MINISTRY OF EDUCATION

PHYSICS

for Senior High Schools

TEACHER MANUAL

Year 2

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

Physics

for Senior High Schools

Teacher Manual

Year Two

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

PHYSICS TEACHER MANUAL

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Introduction

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS) curriculum which aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS 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.

This Teacher Manual for Physics is a single reference document which covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year Two of the new curriculum. It contains information for all 24 weeks of Year Two including the nine key assessments required for the Student Transcript Portal (STP).

Thank you for your continued efforts in teaching our children to become responsible citizens.

It is our belief that, if implemented effectively, this new curriculum 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.

Acknowledgements

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SECTION 1: DIMENSION, VECTORS, FLOTATION AND DEFORMATION

Strand: Mechanics and Matter

Sub-Strand: Basic Physics

Learning Outcomes

1. *Use dimensional analysis to check the validity and to derive equations.*
2. *Use the concept of vectors to represent quantities.*

Use the concept of flotation and its related issues to identify substances that will float and give reasons why they will float

Content Standards

1. Demonstrate understanding of dimensional analysis and its relevance to working with equations.
2. Demonstrate knowledge and understanding of vectors.
3. Demonstrate knowledge and understanding of flotation.

Strand: Mechanics and Matter

Sub-Strand: Matter

Learning Outcome: *Use the concept of elasticity to predict the behaviour of materials under the influence of stress and strain.*

Content Standard: Demonstrate knowledge and understanding of the behaviour of materials.

HINT

- *Learners should be assigned their Individual **Portfolios** in Week 2 to be presented in Week 21. Refer to **Appendix A** at the end of this section and the Teacher Assessment Manual and Toolkit page 22 for information on the portfolio.*
- *Learners should be assigned **Group Project** in Week 3 on the use of electric fields in technology and present their research findings in Week 7. Refer to **Appendix B** at the end of this section and the Teacher Assessment Manual and Toolkit page 27 for more information on the project.*

INTRODUCTION AND SECTION SUMMARY

This section introduces learners to the fundamental concepts of dimensional analysis and the use of vectors; both of which are invaluable tools in physics and are applicable to many of its branches.

The section continues to look at the branch of matter, building on some of the content from Year 1. This includes density, flotation and deformation.

The weeks covered by the section are:

Week 1: Dimensional analysis

Dimensional analysis is essential for deriving and for ensuring the validity of equations, helping learners develop strong problem-solving skills and a deeper comprehension of the relationships between different physical quantities. How can we verify if an equation is dimensionally correct? Why is dimensional analysis crucial in physics and engineering?

Week 2: Vectors

Another key skill, which underpins much of the mathematical work that we do in physics, is the use of vectors. A vector is a quantity with both a direction and a magnitude, such as force and acceleration. We can resolve vectors into two perpendicular components to analyse their effects in those planes. We can also find the resultant of two vectors to discover, for example, the overall effect of multiple forces.

Week 3: Density, Archimedes' principle and Principle of flotation

Learners should be able to identify substances that will float and understand why they do so. Why does a heavy ship float while a small stone sinks? What factors determine whether an object will float or sink in a liquid? Flotation explores the principles of buoyancy and density, enabling learners to understand the practical reasons behind why certain substances float while others sink.

Week 4: Deformation

Learners should predict the behaviour of materials under stress and strain. The behaviour of materials, including their elasticity, their Young Modulus and their breaking stress, provides critical insights into how materials respond to various forces. This is crucial for applications in engineering and material science. What happens to a material when it is stretched or compressed? How do engineers ensure that structures can withstand various forces?

SUMMARY OF PEDAGOGICAL EXEMPLARS

The pedagogical strategies employed in this section are designed to enhance learner engagement and understanding through practical and critical knowledge applications.

Dimensional analysis and vector analysis is taught through problem-solving sessions that use practical examples, helping learners see the real-world relevance of these techniques.

For flotation, demonstrations and experiments allow learners to observe objects floating or sinking in different liquids, making the concepts tangible and easier to grasp. The behaviour of materials is also explored through hands-on activities and simulations, enabling learners to observe and predict how materials react under various conditions.

ASSESSMENT SUMMARY

Assessment methods in this section are designed to evaluate both the understanding and practical application of the concepts taught, following Bloom's amended taxonomy.

Dimensional analysis and vector analysis will be assessed through problem-solving exercises and written tests to measure learners' ability to derive and validate equations.

For flotation, learners will be assessed through practical tests and quizzes that evaluate their grasp of buoyancy and density principles.

The behaviour of materials will be assessed through experimental reports and practical assessments of experiments involving elasticity, stress, and strain.

WEEK 1

Learning Indicators

1. *Check the validity of equations*
2. *Establish the relationship between quantities*
3. *Resolve vectors into their components*
4. *Determine the resultant of two vectors*

FOCAL AREA 1: DIMENSIONAL ANALYSIS

In physics, the word "dimension" denotes the physical nature of a quantity. For example, when playing "small poles," we use our feet to measure distances, or when drawing a circle for play, we use our arm's length as the radius. These are different ways of giving a unit for length. The symbols used to specify length, mass, and time dimensions are L, M, and T, respectively. Brackets [ ] are often used to denote the dimensions of a physical quantity.

Figure 1: *QR code for a video on dimensional analysis*

In physics, it's often necessary to deal with mathematical expressions that relate different physical quantities. Dimensional analysis is a method used to validate equations by ensuring that the dimensions on both sides of the equation match. This technique helps verify the correctness of equations and ensures they are dimensionally consistent.

For example, consider the equation for speed, $v = \frac{d}{t}$, where v is speed, d is distance, and t is time. The dimensions on both sides must be the same. Speed has dimensions $[L][T]^{-1}$, distance has dimensions $[L]$, and time, the denominator, has dimensions $[T]$. Therefore, the equation is dimensionally consistent.

Learners can be given various physical equations to analyse and practice validating equations using dimensional analysis. They can break down the dimensions of each term and ensure they match on both sides. This practice helps identify errors in the equations and reinforces the importance of dimensional consistency. Deriving equations using dimensional consistency involves using the fundamental dimensions to form equations that describe physical phenomena. Using this method teaches learners how to derive meaningful equations from fundamental principles.

