1	0	
AND	1	1	
OR	0	0	
OR	0	1	
OR	1	0	
OR	1	1	
NAND	...	...	
NOR	...	...	

a. Fill in the "Output" column based on whether the corresponding LED lights up for each combination of inputs.

6. Once all circuits are tested and truth tables are created, gather as a group to discuss:

a. What patterns did you observe in your truth tables?

b. How do the outputs of each logic gate differ based on their inputs?

c. Were there any challenges faced while building or testing your circuits?

7. Prepare a brief presentation summarising your findings, including:
   - **d.** The truth tables created for each logic gate.
   - **e.** Any interesting observations or challenges encountered during the activity.

Activity 8.19 Researching Logic Gates and Designing a Digital Circuit

Objective: Work in groups to research a specific logic gate (e.g., NOT, AND, OR, NAND, NOR), understand its functions and applications, identify a community need that can be addressed with a digital circuit, and design a circuit using your assigned logic gate to meet that need.

Materials Needed

1. Access to Computers or Devices:

2. Paper and Pens/Pencils:

3. Provided Resources for Research

- **a.** All About Circuits: Logic Gates
- **b.** Electronics Tutorials: Logic Gates
- **c.** Wikipedia: Logic Gates
- **d.** Khan Academy: Digital Circuits
- **e.** Electronics Hub: Applications of Logic Gates

What to do

1. Organise yourselves into groups of no more than five
2. Each group will choose one specific logic gate to research. The options include:
   - **a.** NOT Gate
   - **b.** AND Gate
   - **c.** OR Gate
   - **d.** NAND Gate
   - **e.** NOR Gate
3. Use the provided resources to gather information about your chosen logic gate. Focus on:
   - **a.** The function of the gate (how it operates).
   - **b.** Examples of truth tables for your gate.
   - **c.** Common applications in real-world scenarios.
   - **d.** Any relevant examples of how it is used in digital circuits.
4. Discuss as a group to identify a community need that can be addressed with a digital circuit. Some examples might include:
   - **a.** An automatic lighting system for public areas.
   - **b.** A simple alarm system for security.
   - **c.** A temperature-controlled fan system.
   - **d.** A voting system for community decisions.
5. **Design the Circuit**
   - **a.** Using your chosen logic gate, design a simple circuit that addresses the identified community need.
   - **b.** Create a schematic diagram of your circuit showing how components are connected.
6. Organise your findings into a presentation format using presentation software or create a poster.
7. Each group should present their findings to the class.
8. After all presentations are complete, participate in a class-wide discussion about what you learned from each group's project. Consider these guiding questions:
   - **a.** What were some common themes in the projects?

b. How do different logic gates contribute to solving community needs?

c. What challenges did you encounter during your research?

Activity 8.20 Simulating Logic Gates and Analysing Combined Circuits

Objective: use a simulation tool to create circuits that utilise single and multiple logic gates (e.g., a NAND gate followed by a NOT gate).

Materials Needed

1. Access to Computers or Devices with Internet
2. **Simulation Tool**
   - Logic Gate Simulator (or any other preferred online logic gate simulator such as CircuitVerse, Logicly, or Logigator).

What to do

1. Organise yourselves into groups of no more than five
2. Open the chosen logic gate simulator on your computer or device using the provided link.
3. **Familiarise with the Simulator**

   a. Take a few minutes to explore the features of the simulator. Understand how to add logic gates, connect them, and observe outputs.

   b. Review how to use inputs (like switches) and outputs (like LEDs) within the simulator.
4. As a group, decide which logic gates you want to work with. You can start with basic gates (AND, OR, NOT) and then combine them into more complex circuits (e.g., NAND followed by NOT).
5. Begin by creating simple circuits using individual logic gates:

   a. Build a circuit for each type of gate you selected.

   b. Test each circuit with different input combinations and record the outputs.
6. Now, create combined circuits using multiple logic gates. For example:

   c. Connect a AND gate followed by a NOT gate (this creates a NAND configuration).

   d. Experiment with other combinations such as AND followed by OR or NOR followed by AND.

7. Observe how the output changes based on different input combinations.
8. For each combined circuit, analyse its behaviour:
   - **e.** What are the outputs for each combination of inputs?
   - **f.** How do the outputs compare to what you would expect based on truth tables for individual gates?
   - **g.** Discuss any patterns or unexpected results you observe.
9. As a group, discuss the implications of combining different logic gates:
   - **h.** How can combining gates be used to create more complex circuits?
   - **i.** What are some real-world applications of these combined circuits?
   - **j.** Consider how digital systems utilise these combinations in practical scenarios (e.g., computers, alarms, automated systems).

BOOLEAN NOTATION

Boolean algebra is a mathematical system used to work with binary variables, which can take on only two values: 0 (false) and 1 (true). Unlike numerical values, these binary values represent logical states and are fundamental to the design of digital circuits and computer systems.

Basic Operators in Boolean Algebra

Boolean algebra uses specific operators to define logical operations. These operators are represented by the following symbols:

1. **AND** (·): The output is 1 (true) only if both inputs are 1.
   Boolean expression: $X = A \cdot B$
2. **OR** (+): The output is 1 (true) if at least one input is 1.
   Boolean expression: $X = A + B$
3. **NOT** ($'$ *or* $\overline{A}$): The output is the opposite (complement) of the input.
   Boolean expression: $X = A'$ or $X = \overline{A}$

Logic Gate Symbols and Boolean Expressions

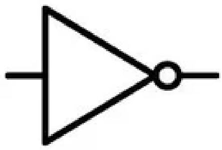
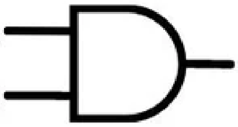
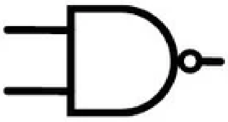
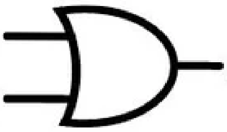
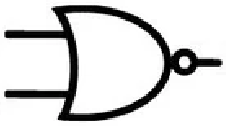
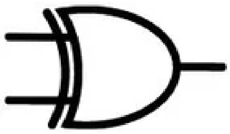
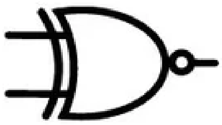
Name	Symbol & notation	Explanation
NOT	 $\overline{A}$	The inverter NOT simply accepts an input and **outputs the opposite**.
AND	 AB	**All inputs** must be positive (1) before the output is positive (1 or ON)
NAND *Not AND	 $\overline{A.B}$	Same as AND, but the **outcome is the inverse** (NOT). So, perform **AND first, then apply NOT** to the output.
OR	 $A+B$	**At least** one input must be positive (1) to give a positive output (1 or ON). **All** inputs could also be positive.
NOR *Not OR	 $\overline{A+B}$	Same as OR, but the **outcome is the inverse** (NOT). So, perform **OR first, then apply NOT** to the output.
XOR *eXclusive OR	 $A \oplus B$	**Only one** input can be positive (1) to give a positive output (1 or ON). If both are positive, the output is negative (0 or OFF)
XNOR *eXclusive Not OR	 $\overline{A \oplus B}$ *ComputerEngineeringforBabies.com	**All inputs** must be the same (either high or low) for a positive output (1). Otherwise, the output is negative (0 or OFF)

Figure 8.12: Boolean expressions for basic logic gates

Here is the truth table for two inputs (A and B) across various logic gates:

A	B	NOT A	NOT B	A OR B	A AND B	A NOR B	A NAND B	A XOR B	A XNOR B
0	0	1	1	0	0	1	1	0	1
0	1	1	0	1	0	0	1	1	0
1	0	0	1	1	0	0	1	1	0
1	1	0	0	1	1	0	0	0	1

Some laws of Boolean algebra

1. **Complement Law**

   The Complement Law states that:

   a. A variable AND its complement is always 0:

   $A\overline{A} = 0$

   This is because:

   i. If $A = 1,\ \overline{A} = 0,\ so\ 1.0 = 0$

   ii. If $A = 0,\ \overline{A} = 1,\ so\ 0.1 = 0$

   b. A variable OR its complement is always 1:

   $A + \overline{A} = 1$

   i. If $A = 1,\ \overline{A} = 0,\ so\ 1 + 0 = 1$

   ii. If $A = 0,\ \overline{A} = 1,\ so\ 0 + 1 = 1$

2. **Distributive Law**

   The Distributive Law allows you to distribute AND (.) and OR (+) operators over each other.

   a. Distributing AND over OR:

   $A.(B + C) = (A.B) + (A.C)$

   i. Multiply A with both B and C, then OR the results.

   b. Distributing OR over AND:

   $A + (B.C) = (A + B).(A + C)$

   i. Add A to both B and C, then AND the results.

These laws are fundamental in simplifying Boolean expressions and designing logic circuits.

Deriving a Boolean Expression from a Truth Table

You have learned how to generate a truth table from a Boolean expression or algebra. Equally important is the ability to reverse this process. From a given truth table, you can derive a Boolean expression that represents the logical behaviour of an electronic circuit.

To derive a Boolean expression from a truth table, follow these steps:

Step 1: Identify Rows Where the Output is 1

a. Look at the output column of the truth table. Identify all rows where the output is **1** (true).

b. For each row where the output is **1**, note the corresponding values of the inputs (A, B, etc.).

Step 2: Write the Boolean Term for Each Row

a. For each identified row, write a product term (AND combination) that represents the input conditions:

i. Use the variable (A, B) if its value is 1.

ii. Use the negation ($\overline{A}$, $\overline{B}$) if its value is 0.

Example:

If A=1 and B=0, the term is $A\overline{B}$

Step 3: Combine the Terms Using OR (+)

a. Combine all the product terms (ANDs) using the OR (+) operator. This forms the **sum-of-products (SOP)** expression.

Example:

For a truth table with the following outputs:

Row 1: A=0, B=1→$\overline{A}$.B

Row 2: A=1, B=1→A·B

The Boolean expression becomes: $\overline{A}.B + A \cdot B$

Step 4: Simplify the Expression (if needed)

a. Use Boolean algebra rules to simplify the expression, if possible.

Example 1

Derive a Boolean expression for the truth table below:

A	B	F(Output)
0	0	0
0	1	1
1	0	1
1	1	0

Steps:

1. Identify rows where F=1:
   a. Row 2: A=0, B=1→$\overline{A}$.B
   b. Row 3: A=1, B=0→A·$\overline{B}$
2. Write the Boolean expression:
   The sum of products (SOP) $F = \overline{A}.B + A.\ \overline{B}$
3. Simplify (optional): In this case, the expression is already in its simplest form.

Example 2

Derive a Boolean expression for the truth table below:

A	B	Output (F)
0	0	1
0	1	1
1	0	0
1	1	0

Steps:

1. **Identify Rows Where Output (F) = 1**
   a. Row 1: A=0, B=0
   b. Row 2: A=0, B=1
2. **Write the Boolean Term for Each Row**
   a. Row 1: $\overline{A}.\ \overline{B}$
   b. Row 2: $\overline{A}.B$

3. **Combine the Terms Using OR (+)**

   The sum of products (SOP) $F = \overline{A}.\ \overline{B} + \overline{A}.B$

4. **Simplify the Expression (if possible)**

   f. Factor out $\overline{A}$

   $F = \_A\ .(\overline{B} + B)$

   g. Simplify using the identity $(\overline{B} + B) = 1$

   $F = \overline{A}$

   Final Boolean Expression

   $F = \overline{A}$

Explanation

This truth table represents a **NOT gate** applied to input A, where the output is true only when A=0, regardless of B.