LEARNING TASKS

1. Validate equations using dimensional analysis.
2. Derive equations using dimensional consistency.

PEDAGOGICAL EXEMPLARS

1. Problem-Based and/or Collaborative Learning

a. Provide learners with various equations to validate using dimensional analysis, ensuring they understand that units must match on both sides. Learners could do this individually or in groups.

i. Ensure that a worked example is provided to support learners if needed.

ii. For more able learners, provide a list of more complex equations from various branches of physics for verification.

b. Provide problems for groups to derive equations from a list of related variables, ensuring dimensional consistency and sharing steps.

i. Ensure that a worked example is provided to support learners if needed.

c. In groups of mixed ability, discuss the importance of dimensional analysis including verification and derivation of formulae. Prompt learners to consider the impact of poor dimensional analysis in various scenarios or industries.

KEY ASSESSMENT

Level 1: What is the purpose of dimensional analysis?

A. To measure the length of an object.

B. To check the consistency of equations.

C. To find the mass of an object.

D. To solve algebraic equations.

Level 2: Demonstrate the dimensional consistency of the equation $s = ut + \frac{1}{2}at^2$.

Level 3: Discuss the limitations of dimensional analysis and provide examples where it may not be sufficient to validate an equation.

Level 4: Conduct research on a historical scientific discovery that involved dimensional analysis. Prepare a brief report and presentation that explains the role of dimensional analysis in the discovery.

FOCAL AREA 2: VECTORS

Vectors are quantities with both magnitude and direction, essential for describing physical phenomena like forces and velocities. For example, in the 2023 African Games Final between the Ghana Black Princesses and the Nigerian Falconets, Mukarama Abdulai scored the winning goal in the 98th minute. When she kicked the ball, the force she applied to the ball can be represented as a vector. This vector has both magnitude (the force behind of the kick) and direction (the angle at which the ball is kicked).

Resolving Vectors

Resolving a vector into two perpendicular components is a fundamental skill in physics. Often, these components are horizontal and vertical.

The force with which Mukarama Abdulai kicked the ball can be broken down into two components:

1. Horizontal component (F_x) represents the force that moves the ball horizontally towards the goal.
2. Vertical component (F_y) represents the force that lifts the ball vertically off the ground.

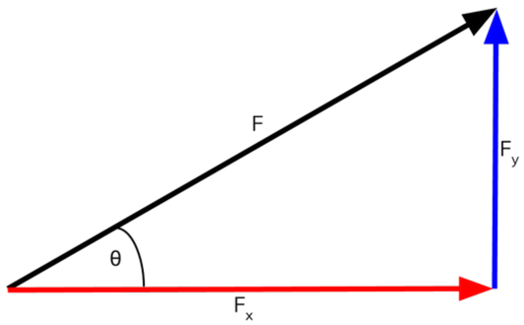


Figure 2: *Components of the vector F applied on the football*

Mukarama kicked the ball with a force F at an angle q to the horizontal and using trigonometric functions:

$F_x = F\ Cos\ \theta$

$F_y = F\ Sin\ \theta$

This resolution helps analyse vector quantities in different directions.

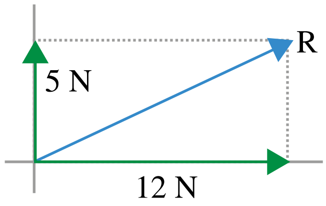
Figure 3: *QR code to access the PhET Interactive Virtual Simulation on Vectors*

Finding the Resultant of Two Vectors

Determining the resultant magnitude (R) of two perpendicular vectors involves using the Pythagorean theorem.

$R = \sqrt{F_x + F_y}$

e.g.,



Solution

$R = \sqrt{12^2 + 5^2}$

$R = \sqrt{144 + 25}$

$R = \sqrt{169}$

$R = 13\ N$

The angle to the horizontal of the resultant vector can be found trigonometrically;

$\tan\theta = \frac{5}{12}$

$\theta = \tan^{-1}(\frac{5}{12})$

$\theta = 22.6$ degrees

In the case of non-perpendicular forces, such as the tension in the two pieces of string which suspend a picture frame, the resultant can be determined using the parallelogram or triangle method. In the parallelogram method, vectors $\vec{a}$ and $\vec{b}$ are represented as adjacent sides of a parallelogram. The diagonal of the parallelogram represents the resultant vector.

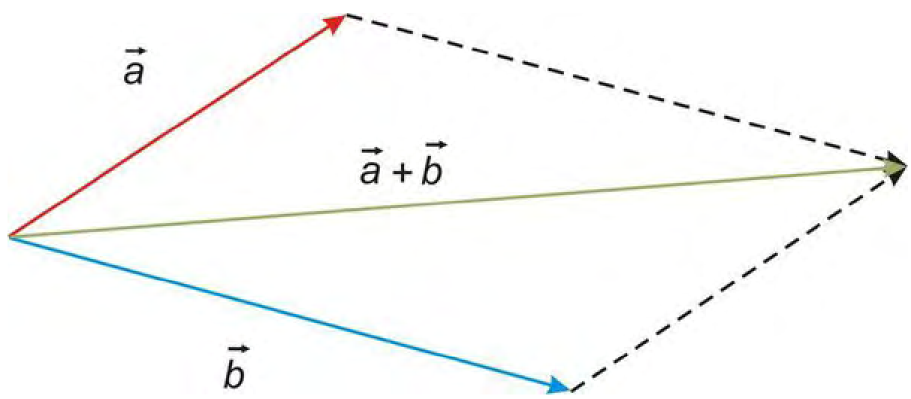


Figure 4: *Parallelogram Method of resolving vectors*

Alternatively, in the triangle method, the vectors are arranged head-to-tail, and the resultant vector is drawn from the first vector's tail to the second vector's head.

LEARNING TASKS

1. Resolve a vector into its horizontal and vertical components.
2. Determine the resultant of two perpendicular vectors using the Pythagorean theorem.
3. Determine the resultant of two non-perpendicular vectors using the parallelogram or triangle method.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   - **a.** Provide vectors at various angles for learners to resolve into horizontal and vertical components using trigonometric functions.
     - i. Ensure that a worked example is provided to support learners if needed.
   - **b.** Provide learners with some more contextualised examples of vectors which need resolving into two perpendicular components, such as blocks balanced on slopes (find components parallel and perpendicular to the slope) and boats being pulled by two angled tow-ropes (find components in the direction of the river flow and in a direction pointing directly towards the bank).
     - i. Ensure that a worked example is provided to support learners if needed; learners often find it challenging to form the relevant triangles and to identify the trigonometric functions needed when the components are not horizontal and vertical.
   - **c.** Guide learners to determine resultants of perpendicular vectors using the Pythagorean theorem.
     - i. Ensure that a worked example is provided to support learners if needed.
   - **d.** Guide learners to determine resultants of non-perpendicular vectors using the parallelogram or triangle method.
     - i. Ensure that a worked example has been demonstrated by the teacher, alongside a tutorial reminding learners how to use a protractor to replicate a vector arrow elsewhere on the page.
2. **Project-Based Learning**
   - **a.** Conduct experiments to visualise electric field patterns using materials like semolina or iron filings, comparing experimental patterns with theoretical illustrations. Discuss, in small groups, how both the magnitude and direction of the electric/magnetic fields can be inferred from the patterns observed.

KEY ASSESSMENT

Level 1: If two vectors are acting at right angles to each other, how would you determine the magnitude of their resultant?

Level 2: Determine the magnitude and direction of the resultant of two vectors, one with a magnitude of 5 N directed east and the other with a magnitude of 12 N directed north.

Level 3: Vectors K and L have arbitrary magnitudes and directions. Derive a general formula for the resultant of these vectors in terms of their magnitudes and the angle between them.

Hint

The recommended mode of assessment for week 1 is ***class exercise****. Use the Level 3 question as a sample question* and refer to the *Teacher Assessment Manual and Toolkit page 63 for more information on class exercise.*

WEEK 2

Learning Indicators

1. *Explain/define the term 'density'*
2. *State Archimedes' principle*
3. *State principle of flotation*

FOCAL AREA 1: DENSITY

Density is a crucial property of substances, defined as the mass per unit volume. Represented by the equation $\rho = \frac{m}{V}$, where ρ (rho) symbolises density, m is mass, and V is volume, density helps determine whether objects sink or float and aids in identifying their composition.

The density of a substance also reveals insights into its phase and substructure. Solids and liquids have comparable densities because their atoms are closely packed, while gases have much lower densities due to the empty space between atoms.

Figure 5: *QR code for a YouTube video illustrating the particle arrangements in different phases of matter*

Calculating density involves measuring the mass and volume of a substance. For example, if a metal cube has a mass of 500 grams and occupies a volume of 100 cubic centimetres, its density would be

$$\rho = \frac{500g}{100\,cm^3} = 5\,g/cm^3$$

In the classroom, learners can engage in experiments to measure the densities of various objects. Regular objects like cubes and cylinders can calculate their volume using geometric formulas, while irregular objects can measure their volume through water displacement. This hands-on approach solidifies the concept and enhances learners' experimental skills.

One experiment to understand density involves measuring the density of regular objects. Learners can use metal cubes, cylinders, balance scales, and rules. They measure the mass of the object using a balance scale, calculate the volume using the ruler (for a cube, $V=side^3$; for a cylinder, $V=\pi r^2 h$), and then calculate the density using $\rho=mV$. This helps learners understand how to measure and calculate the density of regular-shaped objects.

Another experiment involves measuring the density of irregular objects. Using irregular objects (e.g., rocks), a graduated cylinder, a balance scale, and water, learners measure the mass of the object with a balance scale, fill the graduated cylinder with a known volume of water, submerge the object in the water, and measure the new volume. By subtracting the initial volume of water from the final volume, they calculate the object's volume. Finally, they calculate the density using $\rho = m/V$. This experiment teaches learners how to determine the density of objects with irregular shapes using water displacement.

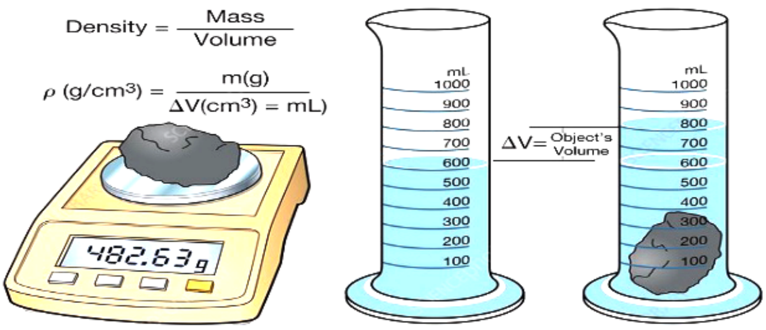


Figure 6: *Experiment to measure the density of an irregular solid*

A comprehensive understanding of density involves comparing the densities of various substances. Learners can conduct experiments to measure the densities of materials like metals, wood, and liquids and can analyse their results in order to justify the use of these materials in various applications. Learners can also experiment with various objects (e.g., wood, metal, plastic) and a water tank to understand the relationship between density and buoyancy.

An interesting challenge for learners, using the concept of density, is calculating the mass of water in Lake Bosomtwe, located in the Ashanti Region of Ghana.

Figure 7: *Aerial view of Lake Bosomtwe*

This impact crater lake, one of the world's youngest and best-preserved mid-sized impact craters, has an average depth of 71.5 meters and a surface area of 49 square kilometres.

By knowing the volume and density of water, learners can calculate the lake's mass, integrating their understanding of density with real-world geography and environmental science. We can calculate the lake's volume from its dimensions and use 1.000×10^3 kg/m^3 as the density of water. Then the mass can be found from the definition of density $m = \rho V$.