Example 3

Consider the table below. Derive the Boolean expression for the logic circuit.

A	B	C	Y (Output)
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Steps:

1. **Identify Rows Where Output (Y) is 1:**

   For the truth table above, the output (Y) is 1 for the following combinations:

   Row 4: (A = 0, B = 1, C = 1) → $\overline{A}.B.C$

   Row 6: (A = 1, B = 0, C = 1) → $A\overline{B}.C$

   Row 7: (A = 1, B = 1, C = 0) → $A.B.\ \overline{C}$

   Row 8: (A = 1, B = 1, C = 1) → $A.B.C$

2. **Write the Sum of Products**

   $Y = \overline{A}.B.C + A\overline{B}.C + A.B.\ \overline{C} + A.B.C$

3. **Simplify the Expression (if possible)**: You can apply Boolean algebra rules to simplify the expression if needed. However, in this case, the expression captures all the true outputs based on the given conditions.

   Thus, the derived Boolean expression that corresponds to the truth table provided is

   $Y = \overline{A}.B.C + A\overline{B}.C + A.B.\ \overline{C} + A.B.C$

The expressions generated from the truth tables represent the logical functions described by the truth table.

Combinational circuits

When multiple logic gates are put together, they form combinational circuits.

Combinational circuits are a type of digital circuit whose output is a pure function of the present input only, without any memory element. This means that the output at any given time depends solely on the inputs at that time, irrespective of previous inputs.

Common examples of combinational circuits include adders, subtractors, multiplexers, demultiplexers, and encoders. They are used in various digital systems for performing arithmetic operations, data routing, and logic operations. The design of combinational circuits often involves using Boolean algebra and logic gates like AND, OR, and NOT.

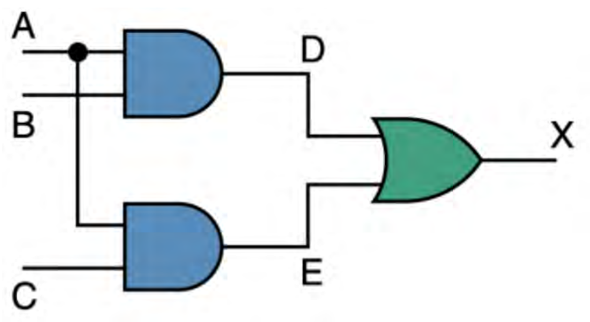


Figure 8.13: Combinational circuits

Circuit Description for Figure 8.13

First AND Gate takes inputs A and B. Its output is D = A·B

Second AND Gate takes inputs A and C. Its output is E = A·C.

The outputs of the two AND gates (D and E) are combined using **an OR Gate** to produce the final output X.

Boolean Expression

The circuit's final output X can be expressed as: X= (A·B) + (A·C)

Truth Table

A	B	C	D = A·B	E = A·C	X = D + E
0	0	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	1

Logic Interpretation

1. X is 1 if and only if A = 1, and at least one of B or C is also 1.
2. If A = 0, X is always 0, regardless of B or C.

This circuit ensures that the output depends on A being high, and then either B or C being high to produce a positive output.

Activity 8.21 Exploring Truth Tables and Forming Sum of Products (SOP) Expressions

Objective: Work with truth tables for three-input logic functions.

Materials Needed

1. Truth Table for a Three-Input Logic Function

A	B	C	Output (Z)
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	0

2. Additional Truth Tables for independent practice (provided below).
3. Paper and pens/pencils for taking notes.

What to do

Part A: Guided Example

1. Review the provided truth table. Each row represents a unique combination of inputs (A, B, C) and the corresponding output (Z).
2. Go through the truth table and identify which rows have an output of Z = 1. Write down the input combinations for these rows:
   - **a.** Row 2 where A = 0, B = 0, C =1
   - **b.** Row 3 where A = 0, B = 1, C = 0
   - **c.** Row 5 where A= 1, B = 0, C = 0
   - **d.** Row 6 where A =1, B = 0, C = 1
3. For each identified row with an output of Z = 1, write the corresponding product term: Remember that:
   - **a.** If the input is **0**, use the negation (NOT) of that variable (e.g., A becomes A').
   - **b.** If the input is **1**, use the variable as is.

Here are the product terms for each identified row:

i. For A=0, B=0, C=1: The product term is A′B′C

ii. For A=0, B=1, C=0: The product term is A′BC′

iii. For A=1, B=0, C=0: The product term is AB′C′

iv. For A=1, B=0, C=1: The product term is AB′C

4. Combine the product terms using the OR operator (+) to form the Sum of Products (SOP) expression:

Z=A′B′C+A′BC′+AB′C′+AB′C

Part B: Independent Practice

5. Work on Additional Truth Tables:

a. Below are additional truth tables for you to convert into SOP expressions independently.

Truth Table Example #2:

A	B	C	Output (Z)
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

Truth Table Example #3:

A	B	C	Output (Z)
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1

6. For each truth table:
   a. Identify rows with Z = 1.
   b. Write down the corresponding product terms.
   c. Combine these product terms to form the SOP expression.

Activity 8.22 Designing Practical Digital Circuits for Community Applications

Objective: work in groups to design simple digital circuits that can be used for practical applications in your community.

Materials Needed

1. Access to Computers or Devices
2. Breadboards
3. Logic Gate ICs:
   a. NAND Gate
   b. NOR Gate
   c. NOT Gate
   d. AND Gate
   e. OR Gate
4. Resistors
5. LEDs
6. Push Buttons or Switches
7. Power Supply
8. Jumper Wires
9. Paper and Pens/Pencils

What to do

1. Organise yourselves into groups of no more than five
2. As a group, discuss and identify a specific community need that could be addressed with a digital circuit. Some examples might include:
   a. A digital lock system that opens with a specific combination.
   b. An automatic lighting system for public areas.
   c. A simple alarm system for security.

   d. A temperature-controlled fan system.

3. Once you have identified the need, research how digital circuits can address it. Consider what logic gates will be necessary for your design. Write down the requirements for your circuit, including:
   a. Inputs needed (e.g., buttons, switches).
   b. Expected outputs (e.g., LED indicators, alarms).
4. Create a truth table based on the desired functionality of your circuit.
5. **Write the Boolean Expression:**
   a. From your truth table, identify the rows where the output is 1.
   b. Write the corresponding product terms for each row:
      i. If an input is 0, use its negation (e.g., A becomes A').
      ii. If an input is 1, use the variable as is.
   c. Combine these product terms using the OR operator (+) to form the Sum of Products (SOP) expression.
6. **Construct the Circuit:**
   a. Using a breadboard, gather all necessary components and construct your digital circuit according to your design and Boolean expression.
   b. Ensure all connections are secure and that you have correctly implemented the logic gates needed for your design.
7. **Test Your Circuit:**
   a. Once built, test your circuit to ensure it works as intended.
   b. Make any necessary adjustments to improve functionality.
8. **Prepare Your Presentation:**
   a. Organise your findings into a presentation format using presentation software or create a poster.
   b. Your presentation should include:
      i. An introduction to the community need you are addressing.
      ii. The logic gates used in your design and their functions.
      iii. The truth table and corresponding Boolean expression.
      iv. The schematic diagram of your circuit.
      v. Observations from building and testing the circuit.

9. Each group should present their findings to the class.

10. Class Discussion

a. After all presentations are complete, participate in a class-wide discussion about what you learned from each group's project.

b. Use these guiding questions to facilitate discussion:

i. What were some common themes in the projects?

ii. How do different logic gates contribute to solving community needs?

iii. What challenges did you encounter during your research or building process?

iv. How could these designs be further improved or expanded?

LOGIC APPLICATIONS AND MICROCONTROLLER

Combinational Logic Circuits

Combinational logic circuits are fundamental elements in digital electronics. They are composed of logic gates that produce specific outputs based on current inputs, without relying on memory or past states. These circuits play a vital role in performing arithmetic, data processing, and control tasks in digital systems.

Types of Combinational Logic Circuits

1. **Adders**

   a. **Half Adder**: A simple circuit for adding two single-bit binary numbers, producing:

      i. **Sum**: Calculated using an XOR gate.

      ii. **Carry**: Generated using an AND gate.

   b. **Full Adder**: Adds three binary numbers (including carry) and produces:

      i. **Sum and Carry**: Utilises two half-adders and an OR gate.

2. **Multiplexers (MUX)**

   a. Selects one input from several options and forwards it to a single output.

   b. Commonly used in communication systems for managing multiple data streams.

3. **Decoders**
   a. Converts binary information from 'n' input lines to a maximum of 2^n unique output lines.
   b. Applications include data demultiplexing and memory address decoding.
4. **Encoders**
   a. The reverse of decoders, converting 2^n input lines into 'n' output lines.
   b. Provides a binary code corresponding to the active input.

Microcontrollers

Microcontrollers are compact integrated circuits that manage specific operations in embedded systems. They integrate a processor, memory, and input/output (I/O) peripherals on a single chip.

Arduino: A Popular Microcontroller Platform

Arduino is an open-source hardware and software platform, ideal for creating interactive projects.

Key Features of Arduino

1. **Microcontroller**: Utilises Atmel AVR microcontrollers (e.g., ATmega328), which include:
   a. CPU, flash memory, SRAM, and EEPROM.
2. **Digital and Analogue I/O Pins**
   a. Digital pins: Configurable as input or output.
   b. Analogue pins: Used to read variable voltage levels.
3. **USB Interface**
   a. Facilitates programming and communication with a computer.
   b. Provides power when connected to a computer.
4. **Power Supply**
   a. Can be powered via USB or an external power source.
   b. Includes an onboard voltage regulator for stability.
5. **Development Environment**
   a. Arduino IDE (Integrated Development Environment): Simplifies writing, compiling, and uploading code.

b. Supports C++ programming with user-friendly functions.

Applications of Microcontrollers

1. **Automatic Street Lighting System**
   a. Automatically turns streetlights on at dusk and off at dawn.
   b. Uses an Arduino and a light-dependent resistor (LDR).
2. **Smart Irrigation System**
   a. Waters plants automatically based on soil moisture levels.
3. **Home Security System**
   a. Detects motion and triggers an alarm.

Activity 8.23 Learning from William Kamkwamba and Designing Practical Digital Projects

Objective: watch a video about William Kamkwamba and how he used physics to solve challenges in his community and then explore the theory behind setting up and programming simple projects and also to work in groups to develop a more complex project, such as a home security system using a PIR sensor and buzzer or a temperature monitoring system using a temperature sensor and LCD.

Materials Needed

1. Video: **"The Boy Who Harnessed the Wind» (accessible on streaming platforms online)**
2. Access to Computers or Devices:
3. Microcontroller Kits
4. Sensors and Components
   a. PIR motion sensor (for security system)
   b. Temperature sensor
   c. Buzzer (for alarms)
   d. LCD display (for temperature monitoring)
   e. LEDs (for visual indicators)
   f. Resistors, jumper wires, and breadboards.
5. Programming Software
   a. Arduino IDE or similar software for coding.

6. Paper and Pens/Pencils

What to do

Part A: Watch the Video

1. Watch the video about William Kamkwamba. Pay attention to how he identified problems in his community and used physics to create solutions.
2. After watching, discuss as a group:
   a. What challenges did William face?
   b. How did he use physics to solve these challenges?
   c. What can you learn from his story about creativity and resourcefulness?

Part B: Explore Project Theory

3. Research the theory behind setting up basic projects such as:
   a. Automatic Street Lighting: Using light sensors to turn lights on at dusk.
   b. Smart Irrigation Systems: Using soil moisture sensors to water plants automatically.
4. Learn about the components needed for these projects:
   a. How sensors work (e.g., light sensors, moisture sensors).
   b. How microcontrollers can be programmed to respond to sensor inputs.
5. Review step-by-step guides for implementing these projects. Here's an example for an automatic street lighting system:

   Automatic Street Lighting System Steps:

   a. Connect the light sensor to the microcontroller.
   b. Connect an LED or relay module to control the street light.
   c. Write a simple program that reads the light sensor value.
   d. If the value is below a certain threshold (indicating darkness), turn on the LED/relay.
   e. Test your circuit and adjust thresholds as necessary.

Part C: Develop Complex Projects

6. **Choose a Complex Project**
   a. As a group, choose one of the following complex projects to develop:

- **i.** Home Security System: Using a PIR sensor and buzzer.
- **ii.** Temperature Monitoring System: Using a temperature sensor and LCD display.

7. Plan Your Project

a. Write down your project requirements:

- **i.** Inputs needed (e.g., PIR sensor for motion detection).
- **ii.** Outputs expected (e.g., buzzer alarm, LCD display).

b. Create a schematic diagram showing how components are connected.

Follow steps 8-10 only if the equipment is available

8. Build Your Circuit

a. Gather all necessary components and build your circuit according to your design.

b. Ensure all connections are secure.

9. Program Your Microcontroller

a. Write the code needed for your project using Arduino IDE or similar software.

b. Test your code as you develop it, ensuring that all parts of your project function correctly.

10. Test Your Project

a. Once built, thoroughly test your project to ensure it works as intended.

b. Make any necessary adjustments based on testing results.

Part D: Present Your Findings

11. Prepare Your Presentation

a. Organise your findings into a presentation format using presentation software or create a poster.

b. Your presentation should include:

- **i.** An introduction to the community need you are addressing.
- **ii.** The components used in your design and their functions.
- **iii.** The schematic diagram of your circuit.
- **iv.** The Boolean expression for your circuit.

v. Observations from building and testing the project.

12. Each group will present their findings to the class.

Activity 8.24 Simulation to create a Half Adder

Use the instruction and simulation linked below to build a half adder. Click here

SIMPLE INTEGRATED CIRCUIT

An integrated circuit (IC) is a small chip made of semiconductor material that contains many interconnected electronic components such as transistors, resistors, capacitors, and diodes. This material is usually made of silicon, but other materials such as germanium and gallium arsenide can also be used.

ICs are designed to perform a specific function, such as amplifying signals, switching signals on and off, or storing information. They can be found in almost every electronic device, from cell phones and computers to cars and medical equipment.

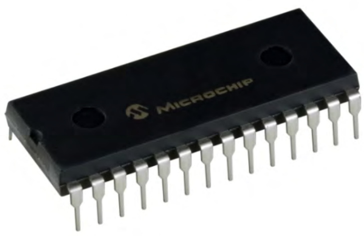


Figure 8.14: Image of a simple integrated circuit

Here are some characteristics of ICs:

1. **Size**: ICs are very small, about the size of a human fingernail.
2. **Components**: ICs can contain hundreds to billions of components, including resistors, transistors, and capacitors.

3. **Manufacturing**: ICs are made using photolithography, a process that uses ultraviolet light to print the components onto a single substrate.
4. **Types**: There are three types of ICs: digital, analogue, and mixed.
5. **Uses**: ICs can function as microprocessors, amplifiers, or memory.
6. **Application-specific ICs (ASICs)**: ASICs are designed to perform a specific function and are not reconfigurable. For example, a speed controller IC for a remote-control car can only do one job.

Types of Simple Integrated Circuits

1. **Analogue Integrated Circuits**
   a. Designed to process continuous signals.
   b. Commonly used in applications such as radios, televisions, audio amplifiers and radio frequency circuits.
   c. Examples include operational amplifiers (op-amps) and voltage regulator.
2. **Digital Integrated Circuits**
   a. Operate on discrete binary values (0s and 1s).
   b. Used for logic operations and data processing.
   c. Include components like microprocessors, memory chips, and logic gates.
3. **Mixed-Signal Integrated Circuits**
   a. Combine both analogue and digital functions on a single chip.
   b. Used in applications like data converters (ADC/DAC) and sensor interfaces.

Applications of Simple Integrated Circuits

Simple integrated circuits are found everywhere in electronic devices. They are found in:

1. **Consumer Electronics**: Such as smartphones, televisions, and audio equipment.
2. **Computers**: Including microprocessors and memory chips.
3. **Automotive Systems**: For control systems and sensors.
4. **Medical Devices**: Used in diagnostic equipment and monitoring systems.

Benefits of Integrated Circuits

The integration of multiple components into a single chip offers several advantages:

1. **Size Reduction**: ICs significantly decrease the physical size of electronic devices.
2. **Cost Efficiency**: Mass production reduces manufacturing costs compared to discrete components.
3. **Improved Reliability**: Fewer connections mean lower chances of failure.

The design and fabrication of ICs involve several steps, including:

1. Design Specification: Defining the IC's functionality and performance requirements.
2. Circuit Design: Creating a schematic diagram of the circuit.
3. Layout Design: Translating the schematic into a physical layout that can be fabricated on a semiconductor wafer.
4. Fabrication: Using photolithography, doping, etching, and other semiconductor processing techniques to create the IC on a wafer.
5. Testing: Verifying the IC's functionality and performance.
6. Packaging: Encasing the IC in a protective package and adding external connections

Activity 8.25 Researching Aspects of IC Design and Fabrication

Objective: work in groups to research specific aspects of integrated circuit (IC) design and fabrication.

Materials Needed

1. Access to computers or devices with internet access for research
2. Presentation software (e.g., PowerPoint, Google Slides) or poster materials
3. Paper and pens/pencils for note-taking
4. Resources for research, including:
   a. Science.gov
   b. MDPI Electronics Journal
   c. Chip Design Reddit Discussion

d. UTRGV IC Design Fabrication Project

What to do

1. Organise yourselves into groups of no more than five. As a group, discuss and choose a specific aspect of IC design and fabrication to research. Suggested topics include:

- **a.** Circuit design
- **b.** Layout design
- **c.** Fabrication techniques
- **d.** Testing and validation of ICs
- **e.** Emerging technologies in IC design (e.g., FinFETs, 3D ICs)
- **f.** CAD tools used in IC design

2. Use the provided resources to gather information about your chosen topic. Take notes on key concepts, processes, and relevant examples. Focus on finding essential information quickly since you have limited time.

3. Organise your findings into a presentation format using presentation software or create a poster. Your presentation should include:

- **a.** An introduction to your topic
- **b.** Key concepts and processes involved
- **c.** Relevant examples or case studies
- **d.** Recent advancements or challenges in the field
- **e.** A conclusion summarising your findings

4. Practice your presentation as a group. Ensure that each member has a role in presenting the information.

5. Each group should present their findings to the class. After each presentation, engage in a brief Q&A session where classmates can ask questions or provide feedback.

6. After all presentations are complete, take a moment to reflect on what you learned from both your research and the presentations from other groups.

Activity 8.26 Constructing and Testing Integrated Circuits (ICs) on a Breadboard

Objective: construct and test your integrated circuits (ICs) using a breadboard or prototyping platform.

Materials Needed

1. Solderless breadboard
2. Various components (e.g., resistors, capacitors, LEDs, transistors, ICs)
3. Power supply (e.g., batteries or a DC power supply)
4. Jumper wires
5. Multimeter (for testing)
6. Circuit diagrams or schematics for your IC designs
7. Paper and pens/pencils for notes

What to do

1. Organsie yourselves into groups of no more than five, .
2. Decide on a simple IC design to construct. This could be a basic logic gate (AND, OR), an amplifier circuit, or any other design you have studied. Ensure that you have the necessary components for your chosen design.
3. Collect all the materials needed for your circuit assembly:
   a. Breadboard
   b. Components (ICs, resistors, capacitors, etc.)
   c. Jumper wires
   d. Power supply
4. Before starting the assembly, review the circuit diagram or schematic for your design. Make sure everyone in your group understands how the circuit is supposed to function.
5. Start placing components on the breadboard according to the circuit diagram:
   a. Insert ICs into the breadboard, ensuring that they are properly oriented.
   b. Connect resistors, capacitors, and other components as indicated in the schematic.
   c. Use jumper wires to make connections between components.

Pay attention to the placement of power and ground connections to ensure proper functionality.

6. Once your circuit is fully assembled, connect the power supply to the breadboard. Use a multimeter to check for correct voltage levels at various points in the circuit. Observe any output devices (like LEDs) to see if they function as expected.
7. If the circuit does not work as intended:
   a. Double-check all connections against the schematic.
   b. Ensure that all components are functioning correctly.
   c. Look for any short circuits or incorrect placements of components on the breadboard.
8. Take notes on your assembly process, any challenges faced, and how you resolved them. Record any measurements taken with the multimeter.
9. Each group should prepare a brief presentation summarising their IC design, assembly process, testing results, and any troubleshooting steps taken.
10. Each group should present their findings to the class. After each presentation, engage in a brief Q&A session where classmates can ask questions or provide feedback.

ADDITIONAL READING MATERIALS

1. **Books**:
   a. Digital Fundamentals by Thomas L. Floyd
   b. Digital Logic and Computer Design by M. Morris Mano
   c. The Art of Electronics by Paul Horowitz and Winfield Hill
   d. Introduction to Digital Electronics by J. Crowe and B. Hayes
   e. Digital Systems: Principles and Applications by Ronald J. Tocci and Neal S. Widmer
2. **Online Resources**:
   a. **Khan Academy**: Digital circuits and binary systems https://www.khanacademy.org
   b. **All About Circuits**: Comprehensive tutorials on digital electronics https://www.allaboutcircuits.com

   c. **CircuitVerse**: Interactive logic circuit simulation https://circuitverse.org
   d. **SparkFun**: Tutorials on microcontrollers and circuits https://www.sparkfun.com

3. **Articles and Journals**:
   a. IEEE Xplore Digital Library https://ieeexplore.ieee.org
   b. Journal of Electronics and Digital Technologies

REVIEW QUESTIONS

Review questions 8.1

1. State the three key steps involved in ADC and DAC.
2. Briefly explain how the following processes are achieved:
   a. Analogue-to-digital conversion
   b. Digital to analogue conversion
3. A research team is designing a weather monitoring station that uses sensors to measure temperature and humidity. The sensors produce analogue signals that are fed into a digital processing unit for data analysis and storage.
   a. Explain why the analogue signals from the sensors need to be converted into digital signals.
   b. Identify the two main stages of this conversion process and briefly describe their roles.
   c. Discuss two potential challenges the team might face when converting the signals and suggest solutions to address them.
   d. If the digital processor needs to send the data to a display unit in a nearby control room, why might digital-to-analogue conversion be necessary?

Review Questions 8.2

1. What are the two states of binary variables in digital systems?
2. Draw the symbol and truth table of the OR gate.
3. What is a combinational circuit?
4. Compare the functions of an AND gate and an OR gate.
5. Using the truth table below, derive the SOP expression for the output F.

A	B	C	F
0	0	0	0
0	0	1	1

A	B	C	F
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

6. Develop a simple digital circuit using AND, OR, and NOT gates to implement the following logic: The output is high only when A is high, B is low, and C is high.