Figure 8: *Aerial view of Lake Bosomtwe*

LEARNING TASKS

1. Explain the concept of density and how it is calculated.
2. Measure and compare the densities of different objects (regular and irregular) through experimentation.
3. Describe the relationship between density and buoyancy.
4. Explore real-world applications of density.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   - **a.** Provide learners with a brief introduction to the concept of density, including its formula (Density = mass/Volume) and define the term 'buoyancy'.
   - **b.** Ask learners to brainstorm and discuss in groups what factors might affect the density and buoyancy of an object. Ask each group to share their ideas with the class.
   - **c.** Having established the relationship between density and buoyancy (either by experimentation as outlined below or by independent research), learners create a presentation on real-world applications of density, such as its use in designing life jackets, submarines, and hot air balloons. They present their projects to the class, highlighting the connections between their experiments and real-world applications.
   - **d.** Provide learners in mixed-ability groups with a scenario: determining the best materials for building a small boat. Applying their initial findings to the scenario, they present their conclusions to their class on which materials would be most suitable for building the boat based on density and buoyancy.

2. **Problem-Based Learning**
   a. Provide learners with a series of problems involving the use of the density formula, as well as some problems which require them to calculate the volume of a regular-shaped object from its dimensions.
      i. Provide a worked example for less able learners.
      ii. Ensure that problems become increasingly challenging in order to stretch the more able learners. This should include problems requiring the learners to give their answers in both gcm^{-3} and kgm^{-3}; some learners will find the conversion from cm^{-3} to m^{-3} (and vice versa) challenging and should have access to a worked example if needed.
3. **Project-Based Learning**
   a. Supply learners with various regular-shaped objects (e.g., a marble, a piece of wood, a plastic block, and a liquid such as cooking oil). Learners measure the mass and dimensions of each object and record the results. They should calculate the volume and subsequently the density of the material.
   b. In the absence of practical equipment, use online simulations to investigate density.

Figure 9: *Simulations to investigate density*

   c. Learners predict whether their object will sink or float and then place each object in water to observe and confirm their predictions. Learners should write a written summary of how density relates to buoyancy.
   d. Learners perform measurements and calculations as above but using irregular-shaped objects and the water displacement method to find their volume.

KEY ASSESSMENT

Level 1: Density is defined as the mass per unit volume of a substance. True/False.

Level 2: Calculate the density of a block of metal with a mass of 50 grams and displaces 20 cubic centimetres of water.

Level 3: You are given three liquids with different densities. Describe an experiment to determine their densities in order of increasing magnitude.

Level 4: Research how density is crucial in the design of submarines. Prepare a brief report and presentation explaining how density influences submarines' operation and the materials used in their construction.

FOCAL AREA 2: ARCHIMEDES' PRINCIPLE AND FLOTATION

Figure 10: *Scan this QR code for a video on Archimedes and the foundational theory of his principle.*

Archimedes' principle and flotation are fundamental concepts in physics that explain the buoyancy of objects submerged in fluids; in other words, they explain why some objects float and others sink.

Archimedes' Principle was discovered by the ancient Greek mathematician and scientist Archimedes when he famously determined whether a crown was made of pure gold without damaging it. It states that an object submerged in a fluid, experiences an upward force (upthrust), also known as a buoyant force, equal to the weight of the fluid displaced by the object. If this buoyant force exceeds the object's weight, the object will float. If it is less, the object will sink. This concept is foundational in understanding how and why objects float or sink in fluids.

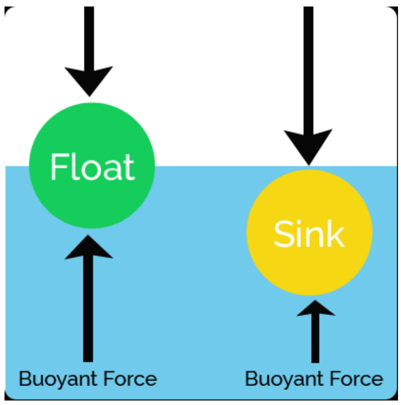


Figure 11: *Comparison of objects and the gravitational and buoyant forces acting on them*

One way to explore this principle in the classroom is through experiments determining the buoyant forces (upthrust) on various objects. This hands-on approach helps learners visualise and quantify the buoyant force acting on different objects.

The concept of buoyancy is further enriched by determining how the density of different fluids affects buoyancy. Learners can perform experiments using fluids of varying densities, such as water, oil, and saltwater. By measuring the buoyant force on the same object in each fluid, they can observe how a denser fluid exerts a greater buoyant force, making it easier for objects to float. For instance, an egg that sinks in freshwater may float in saltwater due to the increased density and resulting buoyant force of the saltwater.

Figure 12: *Scan this code for a video on buoyancy*

These experiments illustrate Archimedes' Principle and emphasise the relationship between fluid density and buoyancy.

Another practical application of Archimedes' Principle involves solving real-world problems. For example, learners can investigate why ships float despite being made of dense materials like steel. By understanding that the ship's shape causes it to displace a large volume of water, they can calculate the buoyant force and see how it balances the ship's weight, allowing it to float. Learners can also explore how submarines control their buoyancy by adjusting the volume of water in their ballast tanks.

LEARNING TASKS

1. Explain the concept of Archimedes' Principle and its foundational theory.
2. Determine the buoyant forces (upthrust) on various objects.
3. Apply Archimedes' Principle to solve real-world problems.
4. Determine how the density of different fluids affects buoyancy.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based / Collaborative Learning**
   - **a.** Introduce Archimedes' Principle and its foundational theory (videos reconstructing and explaining the history of the 'Eureka' moment are available online). Ask learners to discuss, in mixed ability groups, how this principle might apply to everyday objects. Encourage the learners to share the outcomes of their discussions with the class.
2. **Problem-Based Learning**
   - **a.** Present pupils with a series of problems to solve regarding objects of different densities submerged in water, requiring them to calculate
     - i. the volume of water that would be displaced whilst the object is in the equilibrium position.

ii. the resultant force on the object when fully submerged in water.

iii. the effect of submerging the same object into a fluid of a different density to water.

Note that there should be worked examples available for less able learners, and that the problems should increase in challenge for the more able leaners.

b. Challenge learners to solve real-world problems, such as designing a simple boat/flotation device to support a given weight. Learners should be tasked with producing a diagram annotated with specific design features chosen for the object to float.

3. Project-Based Learning

a. Learners select various objects and measure their buoyant forces (upthrust) by submerging them in water and recording the displaced water volume. They should calculate, or measure, the weight of the displaced water and compare this with the weight of the object itself to determine whether it would sink or float.

b. Learners gently place the same objects into water to confirm their predictions. They could extend their investigation by observing how much of the object remains submerged in the water having been allowed to reach equilibrium; the approximate volume of displaced water could be estimated. This should be compared to the weight of the object itself, and learners should draw a conclusion as to the relationship between the upthrust and the object's weight in the equilibrium position.

c. In the absence of practical equipment, online interactive simulations can be used to investigate buoyancy. An example:

Figure 13: *Simulation on buoyancy*

d. Have learners test the buoyancy of objects in different fluids, such as oil, saltwater, and syrup, and report on how the density of these fluids affects the buoyancy.

KEY ASSESSMENT

Level 1: If an object displaces 5 kg of water, what is the buoyant force (upthrust) acting on it?

Level 2: Explain how Archimedes' Principle can determine whether an object will float or sink.

Level 3: Discuss how changes in fluid density affect the buoyant force and provide examples.

Level 4:

1. Design a project where you create a model boat that can carry a specific load without sinking. You must plan, build, test, and refine your design and present your findings.
2. Measure and compare the densities of different objects (regular and irregular) through experimentation to be presented in week 5.

Hint

The recommended mode of assessment for week 2 is ***Portfolio.*** *This is to be submitted in Week 21. Refer to* ***Appendix A*** *at the end of this section and the Teacher Assessment Manual and Toolkit page 22 for information on the portfolio..*

WEEK 3

Learning Indicator: *Distinguish elastic deformation from plastic deformation*

FOCAL AREA 1: DEFORMATION

Although a solid may have a definite shape and volume, it's possible to change it by applying external forces. When an external force is applied, a solid can undergo either elastic or plastic deformation. Elastic deformation is a reversible change in the shape of a material under the influence of an applied force. Once the force is removed, the material returns to its original shape and size. This is called elastic behaviour. On the other hand, plastic deformation is a permanent change in the shape of a material when the applied force exceeds the material's yield strength. Once the force is removed, the material does not return to its original shape.

The elastic properties of solids are discussed in terms of stress and strain. Stress is the force per unit area causing a deformation. We will discuss strain later in this topic.

Three main types of stress produce deformation: compressional stress, tensional stress, and shear stress. Compressional stress occurs when forces are applied inward, compressing the material. Tensional stress occurs when forces are applied outward, stretching the material. Shear stress occurs when forces are applied parallel to the surface of a material, causing it to deform by sliding layers over each other.

A relatable scenario is the use of bridges and buildings. These structures experience different types of stress. Columns in buildings are under compressional stress, while cables in bridges experience tensional stress. These stresses can cause elastic and plastic deformation depending on the material and the magnitude of the forces. For example, the slight flexing of a bridge under the weight of vehicles illustrates elastic deformation, while the permanent bending of a metal beam under extreme load demonstrates plastic deformation.

A rubber band, a metal spring, and a small weight can be used to demonstrate elastic deformation to learners. By attaching the weight to the rubber band and then to the metal spring, they can observe the deformation and see how both materials return to their original shapes once the weight is removed.

To illustrate plastic deformation, learners can bend a metal wire or a plastic spoon with significant force. They will observe that these materials remain bent even after the force is removed, demonstrating plastic deformation. Ceramics can also be tested, but typically, ceramics do not exhibit plastic deformation; instead, they tend to fracture under high stress due to their brittleness.

Analysing real-world scenarios can further enhance understanding. For instance, during a car accident, the metal parts of a car undergo plastic deformation to absorb the impact energy, protecting the occupants. In sports, the strings of a tennis racket experience tensional stress when hitting a ball, and the frame experiences compressional and shear stresses. These stresses affect the performance and durability of the equipment.

Another significant real-world application of these concepts is in understanding how earthquakes occur. Earthquakes result from the deformation of the Earth's crust due to the movement of tectonic plates. These plates are constantly moving but can become stuck at their edges due to friction. When the stress on the edge overcomes the friction, there is an abrupt release of energy in the form of seismic waves, causing an earthquake. This release can cause elastic and plastic deformation in the Earth's crust. Initially, the rocks may bend (elastic deformation), but once the stress exceeds a certain limit, the rocks break and shift (plastic deformation), leading to an earthquake.

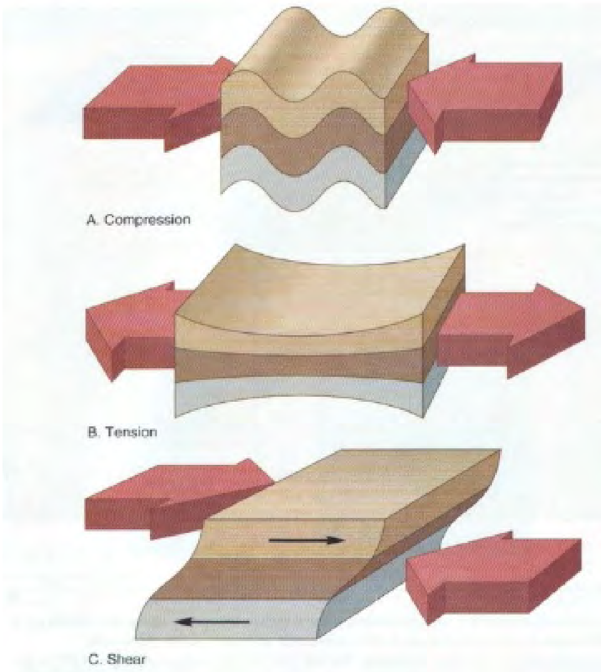


Figure 14: *Types of stress that produce deformation of the Earth's crust*

LEARNING TASKS

1. Define elastic and plastic deformation.
2. Provide elastic and plastic deformation examples in metals, ceramics, and polymers.
3. Identify types of stress (compressional, tensional and shear) that produce deformation in different materials.
4. Compare and contrast elastic and plastic deformation in various materials through simple experiments.
5. Analyse real-world scenarios to identify types of deformation and the stresses involved.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   - **a.** Introduce the concepts of elastic and plastic deformation and discuss their significance. Learners share what they already know and want to know about deformation. Use examples to illustrate the definitions, focusing on key terms.
   - **b.** Learners watch a video on elastic and plastic deformation.