Review Questions 8.3

1. State three components that can be fabricated to form an integrated circuit.
2. What are the advantages of using integrated circuits over individual electronic components regarding size, power consumption, and reliability?
3. How can integrated circuits be classified based on their function
4. How are integrated circuits used in smartphones, computers, or appliances?

ANSWERS TO REVIEW QUESTIONS

SECTION 1

Dimensional Analysis and Vectors

1. Dimensional analysis is used to
   a. find the units of physical quantities
   b. check the validity of an equation,
   c. derive an equation between physical quantities

2. $[pv] = ML^2T^{-2}$

   $[mv^2 - mgh] = ML^2T^{-2}$

   Since the dimensions on both sides of the equation are the same, the equation is valid

3. $T \propto \sqrt{\frac{m}{k}}$

4. a. $a_x = 4.70\ ms^{-2}$
   b. $a_y = 1.7\ ms^{-2}$

5. a. 32.14 m
   b. 38.30 m

SECTION 2

Review Questions 2.1

1. *$Q = mc\Delta T$, where Q = heat energy, m = mass, c = specific heat capacity, and ΔT = change in temperature.*

2. a. Specific heat capacity is defined as the amount of heat required to change the temperature of 1 kg of a substance by 1°C or 1 K
   b. The specific heat capacity of a substance affects the amount of heat needed to change its temperature in direct proportion. A higher specific heat capacity means more heat is required to increase the temperature, while a lower specific heat capacity means less heat is needed.

3. 11700 J
4. The temperature rise will be half, i.e., 5°C because heat is distributed over a larger mass.
5. Water has a high specific heat capacity, meaning it absorbs and releases heat slowly. This characteristic helps regulate temperatures near coastal areas, as the water absorbs heat during the day and releases it at night, preventing extreme temperature changes. Inland areas, with less water, experience more drastic temperature variations.

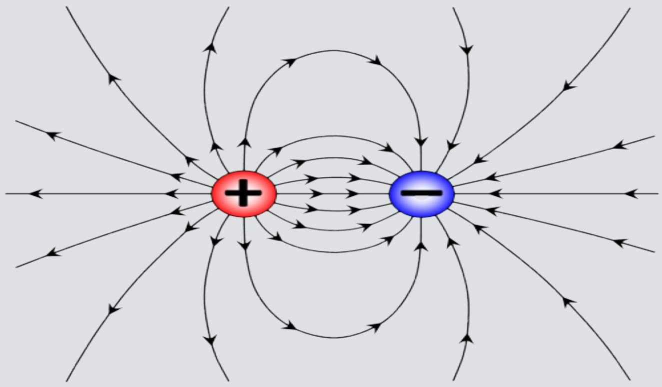
Review Questions 2.2

1. Specific latent heat of vaporisation is the quantity of heat required or removed when a unit mass (1kg) of a substance changes from liquid to vapour or vice versa, without a temperature change. SI unit is Jkg^{-1}
2. This is because the heat energy absorbed or lost during the change of phase goes solely into changing the phase of the substance at the boiling or freezing point of the substance (by weakening and breaking bonds between molecules). The temperature will begin to change only when the substance has fully changed phase.
3. 0.0186 kg
4. When water droplets dry off the skin after a rain shower, the process of evaporation is at work. Here's how it happens:
   a. Evaporation Process: The water on your skin absorbs latent heat of vaporisation from your body and the surrounding air. This heat energy gives the water molecules enough energy to turn from liquid into gas and escape into the air.
   b. Cooling Effect: As the water evaporates, taking heat away from your skin in the form of latent heat, it lowers the temperature of your skin, hence the sensation of coldness on your skin.

   This cooling effect is similar to how sweating cools down the body: as the sweat evaporates, it carries away body heat, helping to regulate temperature.

SECTION 3

Review Questions 3.1

1. Coulomb's law of electrostatics states that the magnitude of the electrostatic force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them.
2. 
3. 3.37 N
4. 0.2 m
5. 0.7192 N
6. a. New charge on each sphere: +5 μC

   b. Electrostatic force after separation: 0.22475N, which is the same as the initial force before they touched.

Review Questions 3.2

1. a. Electric field strength is the force experienced by a unit positive charge placed at a point in an electric field.

   b. Electric potential is the work done or energy spent on bringing a unit test charge from infinity to a point in an electric field.
2. Electric field strength (NC^{-1}), electric potential (JC^{-1})
3. 2.0×10^{-4} C
4. 6 875 V
5. a. V= 6000 V/m

   b. 324.799×10^{6} ms^{-1}

Review Questions 3.3

1. The capacitance (C) of a capacitor is calculated using the formula: $C = Q$ _ _ where Q is the charge stored on one plate of the capacitor (in coulombs) and V is the voltage across the capacitor (in volts).
2. In a parallel connection, all capacitors have the same voltage across their terminals. In contrast, for capacitors connected in series, the total voltage across the series combination is divided among the capacitors, meaning each capacitor may have a different voltage drop depending on its capacitance.
3. If the distance is doubled, the capacitance will be halved, as capacitance is inversely proportional to distance.
4. 1.0 μF
5. 5.0 μF

Review Questions 3.4

1. The energy stored in a capacitor can be calculated using the formula:

   $E = 1$ _ _ CV^2

   where E is the energy in joules, C is the capacitance in farads, and V is the voltage across the capacitor in volts.
2. If the voltage across a capacitor is doubled, the energy stored increases by a factor of four. This is because energy is proportional to the square of the voltage
3. $0.0072J$

SECTION 4

1. Photoelectric effect is the emission of electrons from the surface of a metal when exposed to radiation of appropriate frequency/wavelength.
2. a. Photoelectric emission occurs only if the frequency of the incident radiation is above the threshold frequency of the metal.

   b. Photoelectric emission starts immediately the surface of the metal begins to be illuminated by light of appropriate frequency.

c. The kinetic energy of the ejected electrons is proportional to the frequency of the incident light and is independent of the light's intensity.

d. The number of electrons emitted per second is proportional to the intensity of the incident radiation provided the frequency of the light is above the threshold frequency.

3. $E = W_o + KE_{max}$

Where:

- E is the energy of photon,
- W_o is the work function of a metal,
- KE_{max} is the maximum kinetic energy of the ejected electron.

4. 4.2×10^{-20} J

5. 264 nm

6. a. The photon's energy is 3.1 eV, comparatively greater than the work function (2.2 eV). Consequently, electrons are emitted from the surface of the metal.

b. The kinetic energy of the electrons is 0.9 eV, but with 300 nm light, the kinetic energy is 1.94 eV, thus, KE_{max} increases as the photon's energy is higher for 300 nm light.

c. **Number of emitted electrons:** Doubling the intensity increases the number of photons incident on the metal. Since each photon can eject one electron (if $E_{photon} > W_o$), the number of emitted electrons increases.

Kinetic energy of emitted electrons: The kinetic energy depends only on the photon's energy and the work function, not on the intensity. Therefore, $KE_{max} = 0.9\ eV$remains unchanged.

i. Alpha particle

ii. Beta particle

iii. Gamma-ray

7. 7.5 grams of it will be left. All of it does not decay at the end of the 12 months because, in the second half-life, only half of the mass left (15 grams) will decay, leaving 7.5 grams).

8. 6 years

9. 25 g

10. The radioactive waste must be stored for at least 70 years to reduce its activity to less than 1% of the original level.

SECTION 5

Review Questions 5.1

1. a. Motion of a football kicked into the air
   b. Motion of a basketball in a free throw
   c. Water sprayed from a fountain
   d. A bullet fired from a gun

2. The angle of projection, 45^0

3. a. Time of flight is the total time a projectile takes to travel from the point of projection to where it lands.
   b. Maximum height is the highest vertical point a projectile reaches above the level of its initial projection during its motion.
   c. The range of a projectile is the entire horizontal distance covered by a projectile during the time of flight

4. a. 163.27 m
   b. 40.82 m

5. [$R_{30} = 54.13\ m$, $R_{45} = 62.25\ m$, $R_{50} = 61.56\ m$, $R_{70} = 40.19\ m$, since R_{45} is greater than all the other ranges, 45 is the optimal angle.]

Review Questions 5.2

1. Friction is the force that opposes the relative motion or the tendency of such motion of two surfaces in contact.

2. Static and kinetic friction

3. Moving parts of a machine need lubrication to reduce friction and improve the efficiency of the machine. Noise and overheating will also be reduced.

4. It is no longer easy to push the block because the vertical force exerted by the brother adds to the weight of the block increasing the normal reaction and consequently the friction between the block and the floor. To still move the block, the girl needs to increase the applied force (push harder).

5. 25 kg

Review Questions 5.3

1. a. Swinging a ball on a string in a circle in a circular form
   b. Electrons revolving around the nucleus in Atoms:
   c. Planets orbiting the Sun
   d. A car negotiating a curve
2. a. 5 m/s
   b 50 rad
3. 12.568 rad/s

Review Questions 5.4

1. The tension in the string is maximum at the bottom of the circle. This is because, at the bottom, the string must support both the weight of the object (acting downwards) and provide the centripetal force required to keep the object in circular motion. The total tension is the sum of these two forces, making it greater at the bottom than at the top, where the weight of the object partially offsets the required centripetal force.
2. a. 127.3 m, 15 m/s
   b. It is not safe for the inner lane. Since the inner lane has a shorter radius, the speed limit will be reduced.]

SECTION 6

Review Questions 6.1

1. Fleming's Left Hand Rule states that if the forefinger, the thumb and the second finger of the left hand are placed mutually at right angles to each other, then the forefinger points in the direction of magnetic field; the thumb points in the direction of motion of the conductor and the second finger points in the direction of current.
2. 3 N

Review Questions 6.2

1. A motor works on the principle that a current-carrying conductor placed in a magnetic field experiences a force due to the interaction between the magnetic field and the current. Opposite sides of the motor are forced in opposite directions, causing a torque.

2.a. 0.015 Nm

b. 0 N

Review Questions 6.3

1. $F = qvBsin\theta$

Where:

F: Magnetic force (in newtons, N)

q: Charge of the particle (in coulombs, C)

v: Velocity of the particle (in meters per second, m/s)

B: Magnetic field strength (in teslas, T)

θ: Angle between the velocity vector and the magnetic field

2.a. 3000 m/s

b. 1.593×10^{-2}m

3. 10000 m/s

SECTION 7

Review questions 7.1

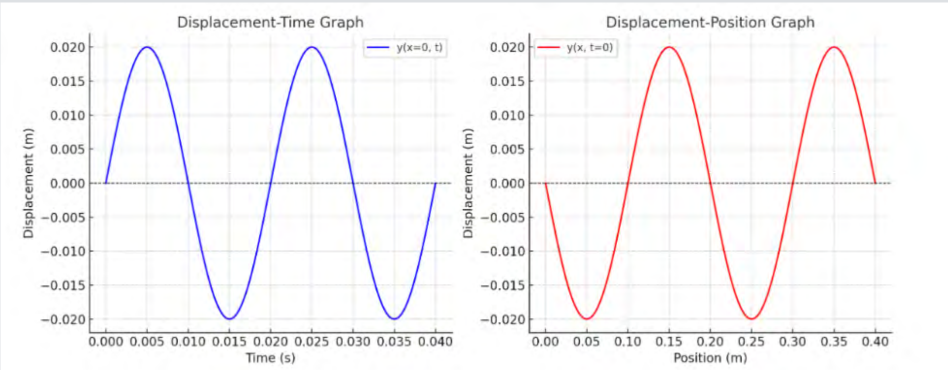
1. a. Amplitude is the maximum displacement of a particle from its equilibrium position.

b. Frequency is the number of complete oscillations made by a particle per second or the number of waves passing through a point per second.

c. Period is the time taken for one complete oscillation or cycle of a wave.

d. Wavelength is the distance between two successive points in phase on a wave, such as two crests, two troughs, or two compressions.