Figure 15: *Scan this QR code for the video on elastic and plastic deformation*

   - **c.** Introduce the term 'stress', focusing on the definition and units. Have learners research the breaking stress of a variety of materials, challenging them to give examples of materials with particularly high breaking stresses.
   - **d.** Guide learners in identifying types of stress (tensile, compressive, shear) and how they cause deformation. Use targeted questioning to build on their existing knowledge and discuss real-world examples. For more able learners this could be a research task instead, with the learners having to produce a poster or summary sheet about the different types of stress and their effect on different materials.
2. **Project-Based Learning:** Learners design and conduct simple experiments to observe deformation in household items. Provide a framework but allow for creativity. Guide them in analysing their results and comparing elastic and plastic deformation in different materials.
3. **Problem-Based Learning:** Present real-world scenarios that require understanding the concepts of elastic and plastic deformation. Ask learners to consider a variety of scenarios and to decide whether it is an example of elastic or of plastic deformation.

KEY ASSESSMENT

Level 1: Elastic deformation is temporary and reversible. (True/False)

Level 2: Provide examples of elastic and plastic deformation in metals, ceramics, and polymers.

Level 3: Describe how you would design an experiment to compare elastic and plastic deformation in different materials.

Level 4

1. Earthquakes can have catastrophic effects on humans. Using ideas about deformation, explain how earthquakes occur.
2. Describe how you would design an experiment to compare elastic and plastic deformation in different materials.

Hint

*The recommended mode of assessment for Week 3 is **Group Project** on the use of electric fields in technology and present their research findings in Week 7. Refer to **Appendix B** at the end of this section and the Teacher Assessment Manual and Toolkit page 27 for more information on how to carry out the project.*

WEEK 4

Learning Indicators

1. *State Hooke's law*
2. *Calculate the energy stored in an elastic material*
3. *Calculate Young's modulus*

FOCAL AREA 1: HOOKE'S LAW AND ENERGY STORED IN AN ELASTIC MATERIAL

Hooke's Law is a fundamental principle in physics, named after the 17th-century British scientist Robert Hooke. It describes the behaviour of elastic materials by establishing a simple linear relationship between the force applied to an object and the resulting deformation. According to Hooke's Law, the force required to extend or compress a spring by some distance is directly proportional to that distance. Mathematically, this relationship is expressed as $F = kDL$, where DL is the magnitude of the deformation (the change in length, for example) produced by the force F, and k is a proportionality constant that depends on the shape and composition of the object and the direction of the force. This principle is visually represented on a graph plotting force against extension. The resulting straight line passing through the origin has a slope that corresponds to the spring constant, k. This graph effectively illustrates how the force applied to a spring, results in proportional deformation, as long as the material remains within its elastic limit.

To understand Hooke's Law in a practical context, one can consider the example of a spring mechanism in a toy gun. When the spring is compressed, it stores potential energy, which is calculated using the formula $PE = \frac{1}{2}kx^2$

This formula shows that the energy stored in the spring is proportional to the square of the displacement and the spring constant. For instance, if a spring with a force constant of 50.0 N/m is compressed by 0.150 metres, the stored energy can be calculated as 0.5625 Joules.

Additionally, Hooke's Law helps us understand how the stored energy translates into kinetic energy. In the toy gun example, if we neglect friction and the mass of the spring, the potential energy stored in the compressed spring is converted into the kinetic energy of a projectile. This relationship allows us to determine the speed at which the projectile is ejected from the gun.

Hooke's Law has significant applications beyond simple springs. In engineering and construction, it helps determine how materials will behave under different loads, which is crucial for designing structures that can withstand specific forces without permanent deformation. For example, understanding the elastic properties of materials is essential in building bridges, where cables experience tensional stress and supports undergo compressional stress.

Figure 16: *The Adomi Bridge at Atimpoku, Eastern Region of Ghana*

In biomechanics, Hooke's Law is used to analyse the elasticity of biological tissues such as tendons and ligaments. These tissues exhibit elastic behaviour similar to springs, and understanding their response to forces is vital for studying movement and the impacts of physical activities on the body.

LEARNING TASKS

1. State Hooke's law and graphically represent the relationship between force and extension.
2. Conduct experiments to determine and calculate the spring constant of materials.
3. Determine the energy stored in elastic materials using the elastic potential energy formula.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   a. Introduce Hooke's law, explaining its significance. Ask learners to summarise the key points, including a sketch of the force-extension graph they would expect to achieve when stretching a spring, labelled with the limit of proportionality and the elastic limit.

b. Introduce the concept of elastic potential energy and the formula. Ask learners to discuss why not all energy stored elastically is transferred into kinetic energy upon release; where does some of the energy go instead? Facilitate a class discussion so that learners can share their thoughts.

2. Project-Based Learning

a. Provide a framework for learners to design their own experiments to verify Hooke's Law for a spring. Guide them to represent the relationship between force and extension graphically.

   i. Note that some learners will struggle to measure/calculate the extension of the spring and will be noting down its length instead. The teacher should address this specifically before the class conduct their experiment, and a worked example of calculating extension from length should be provided.

   ii. Emphasise accurate measurements (address parallax error and the use of fiduciary markers) and data recording. Discuss how to calculate the elastic constant from their data.

   Learners should then use their graph to a) find the spring constant of the spring, having been given the formula and/or definition and b) find the energy stored in the spring using their experimental data.

b. For learners who have completed the above task quickly, suggest an extension task to calculate the effective spring constant and energy stored for two springs in series and parallel.

c. In the absence of practical equipment, the experiment can be performed using online simulations.

Figure 17: *Simulation on Hooke's law*

3. Problem-Based Learning

a. Present real-world scenarios requiring the application of Hooke's law.

b. Provide problems requiring the learners to calculate a) the spring constant and b) the elastic energy stored in elastic materials.

   i. Provide a worked example for less able learners.

ii. Ensure that problems become increasingly challenging to stretch the more able learners. This may include calculating the initial speed of a projectile released from a compressed spring.

c. Learners extend their understanding by calculating the effective spring constant and energy stored for springs in series and parallel configurations.

KEY ASSESSMENT

Level 1: State Hooke's law.

Level 2: Describe how to represent the relationship between force and extension graphically.

Level 3: Describe how you would design an experiment to determine the spring constant of a material and graphically represent the force-extension relationship.

Level 4: Analyse the effectiveness of using the spring constant of a spring to compare the behaviour of one material with another. In other words, would it be reasonable to conclude that iron is a stiffer material than copper if the same force applied to a spring made from each material achieve a greater extension in copper? Support your conclusion with some example calculations and suggest how the experiment could be adjusted to compare the two materials more fairly.

FOCAL AREA 2: YOUNG'S MODULUS

Young's modulus is a parameter that defines the stiffness of materials and their ability to withstand deformation under stress. To understand Young's modulus, we need to define a few key terms:

1. **Tensile Stress:** This is the force applied per unit area of a material. It is calculated by dividing the force (F) applied to the material by the cross-sectional area (A) of the material where the force is applied. Mathematically, it is expressed as:

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

   The unit of tensile stress is Pascal (Pa).

2. **Tensile Strain:** This is the change in length per unit original length of a material under stress. It is a dimensionless quantity calculated by dividing the change in length (ΔL) of the material by its original length (L_0). Mathematically, it is expressed as:

$$\varepsilon = \frac{\Delta L}{L_o}$$

Tensile strain has no units and can either be given as a decimal or as a percentage.

Young's modulus is the ratio of tensile stress to tensile strain in the elastic region of the material's stress-strain curve and is given by:

$$E = \frac{\sigma}{\varepsilon} = \frac{F L_o}{A \Delta L}$$

Young's modulus has units of Pascal (Pa).

As the calculation of Young's modulus takes into consideration the dimensions of the object, it is a good metric by which to compare the stiffness of two materials (whereas the spring constant depends on the dimensions of the object under stress and so does not exclusively relate to the material used).

The easiest way to visualise Young's modulus is on a stress-strain curve, which can be obtained by performing a tensile test on a sample. This curve can be divided into two regions: the elastic region and the plastic region. If the applied stress is low in the elastic region, the material's original dimensions will be completely recovered once the load is removed. However, in the plastic region, larger stresses cause permanent plastic deformation that remains even after the load is removed.

The stress-strain curve is a straight line in the elastic region for most materials (this is not true for some objects, for example rubber bands). The gradient of this straight line represents Young's modulus, denoted by the letter E.

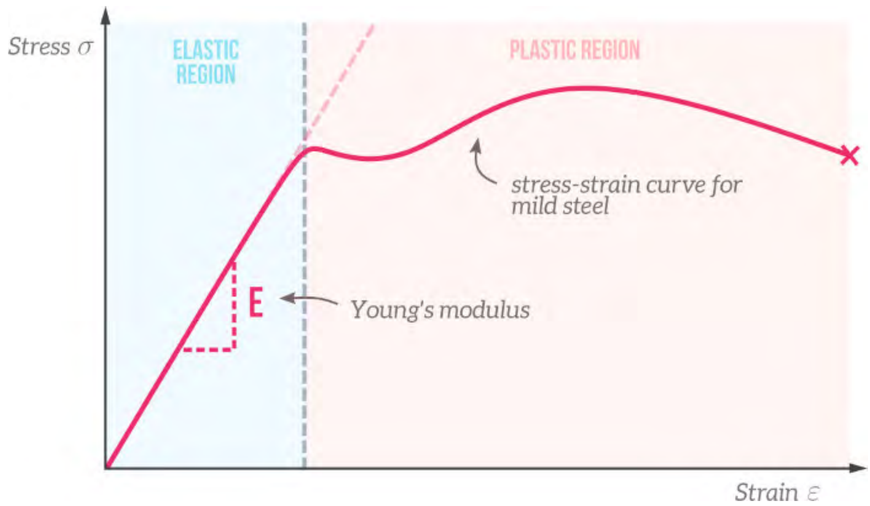


Figure 18: *A material's Young's modulus is equal to the slope of its stress–strain curve in the elastic region*

Comparing the Young's modulus of different materials involves using provided data to calculate and compare their stiffness. For example, materials like steel, rubber, and aluminium have different Young's moduli, indicating their varying stiffness. Steel, with a high Young's modulus, is very stiff, while rubber, with a low Young's modulus, is much easier to stretch.

***Table 1:** Young's modulus of some materials*

Material	Young's Modulus (GPa)
Rubber	0.1
Aluminium alloy	69
Copper	130
Carbon steel	207
Diamond	1200

LEARNING TASKS

1. Define tensile stress, tensile strain, and Young's modulus.
2. Calculate tensile stress and tensile strain and Young's modulus for given data.
3. Compare the Young's modulus of different materials using the provided data.
4. Conduct a simple experiment to measure tensile stress and tensile strain and calculate Young's modulus for a material.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   a. Introduce and define the concepts of tensile stress, tensile strain, and Young's modulus. Guide learners to discuss their significance and the benefits of comparing stress-strain curves to force-extension curves. Use examples to illustrate these definitions and reflections.

2. **Problem-Based Learning**
   a. Guide learners in solving problems that involve calculating tensile stress, tensile strain and Young's modulus from given data sets. Emphasise consistency and accuracy in the layout and solving of equations to find unknown values.
      i. Provide a worked example for less able learners.
      ii. Ensure that problems become increasingly challenging to stretch more able learners.

   b. Provide stress-strain graphs and have learners determine Young's modulus. Discuss the process and ensure they can interpret the results accurately, focusing on graph labelling.

   c. Learners compare the Young's modulus of different materials using the provided data. They discuss the significance of these comparisons and their applications in material selection and engineering.