2. a. Amplitude: 0.05 m.
   b. Angular frequency: 400 rad/s.
   c. Wave number: 2 rad/m.
   d. Wavelength: π m.
   e. Frequency: 63.66 Hz.
   f. Period: 0.0157 s.
   g. Wave velocity: 200 m/s.
   h. Direction: Positive x-direction.
3. a. 0.2 m
   b. $y(x, t) = 2\sin(100\pi t - 10\pi x)$
   c. $[y = 0\ m]$
   d.



Review questions 7.2

1. a. **Infrasound**: Below 20 Hz
   b. **Audible sound**: 20 Hz to 20,000 Hz
   c. **Ultrasound**: Above 20,000 Hz
2. Resonance is the phenomenon where a system vibrates with maximum amplitude when subjected to a frequency matching its natural frequency.
3. Sound requires a medium (air, liquid, or solid) for the transmission of mechanical vibrations. A vacuum lacks particles to transmit these vibrations.
4. Resonance amplifies sound at specific frequencies, allowing for precise identification of the wavelength of sound in the air column. With the

wavelength and frequency known, the speed can be calculated using $v = f\lambda$.

SECTION 8

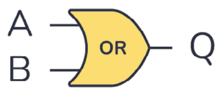
Review questions 8.1

1. a. Reconstruction
   b. Filtering (Smoothing
   c. Amplification (Optional)
2. a. This process converts a continuous analogue signal into a discrete digital signal that can be processed by digital systems. It involves sampling, quantisation and encoding of the analogue signal to obtain a discrete/digital signal.
   b. This process converts discrete digital signals back into continuous analogue signals. It involves the reconstruction and filtering/ smoothing of a digital signal into an analogue signal.
3. **Reason for Analogue-to-Digital Conversion:**
   a. The digital processing unit can only interpret and process discrete data, as it operates in binary format. Converting the analogue signals to digital allows the system to perform computations, store data efficiently, and share information with other digital devices.
   b. **Two Main Stages of Analog-to-Digital Conversion:**
      i. **Sampling:** The continuous analogue signal is measured at regular intervals to capture its values over time.
      ii. **Quantisation**: The sampled values are rounded to the nearest discrete level within a range, converting them into digital form.
   c. **Challenges and Solutions:**
      i. Challenge 1: **Loss of Information During Quantisation:**
      Solution: Use a high-resolution analogue-to-digital converter (ADC) with more bits to minimise quantisation error.
      ii. Challenge 2: **Noise Interference in Analog Signals:**
      Solution: Implement proper filtering techniques to remove noise before conversion.
   d. Reason for Digital-to-Analog Conversion:

The display unit may use an analogue system to show the temperature and humidity (e.g., moving pointers or smooth graphs). Digital-to-analogue conversion ensures that the data is transformed into a format suitable for such displays.

Review questions 8.2

1. Logic ‘0’ (Low) and Logic ‘1’ (High).
2.



A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

3. A combinational circuit is a type of digital circuit where the output depends only on the current inputs, without memory elements.
4. An AND gate requires all inputs to be high for the output to be high, while an OR gate requires at least one input to be high for the output to be high.
5. $F = \overline{A}.\ \overline{B}.C + \overline{A}.B.\ \overline{C} + A.\ \overline{B}.\ \overline{C} + A.B.C$
6. To achieve the specified logic:
   a. Use a NOT gate on B to invert it.
   b. Use an AND gate to combine A, NOT B, and C.
   c. The output of the AND gate will be high only when A=1, B=0, and C=1.

Review Questions 8.3

1. Transistors, resistors, capacitors, and diodes.
2. They are smaller, consume less power, are more reliable, and cost less when mass-produced.
3. Analogue ICs handle continuous signals, digital ICs process binary signals, and mixed-signal ICs combine both for applications like audio processing.

4. Integrated circuits are the foundation of microprocessors, memory chips, and sensors in devices like smartphones and computers.

ANNEX A - SOLUTIONS TO SOME ACTIVITIES

Dimensional Analysis

Activity 1.1

1. Length, L
2. Mass, M
3. Time, T
4. Amount, n
5. Temperature, θ
6. Luminous intensity, I_v
7. Current, I

Activity 1.2

1. The equation is valid.
2. The equation is not valid, as the left-hand side dimensions are L and the right-hand side dimensions are L^2T^{-1}.

Activity 1.3

1. $h = k\,a\,t^2$

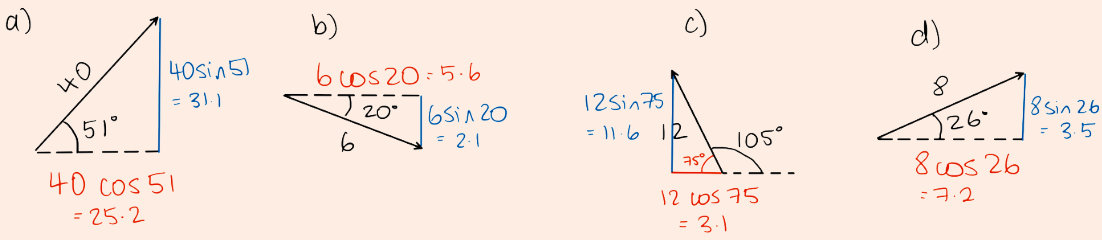
Activity 1.6

$$\textit{Resultant displacement} = \sqrt{100^2 + 50^2} = \sqrt{12500} = 111.8\,m$$

$$\theta = \tan^{-1}\left(\frac{50}{100}\right) = 26.6\ \textit{degrees}$$

Activity 1.7

1.



2.

Step 1: Identify the given information

Magnitude of the force, F = 10.0 N

Angle with respect to the ground, $\theta = 30^0$

Step 2: Use the trigonometric relationships

- $F_x = F \times \cos(\theta)$
- $F_y = F \times \sin(\theta)$

Step 3: Substitute the values

For the horizontal component:

$F_x = 10.0\text{ N} \cos(30^0)$

Using $\cos(30^0) \approx 0.866$:

$F_x \approx 10.0 \times 0.866 = 8.66\text{ N}$

For the vertical component:

$F_y = 10.0\text{ N} \times \sin(30^0)$

Using $\sin(30^0) = 0.5$:

$F_y = 10.0 \times 0.5 = 5.0\text{ N}$

Step 4: Final answer

The horizontal component of the force is 8.66 N.

The vertical component of the force is 5.0 N.

Activity 1.8

1.

Step 1: Identify the given information

Vertical distance (up), y =10 m

Horizontal distance (right), x = 8 m

Step 2: The inclined distance is the hypotenuse of a right triangle formed by the vertical and horizontal distances. Introduce the Pythagorean Theorem to calculate it:

$$d = \sqrt{x^2 + y^2}$$

Where d is the inclined distance, x is the horizontal distance, y is the vertical distance.

Step 3: Substitute the given values and compute to get the inclined distance

$$d = \sqrt{8^2 + 10^2} = 12.8 \, m$$

So, the inclined distance the ball travelled before starting to fall is 12.81 m.

Step 4: Introduce the tangent function to find the angle

$$\tan\theta = \frac{y}{x}$$

Step 5: make θ the subject

To find θ, take the inverse tangent (arctan or $\tan^{-1}$) of both sides:

$$\theta = \tan^{-1}\left(\frac{y}{x}\right)$$

Step 6: Substitute the known values

$$\theta = \tan^{-1}\left(\frac{10}{8}\right)$$

$$\theta = \tan^{-1}(1.25)$$

Using a calculator

$$\theta = 51.34°$$

So, the ball was kicked at an angle of 51.34° to the ground.

2.

Step 1: Identify the given information

Given:

- Force F_1=20 N
- Force F_2=15 N

- The angle between F_1 and F_2 is $\theta = 60°$

Step 2: Introduce the law of cosines

To find the magnitude of the resultant force, we will use the law of cosines:

$$F = \sqrt{F_1^2 + F_2^2 + 2(F_1 \times F_2)\cos\theta}$$

Step 3: Substitute the known values and compute:

$$F = \sqrt{20^2 + 15^2 + 2(20 \times 15)\cos(60°)}$$

$$F = \sqrt{400 + 225 + 300}$$

$$F = \sqrt{925} = 30.41$$

So, the magnitude of the resultant force is 30.41 N.

Step 4: Introduce the law of sines to find the direction (Angle of Motion) with Respect to the East

To find the direction of motion (the angle α that the resultant force makes with the east direction), we can use the law of sines:

$$\frac{F}{\sin\beta} = \frac{F_1}{\sin\alpha}$$

Rearranging to solve for α

$$\alpha = \sin^{-1}\left(\frac{F_1 \sin\beta}{F}\right)$$

Step 5: Substitute the known values and compute

Substitute the known values:

$$\alpha = \sin^{-1}\left(\frac{20\sin(120)}{30.41}\right)$$

$$\alpha = \sin^{-1}\left(\frac{17.32}{30.41}\right)$$

$$\alpha = \sin^{-1}(0.569) = 34.7^0$$

So, the direction of the resultant force is 34.7° north of east.

Activity 1.10

Density = mass / volume $= \frac{1.5kg}{0.0003\,m^3} = 5000kg\,m^{-3}$

$Mass = Density \times Volume$

$Mass = 19{,}320 \text{ kg/m}^3 \times 0.0005\,m^3$

$Mass = 9.66kg$

Volume = mass / density = $\frac{2.4kg}{8000kg\,m^{-3}}$ = 0.0003 m^{-3}

Activity 1.12

Upthrust = volume × density × gravitational field strength

Upthrust, $u = \rho vg = 4 \times 1080 \times 10 = 43200$ N

Activity 1.20

1. **a.** $\frac{(1000 \times 9.81)}{0.05}$ = 196,200Nm-1

b. $0.5 \times 196{,}200 \times 0.05^2 = 245.25$ J

2. **a.** (70 × 9.81) / (75 - 50) = 27.468Nm-1

b. $0.5 \times 27.468 \times 25^2 = 8{,}583.75$ J

3. $0.5 = 0.5 \times 100 \times e^2$

$e^2 = 0.01$

e = 0.1m

4. $E = 0.5 \times 50{,}000 \times 0.05^2$

E = 62.5 J

Activity 1.22

1. **a.** $\frac{600}{0.0005}$ = 1,200,000Nm^{-2}

b. $\frac{0.002}{0.8}$ = 0.0025

c. $\frac{1{,}200{,}000}{0.0025}$ = 480,000,000Nm^{-2}

2. **a.** $\frac{5000}{0.002}$ = 2,500,000Nm^{-2}

b. $\frac{0.001}{2}$ = 0.0005

c. $\frac{2{,}500{,}000}{0.0005}$ = 5,000,000,000Nm^{-2}

3.

$E = 1.1 \times 10^{11}\ Nm^{-2}$

Strain $= \frac{0.003}{1.5} = 0.002$

Stress = E × strain = $1.1 \times 10^{11} \times 0.002$ = 220,000,000 Nm^{-2}

Force = Stress × Area = 220,000,000 × 0.0004 = 88,000N

Activity 2.1

Table 2.2: Heat Capacities

Order from best (1) to worst (6)	Material	Specific heat capacity (J/kg°C)
4	Air	1003
3	Carbon dioxide	839
1	Iron	412
2	Steel	466
6	Water (room temperature)	4181
5	Water (boiling point)	2080

Answer to table 2.1

Activity 2.2

The material that reached the highest temperature had the lowest specific heat capacity, and vice versa.

Activity 2.5

1. Q = m × c × T = 1.5 × 900 × (75-25) = 67.500 J.

2. Energy lost by copper = energy gained by water

500 × c × (150-35) = 600 × 4.18 × (35-25)

57,500 × c = 25,080

C = 0.436 J/g°C

3. Energy lost by metal = energy gained by water

200 × c × (200-30) = 400 × 4.18 × (30-25)

34,000 × c = 8,360

C = 0.246 J/g°

Activity 2.7

Melting: The process of a solid turning into a liquid at its melting point. This involves the addition of heat energy.

Freezing (Solidification): The process of a liquid turning into a solid at its freezing point. This involves the removal of heat energy.

Boiling: the process of a liquid turning into vapour (gas) throughout the volume of the liquid, at its boiling point. It also involves the addition of heat.

Condensation: The process of a gas turning into a liquid in the course of cooling. This occurs at the condensation point of the substance, which is the same as its boiling point.

Sublimation: The process of a solid changing directly into a gas without passing through the liquid state. This process requires the addition of heat energy to the solid.

Deposition: The process by which a gas turns directly into a solid without passing through the liquid state. It occurs when a gas is cooling.

Activity 2.11

$Q = m \times L = 0.5 \times 334{,}000 = 117{,}000$ J

The substance has experienced a state change with no change in temperature.
Energy lost by water = energy gained by substance

Water: $m \times c \times T = 0.4 \times 4200 \times 8 = 13440$ J

$13440 = 0.15 \times L$

$L = 89{,}600$ J/kg

Activity 3.4

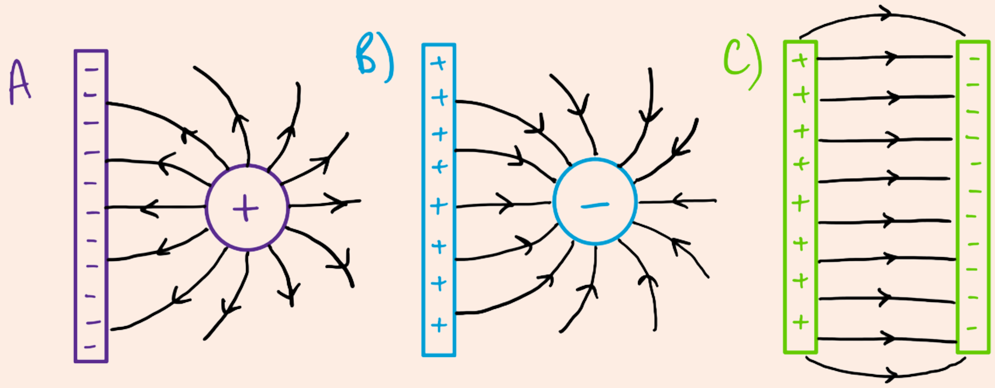


Figure 3.6: Solutions to Activity 3.4

Activity 3.5

$k = \frac{Fr^2}{q1q2}$

Therefore, the units for k are $\mathbf{Nm^2C^{-2}}$.

And, as $k = \frac{1}{4\pi\varepsilon 0}$, the permittivity of free space has units equal to the inverse of the units for k, i.e. $\mathbf{C^2m^{-2}N^{-1}}$.

Activity 3.7

1. 0.008 N

2. 0.009 N

3. 0.8485 m

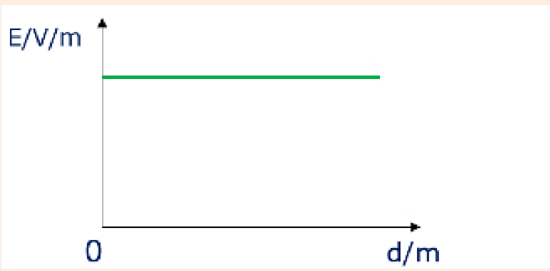
4. 0.00325 N

Activity 3.10

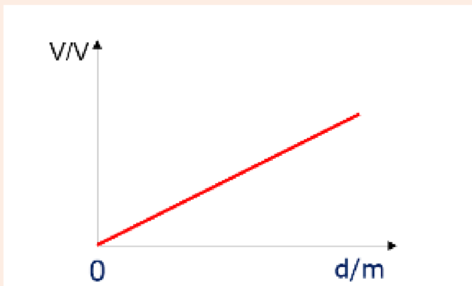
Table 3.2: Field Intensity

	Electric Potential	Electric Field Intensity
Definition	Electric potential at a point is the amount of work done to bring a unit positive charge from infinity to that point.	Electric field intensity (or electric field strength) is the force experienced by a unit positive charge placed at a point in the field.
Unit	Measured in volts (V)	Measured in newtons per coulomb (N/C) or Volts per meter (V/m)
Scalar or vector	It is a Scalar quantity (has magnitude only)	It is a Vector quantity (has both magnitude and direction)
Variation with distance from source charge	It decreases as the distance from the source charge increases, following an inverse relation with distance.	It also decreases with distance, but varies as the inverse square of the distance from the source charge.

Activity 3.11



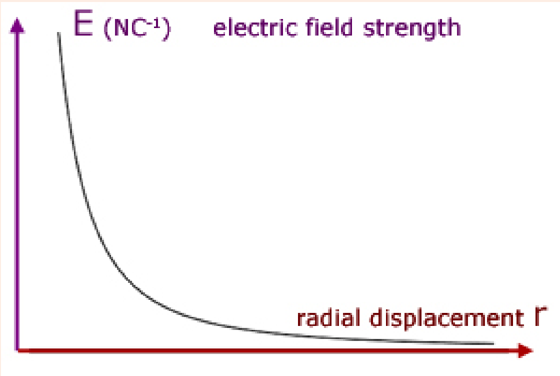
A: Electric field strength against distance



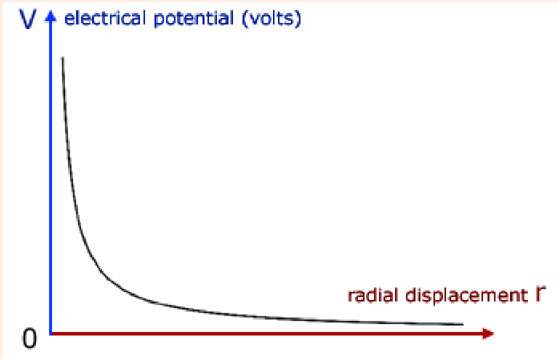
B: Electric potential against distance.

Figure 3.9: Graphs of Electric field strength and Electric potential against distance

Activity 3.12



A: Electric field strength against radial distance



B: Electric potential against radial distance.

Figure 3.10: Graph of Electric field strength and Electric potential against radial distance

Activity 3.13

1. 60 V
2. 10,000 N/C
3. 1.5×10^{-4} J
4. 7.00×10^{5} N/C

Activity 3.18

1. 3μF
2. 1.3275×10^{-11} F
3. 30 μF
4. 1.14 μF

Activity 3.23

1. 2.5×10^{-4} J
2. 10μF
3. 2.25×10^{-4} J

Activity 4.6

1. $E = \frac{hc}{\lambda}$

   $E = \frac{(6.63 \times 10^{-34}) \times (3.0 \times 10^{8})}{(500 \times 10^{-9})}$

   $E = 3.98 \times 10^{-19}$ J

2. $W_o = 2.5 \times 1.6 \times 10^{-19}$ J

   $W_o = 4.0 \times 10^{-19}$ J

   $W_o = h \times f_o$

   $f_o = \frac{W_o}{h}$

   $f_o = \frac{4.0 \times 10^{-19}}{6.63 \times 10^{-34}}$

   $f_o = 6.03 \times 10^{14}$ Hz

   $\lambda_o = \frac{hc}{E}$

   $\lambda_o = \frac{(6.63 \times 10^{-34}) \times (3.0 \times 10^{8})}{(2.5 \times 1.6 \times 10^{-19})}$

   $\lambda_o = 4.8 \times 10^{-7}$ m

3. $E = \frac{hc}{\lambda}$

   $E = \frac{(6.63 \times 10^{-34}) \times (3.0 \times 10^{8})}{(400 \times 10^{-9})}$

   $E = 4.97 \times 10^{-19}$ J

   $W_o = 3.0 \times 1.6 \times 10^{-19}$ J

   $W_o = 4.8 \times 10^{-19}$ J

   $KE_{max} = E - W_o$

   $KE_{max} = 4.97 \times 10^{-19} - 4.8 \times 10^{-19}$

   $KE_{max} = 1.73 \times 10^{-20}$ J

Activity 4.8

Photoelectric effect - the emission of electrons from the surface of a metal when exposed to radiation of appropriate frequency/wavelength.

Photon - quantum of energy carried by a radiation of known wavelength.

Wave-particle duality - the concept that matter exhibits both wave-like and particle-like properties.

Threshold frequency- minimum frequency of an electromagnetic radiation which must be exceeded to be able to eject electrons from the surface of a given metal.

Activity 4.15

1. $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$

$\lambda = \frac{\ln 2}{12}$

$\lambda = 0.05776\ per\ year$

2. $N = N_0 e^{-\lambda t}$,

$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$,

$N = 150\, e^{-\left(\frac{\ln 2}{4} \times 10\right)}$

$N = 26.52\ g$

3. $\lambda = \frac{\ln 2}{3}$

$N_0 = N e^{\lambda t}$

$N_0 = 10\, e^{\frac{\ln 2}{3} \times 6}$

$N_0 = 40\ g$

4. $\lambda = \frac{\ln\left(\frac{N_0}{N}\right)}{t}$

$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

$T_{\frac{1}{2}} = \frac{\ln 2}{\left[\frac{\ln\left(\frac{N_0}{0.2N_0}\right)}{5}\right]}$

$T_{\frac{1}{2}} = 2.15\ years$

Activity 4.16

Radioactivity - spontaneous disintegration or decay of an unstable nucleus with the emission of radiations (α-particles, β-particles, γ-rays) and the release of energy to form a more stable nucleus.

Half-life - the time interval during which half of a given number of radioactive nuclei decay.

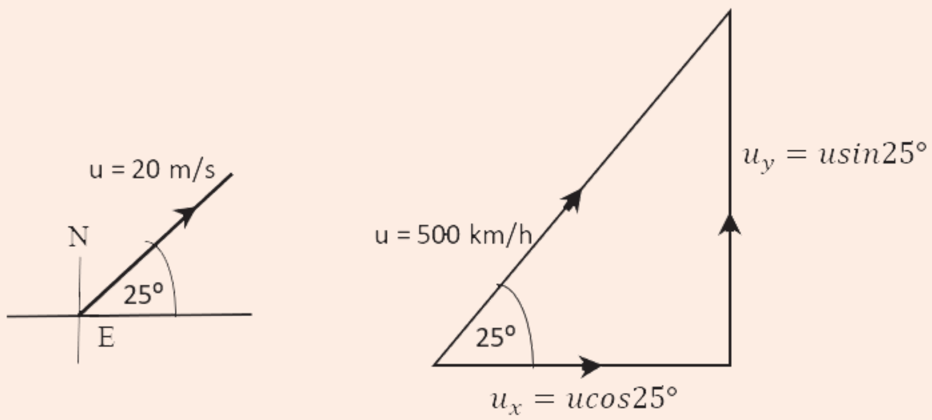
Decay constant - time rate of disintegration per unit nucleus of a radioactive element at an instant.

Decay law -The rate of disintegration/decay of a given nuclide at any time is directly proportional to the number of nuclei N of the nuclide present.

Activity 5.1

Resolving velocities

1.



Horizontal Component

$u_x = u\cos(\theta)$

$= 500\cos(25°)$

$= 453.15\ km/h\ (eastward)$

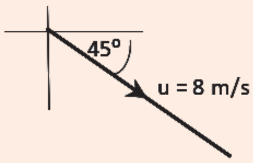
Vertical Component

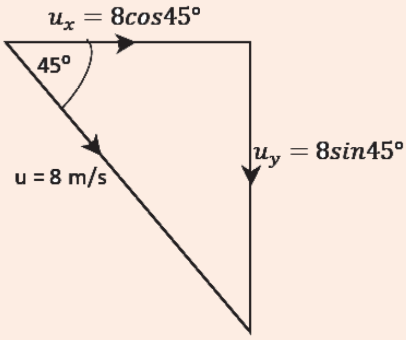
$u_y = u\sin(\theta)$

$= 500\sin(25°)$

$= 211.31\ km/h\ (northward)$

2.





Horizontal Component

$u_x = ucos(\theta)$

$= 8cos(45°)$

$= 5.66\ m/s$

Vertical Component

$u_y = u\ sin(\theta)$

$= 8sin(45°)$

$= -5.66\ m/s\ (negative\ because\ it's\ downward)$

Activity 5.6

1. $t = \sqrt{\frac{2h}{g}}$

$= \sqrt{\frac{2 \times 10}{9.8}}$

$= 1.43\ s$

2. R = 5 × 1.43 = 7.15 m

$R = (ucos\theta) \times t_f$

$= 63.78\ m$

3 **a.** $t_f = \frac{2usin\theta}{g}$

$= \frac{2(15)sin45}{10}$

$= 2.12\ s$

b. $R = (ucos\theta) \times t_f$

$= (15 \cos 45)(2.12)$

$= 22.49\ m$

Activity 5.10

3. $\mu_s = \frac{F_s}{ma} = \frac{50}{200} = 0.25$

4. $\mu_k = \frac{F_k}{ma} = 8\frac{0}{200} = 0.4$

5. $F = F_k + F_{net} = \mu_K mg + ma = m(\mu_K g + a) = 15(0.25 \times 10 + 2) = 67.5\ N$

Activity 5.15

ω = 6 rad/s, t = 10 s, θ = ? where ω = ang. velocity, t = time, θ = ang. displacement

$\omega = \frac{\theta}{t}$,

$\theta = \omega t = 6 \text{ rad/s} \times 10 \text{ s} = 60 \text{ rad}$

ω = 2 rad/s, t = 10 s rev = ?

1 s = 2 rad

$10 \text{ s} = \frac{10\ s}{1\ s} \times 2 \text{ rad} = 20 \text{ rad}$

$2\pi \text{ rad} = 1 \text{ rev}$

$20 \text{ rad} = \frac{20\ rad}{2\pi rad} \times 1 \text{ rev} = 3.182 \text{ rev}$

r = 2 m, ω = 15 rev/min, angular velocity ω in rad/s = ? centripetal force = ?

1 minute = 60 s = 15 rev

$1 \text{ s} = \frac{1\ s}{60\ s} \text{x} 15 \text{ rev} = 0.25 \text{ rev}$

$1 \text{ rev} = 2\pi \text{ rad}$

$\text{rev} = \frac{0.25\ rev}{1\ rev} \times 2\pi \text{ rad} = 1.571 \text{ rad/s}$

m = 2 kg, v = ? $F_C = \frac{mv^2}{r}$

$v = \omega r = 1.571 \times 2 = 3.142 \text{ m/s}$

$F_C = \frac{mv^2}{r} = \frac{2)(3.142\frac{m}{s})^2}{2} = 9.86 \text{ N}$

Activity 5.17

1. $\tan\theta = \frac{v^2}{rg}$

$\tan\theta = \frac{25^2}{50 \times 9.8}$

$\tan\theta = 1.2755$

$\theta = tan^{-1}(1.2755)$

$\theta = 51.3°$

2. $v = \sqrt{rg\tan\theta}$

$= \sqrt{100 \times 10 \times \tan 15}$

$= 16.37\ m/s$

3. $\tan\theta = \frac{v^2}{rg}$

$r = \frac{v^2}{g\tan\theta}$

$r = \frac{30^2}{9.8\tan 40}$

$r = 109.5\ m$

4. $v = \sqrt{rg\tan\theta}$

$= \sqrt{80 \times 9.8 \times \tan 25}$

$= 19.1\ m/s$

Activity 5.21 Forces acting on the object at the bottom of the circle

At the bottom of the circle, two forces act on the object:

- **Tension** (T_{bottom}) in the string, directed **upward** toward the centre of the circle.
- **Weight (mg)** of the object, directed **downward** due to gravity.

Writing the Equation at the Bottom of the Circle

$T_{bottom} - mg = \frac{mv^2}{r}$

$T_{bottom} = \frac{mv^2}{r} + mg$

Forces Acting on the Object at the Top of the Circle

At the top of the circle, two forces act on the object:

- **Tension** (T_{top}) in the string, directed **downward** toward the centre.
- **Weight (mg)**, also directed **downward**.

Writing the Equation at the Top of the Circle

$$T_{top} + mg = \frac{mv^2}{r}$$

$$T_{top} = \frac{mv^2}{r} - mg$$

Maximum Tension occurs at the **bottom** of the circle:

$$T_{max} = \frac{mv^2}{r} + mg$$

Minimum Tension occurs at the **top** of the circle:

$$T_{min} = \frac{mv^2}{r} - mg$$

Activity 5.23

$$T_{bottom} = \frac{mv^2}{r} + mg$$

$$T_{bottom} = \frac{(2) \times 5\ 2}{5} + 2 \times 9.8$$

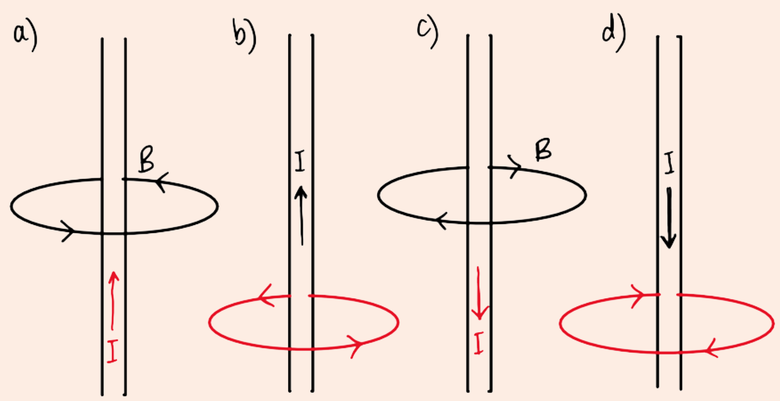
$$T_{bottom} = 52.93\ N$$

$$T_{top} = \frac{mv^2}{r} - mg$$

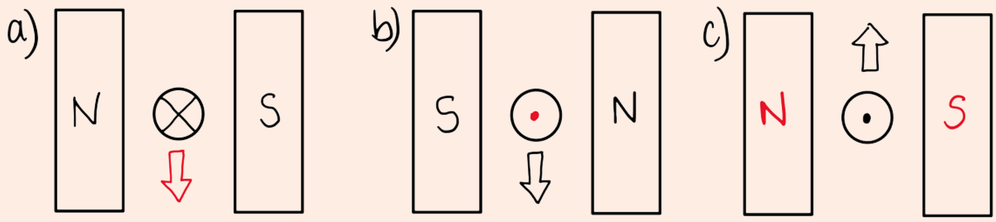
T_top^ $= \frac{0.5 \times 8^2}{0.8} - (0.5 \times 9.8)$

$$T_{top} = 0.725\ N$$

Activity 6.1



Activity 6.4



Activity 6.6

1. B = 0.1 T, I = 3 A, L = 1 m, $\theta = 30°$

F = B · I · L sin θ

F = 0.1 × 3 × 1 × sin (30°)

F = 0.1 × 3 × 1 × 0.5

F = 0.15 N

2. B = 0.3 T, I = 4 A, L = 2 m, $\theta = 45°$

F = B · I · L sin θ

F = 0.3 × 4 × 2 × sin (45°)

F = 0.3 × 4 × 2 × 0.707

F = 1.6968 N

Activity 6.10

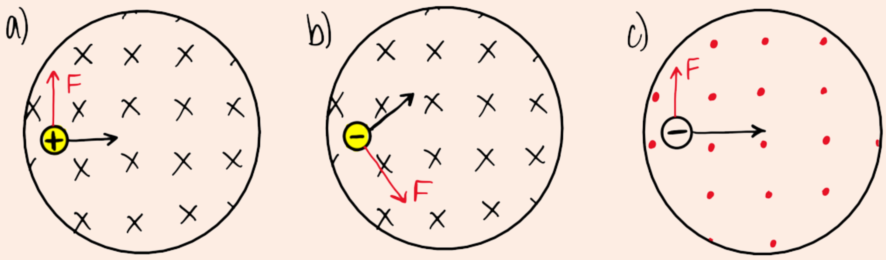
1. B = 0.4 T, I = 3 A, L = 0.15 m, W = 0.25 m, N = 200 turns, $\theta = 45°$

$\tau = n\, I\, B\, A\, sin)$

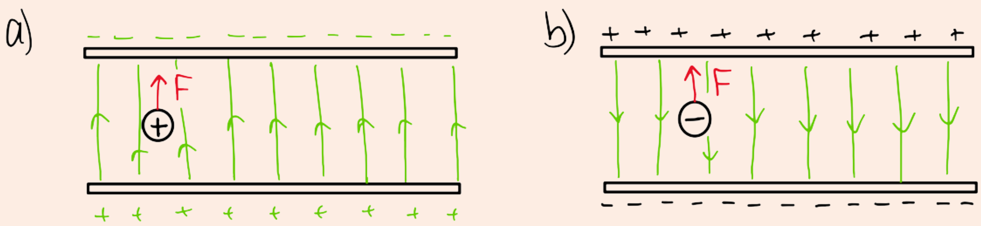
$\tau = 200\ x\ 3\ x\ 0.4\ x\ 0.15\ x\ 0.25\ x\ sin(45)$

$= 6.36\ Nm$

Activity 6.15



Activity 6.16



Activity 6.18

1. Electric force balances with weight, so Eq = mg. F = mg = 3.0×10^{-5} N, q = 4.0×10^{-6} C

$$E = \frac{F}{q} = \frac{3.0\ x\ 10 - 5\ N}{4.0\ x\ 10 - 6\ C} = 7.5\ N/C$$

2. E = 5.2 N/C, B = 0.1 T

$$v = \frac{E}{B} = \frac{5.2\ N/C}{0.1\ T} = 52\ m/s$$

Activity 7.9

Wave Type	Characteristics Observed	Classification
Sound Wave	- Compressions and rarefactions observed in the medium. - Waves travel through air, showing changes in pressure. - Speed varies with medium (faster in solids than in gases).	Longitudinal, Mechanical Wave
Wave on a String	- Up and down movement creates visible waves. - Clear amplitude and wavelength can be measured. - Energy travels along the string without moving the string itself significantly.	Transverse, Mechanical Wave
Fourier Waves	- A combination of multiple sine waves creates complex waveforms. - Changes in frequency and amplitude affect overall shape. - Demonstrates how complex waves can be broken down into simpler components.	Transverse, Mechanical Wave
Wave Interference	- Two waves interacting create patterns of constructive and destructive interference. - Observable nodes (points of no movement) and antinodes (points of maximum movement). - Shows how waves can combine in space.	Can include both Transverse and Longitudinal, Mechanical Wave

Activity 7.14

1. **a.** $y = 0.05sin(10\pi \times 0.5 - 2\pi \times 2) = 0$

b. 0.05 m

2. a. $\omega = 50\frac{rad}{s}, k = 4\ rad/m$

b. $f = \frac{50}{2\pi} = \frac{25}{\pi}\ Hz$

c. $\lambda = \frac{2\pi}{k} = \frac{\pi}{2}, v = \lambda f = \frac{\pi}{2} \times \frac{25}{\pi} = 12.5\ m/s$

3. a. $f = \frac{340}{2} = 170\ Hz$

b. $\omega = 2\pi \times 170 = 1068.14\ rad/s$

4. a. 0.08 m

b. $f = 50\ Hz, \omega = 2\pi \times 50 = 314.16\ rad/s$

5. a. $y = 0.05\sin(10\pi t - \frac{\pi x}{2})$

b. $y = 0.05\sin\left(10\pi(0.1) - \frac{\pi(1)}{2}\right) = 0.05\ m)$

6. a. 0.03 m

b. negative x-direction

c. $\omega = 5\ rad/s, k = 3\ rad/m$

d. $f = \frac{5}{2\pi}\ Hz, v = \frac{2\pi}{3} \times \frac{5}{2\pi} = \frac{5}{3}\ m/s$

Activity 8.3

1. a. 1100

b. 11001

c. 100001

d. 101110

e. 111001

2. a. 13

b. 18

c. 31

d. 24

e. 44

f. 69

Activity 8.13

Down

Up

Up

Down

Up

Activity 8.16

Advantages	Disadvantages
1. **Simplicity**: Easy to understand and implement, especially for basic numerical displays. 2. **Cost-Effective**: Relatively inexpensive, making them suitable for budget-sensitive projects. 3. **Low Power Consumption**: LEDs consume less power compared to other display types like LCDs or OLEDs. 4. **Direct Drive Capability**: Can be directly driven by microcontrollers or simple circuits without needing complex drivers. 5. **Robustness:** Durable and long-lasting under normal operating conditions. 6. **Visibility**: Provides good visibility in low-light environments, especially with bright LEDs.	1. **Limited Character Representation:** Can only display numbers and a small subset of alphabetic characters, making it unsuitable for text-heavy applications. 2. **Aesthetic Limitations**: Lack of flexibility in design; displays are restricted to the fixed 7-segment format. 3. **Viewing Angle:** LEDs can have limited viewing angles, making them less visible from certain angles. 4. **Complex Multiplexing for Multiple Digits**: Requires additional circuitry (e.g., multiplexing or driving ICs) for multi-digit displays. 5. **Power Distribution Challenges**: In systems with multiple digits, the power requirement increases and needs careful management.

Uses of Capacitors

Capacitors are versatile components used in various applications across electronics and electrical engineering. Key uses include

Table 3.4: Component Use

Use	Description
Energy Storage	Stabilising power supplies and providing backup power.
Signal Processing	Filtering frequencies, coupling AC signals, and decoupling noise.
Timing Applications	Creating precise time delays and generating pulses in circuits.
Power Factor Correction	Improving efficiency in power systems.
Motor Starters	Enhancing the performance of AC motors.
Electronic Tuning	Adjusting frequencies in radio and RF circuits.
Surge Protection	Absorbing voltage spikes to protect components.
Lighting	Improving performance and reducing flicker in fluorescent lamps and LED drivers.
Energy Harvesting	Storing energy from renewable sources.
Audio Applications	Directing frequencies in speaker systems and filtering noise.
Medical Devices	Providing quick energy discharge in defibrillators.
Communication Systems	Facilitating modulation and demodulation.
Computing	Stabilising power supply and reducing noise near ICs.

ANNEX B – FURTHER INFORMATION

1. **Time taken to reach maximum height**

   At the maximum height, the projectile stops briefly before falling, so the final velocity $v_y = 0$, therefore;

   $0 = u\sin\theta - gt$,

   $$\boldsymbol{t} = \frac{u\sin\boldsymbol{\theta}}{\boldsymbol{g}}$$

2. **Time of flight (t_f)**

   It is the total time a projectile takes to travel from the point of projection to where it lands. In the absence of air resistance, the motion is symmetrical. This means the time the projectile takes to rise to its maximum height equals the time it takes to descend from the maximum height back to the level of projection.

   $$\boldsymbol{t_f} = \frac{2u\sin\boldsymbol{\theta}}{\boldsymbol{g}}$$

3. **The range (R)**

   This is the entire horizontal distance covered by a projectile during the time of flight, i.e. horizontal distance from launch/projection to landing.

   Remember $x = u\cos\theta$, then $\boldsymbol{R} = u\cos\boldsymbol{\theta}$

4. **Maximum Height**

   This is the highest vertical point a projectile reaches above the level of its initial projection during its motion.

   At the maximum height,

   $v_y = 0$, and we replace y with H

   $0^2 = u^2\sin^2\theta - 2gH$

   $$H = \frac{u^2\sin^2\theta}{2g}$$

Applications of projectile motion

1. **Sports and Games:**
   a. **Throwing and Kicking**: The path of a football, basketball, or baseball follows a parabolic trajectory.
   b. **Golf and Cricket**: Hitting a ball into the air involves projectile motion.

c. **Archery and Javelin**: The arrows or javelins travel in curved paths under the influence of gravity.

In all the examples above, the balls are the projectiles.

2. **Entertainment:**

Fireworks: The bursts of fireworks are designed based on principles of projectile motion.

Theme Park Rides: Rides like roller coasters or water slides often mimic parabolic trajectories.

Annex B – Further information

Table 5.1: Applications of friction

	Daily life	Transportation	Industry/engineering
1	Walking/running	Braking systems	Filing, sanding, grinding, polishing
2	driving	Movement of trains	Belts and pulleys
3	Holding objects	Airplane landing	Friction welding
4	Lighting matches		Sawing, cutting
5	Sharpening tools		Screws, Bolts and nuts, nails
6	cutting		

Table 5.2: Disadvantages of friction and mitigation of friction

Disadvantages	Reducing friction
Reduces efficiency	Polishing
Causes wear and tear	Lubrication
Causes heating of machines	Using wheels and rollers
	Using ball-bearings

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GLOSSARY

7-Segment Display: An electronic display component used to show numbers and some letters using illuminated segments.

ADC (Analogue-to-Digital Conversion): The process of converting continuous analogue signals into digital format for processing and storage.

Amplitude: Maximum displacement of a wave's particle from its equilibrium position.

Analogue Signal: A continuous signal that varies smoothly over time, representing information such as sound or light intensity

Banking: The act of constructing roads in a manner that will help cars negotiate curves at relatively higher speeds.

Boolean Algebra: A mathematical system used to represent and simplify logical operations in binary systems.

Capacitor: A device that stores electrical energy.

Centripetal Force: Force acting on a charged particle in a circular path due to a magnetic field.

Combinational Circuit: A type of digital circuit where the output depends only on the current inputs.

Compression: High-pressure region in a longitudinal wave where particles are close together.

Crossed Field: A region with perpendicular electric and magnetic fields affecting particle motion.

DAC (Digital-to-Analogue Conversion): The reverse process, converting digital signals back into continuous analogue signals.

Deformation: The change in shape or dimensions of a body.

Density: the mass per unit volume of an object.

Diffraction: Spreading of waves around obstacles or through openings.

Digital Signal: A discrete signal that alternates between two states, typically represented as 0 and 1.

Echo: Reflection of sound waves from a surface back to the original location.

Electric Field (E): A field around charged particles exerting force on other charges.

Electric Field Intensity: Force per unit charge in an electric field.

Electric Potential: Work done per unit charge to move a charge in an electric field.

Electromagnet: A magnet created by electric current flowing through a coil of wire.

Electromagnetic Relay: A switch operated using an electromagnet.

Fleming's Left-Hand Rule: A rule to determine the direction of force on a current-carrying conductor.

Flotation: The action of a body floating in a liquid or gas.

Fluid: A liquid or a gas.

Frequency: Number of complete oscillations per second, measured in hertz (Hz).

Friction: The force that opposes the relative motion or the tendency of such motion of two surfaces in contact.

Fusion: The process in which the liquid state turns into the solid state.

Galvanometer: A device that measures small electric currents via coil deflection.

Heat capacity: Heat capacity is defined as the amount of heat required to change the temperature of an object by 1°C or 1 K.

Interference: Overlap of waves, resulting in constructive (amplifying) or destructive (cancelling) patterns.

Latent heat: Latent heat is the quantity of heat required or removed when an object changes state, without a temperature change.

Logic Gate: A basic building block of digital circuits that performs logical operations based on binary inputs.

Lorentz Force: The force on a charged particle moving through electric and magnetic fields.

Magnetic Flux Density (B): The strength of a magnetic field, measured in teslas (T).

Magnetic Force: The force on a current-carrying conductor in a magnetic field.

Microcontroller: A compact integrated circuit designed to perform specific operations in embedded systems.

Motor Principle: A current-carrying conductor in a magnetic field experiences force, causing rotation.

Parallel Conductors: Wires carrying currents, interacting to produce attractive or repulsive forces.

Period: Time taken for one complete wave cycle; reciprocal of frequency.

Photoelectric effect: the emission of electrons from the surface of a metal when exposed to radiations of appropriate frequency/wavelength.

Polarisation: Restricting wave oscillations to a single plane, applicable to transverse waves like light.

Progressive Wave: A wave transferring energy through a medium without permanent displacement of particles.

Projectile - any object that is launched or thrown into the air and moves solely under the influence of gravity.

Radioactivity: the spontaneous disintegration or decay of an unstable nucleus with the emission of radiations (α-particles, β-particles, γ-rays) and the release of energy to form a more stable nucleus.

Rarefaction: Low-pressure region in a longitudinal wave where particles are spread apart.

Refraction: Bending of a wave as it passes between two media with different densities.

Resonance: Maximum vibration amplitude occurring when a system vibrates at its natural frequency.

Solenoid: A coil of wire generating a magnetic field when electric current flows through it.

Specific heat capacity - Specific heat capacity is defined as the amount of heat required to change the temperature of 1 kg of a substance by 1°C or 1 K.

Spring constant: The force required to extend a material per unit length.

Standing Wave: Wave pattern with nodes and antinodes, formed by interference of incident and reflected waves.

Torque: Rotational force on a current-carrying coil in a magnetic field.

Upthrust: The upward force that a liquid or gas exerts on a body floating in it.

Vaporisation: The process in which the liquid state turns into the gas state.

Vector: Quantities which have both magnitude and direction.

Velocity Selector: A device that allows particles with a specific velocity to pass undeflected.

Wave Velocity: Distance a wave travels per second, calculated as frequency multiplied by wavelength.

Wavelength: Distance between two consecutive points in phase, such as crests or compressions.

Young's modulus: The ratio of the stress to the strain in a material.

This book is intended to be used for the Year Two Physics Senior High School (SHS) Curriculum. It contains information and activities to support teachers to deliver the curriculum in the classroom as well as additional exercises to support learners' selfstudy and revision. Learners can use the review questions to assess their understanding and explore concepts and additional content in their own time using the extended reading list provided.

All materials can be accessed electronically from the Ministry of Education's Curriculum Microsite.

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