3. **Project-Based Learning**
   a. Guide learners to design a simple experiment to measure tensile stress and tensile strain. Provide guidance on available equipment, setup, safety, and data recording. Ask learners to consider the most appropriate equipment to use for the quantities that they need to measure; for example, should they use vernier callipers or a ruler to measure the diameter of a wire? Which should they use to measure the extension?
   b. If the equipment is available, learners should perform an experiment to stretch a length of wire (the longer, the better) using hanging masses of increasing weight hanging over a pulley.
      i. The cross-sectional area of the wire can be determined from its diameter, which should be measured using vernier callipers or a micrometer.
      ii. The original length of the wire can be measured using a metre ruler.
      iii. The extension of the wire (dependent variable) can be measured by using a fiduciary marker against a meter-rule; initially these extensions will be very small.
      iv. The force applied (independent variable) can be determined by finding the weight of the hanging masses.

      Learners should take raw data of force and extension and should process these values to find the stress and strain. They should plot a graph of their data in order to find Young's modulus from the gradient.
   c. In the absence of practical equipment, learners should plot a graph of stress against strain and determine Young's modulus from force-extension data of experiments provided and compare the results with theoretical values.
4. **Collaborative Learning**
   a. Learners research the properties of different materials (brittle, ductile, malleable) and produce a poster or summary sheet explaining the terms and giving examples of materials that exhibit these behaviours.

KEY ASSESSMENT

Level 1: Give the definitions of the terms: brittle, ductile, malleable, ultimate tensile stress.

Level 2: A piece of wire of original length 1.2m is extended by 0.005m when a force of 10N is applied. The cross-sectional area of the wire is 2.1×10^{-9} m^2. What is the Young Modulus?

Level 3: The Young Modulus of copper is 130 GPa. A piece of wire of original length 1.2m is extended by 5mm when a force of 10 N is applied. What is the diameter of the wire?

Level 4

1. A piece of wire has a Young Modulus of 210 GPa. A force of 50 kN is hung from the end, and it experiences a strain of 2%. What changes could be made to the dimensions of the wire to reduce this to 1%?
2. Describe how you would design an experiment to determine the spring constant of a material and graphically represent the force-extension relationship.

Hint

The recommended mode of assessment for week 4 is ***group presentation****. Use the level 4 question 2 as a sample question.*

Section 1 Review

Over the past four weeks, we have delved into fundamental physics concepts essential for understanding dimensional analysis, vectors, flotation and the behaviour of materials under various forces.

In week 1 we covered dimensional analysis, an essential tool for ensuring the validity of physics equations. Learners learned to use dimensional analysis to check if equations are dimensionally consistent. They practised deriving equations using dimensional analysis, reinforcing their understanding of the relationships between physical quantities. By mastering this, learners developed strong problem-solving skills crucial in physics and engineering. They should now be able to verify if an equation is dimensionally correct and derive new equations accurately.

In week 2, we explored flotation and buoyancy. Learners learned about the principles of buoyancy, particularly Archimedes' Principle, which states that the buoyant force on an object immersed in a fluid equals the weight of the fluid displaced by the object. This principle was illustrated by comparing a heavy ship, which floats, and a small stone sink. Learners discovered that an object will float if its density is less than the fluid it is in and sink if its density is greater. By the end of this section, learners should be able to explain these phenomena and calculate the buoyant force (upthrust) acting on objects in various fluids, determining whether they will float or sink.

In weeks 3 and 4, we focused on Hooke's Law and the concepts of elasticity. Hooke's Law states that the force required to extend or compress a spring by some distance is proportional to that distance within the elastic limit of the material.

Learners learned to distinguish between elastic deformation, where a material returns to its original shape after the force is removed, and plastic deformation, where permanent deformation occurs. They should be able to explain and conduct experiments to determine the elastic constant of various materials. They should be able to calculate the energy stored in elastic materials using the elastic potential energy formula.

Finally, we studied Young's Modulus, which is a measure of the stiffness of a material. We introduced the concepts of tensile stress, which is defined as the force per unit area, and tensile strain, which is the extension per unit length. Young's Modulus is defined as the ratio of tensile stress to tensile strain in the elastic region of the stress-strain curve. Learners learned to calculate tensile stress and strain from given data and determine Young's Modulus from stress-strain data. By comparing Young's Modulus of different materials, they should understand the relative stiffness of these materials.

APPENDIX A: SAMPLE PORTFOLIO ASSESSMENT

Refer to the Teacher Assessment Manual and Toolkit Section 7.1 on pages 27-30 for guidelines on portfolio assessment.

1. **Task:** Collect all the works in the academic year and compile it into a portfolio to be submitted in Week 21 for assessment. This portfolio will be assessed to evaluate your overall progress throughout the semester.

2. **Example of learners' works to be included in the Portfolio Assessment**
   - **a.** Practical works
   - **b.** Discussion write-ups
   - **c.** Project works
   - **d.** Poster
   - **e.** Presentations
   - **f.** Experiments
   - **g.** Research reports

3. **Example of the structure and organisation of the Portfolio Assessment**

   As part of the structure of the portfolio assessment, make sure the following information has been provided
   - **a.** Cover Page which entails the learner's name, class, subject and period/date.
   - **b.** Table of Contents which has the list of items included with page numbers.
   - **c.** Brief description/background of items such as short description of the significance of sports certificates and awards, background information for each included artefact etc.

4. **Sample mode of administration**
   - **a.** Explain the purpose and components of the portfolio to the learners and provide examples and templates for each section.
   - **b.** Schedule periodic reviews (e.g., every 3-4 weeks) to ensure learners are keeping up with their portfolios and provide feedback and guidance during these checkpoints.
   - **c.** Provide learners with the scoring rubrics and provide detailed explanation on the rubrics.
   - **d.** Final portfolios are due in Week 21 of the academic calendar. Allow a grace period for revisions based on final feedback.

5. **Sample mode of submission/presentation**

   a. Communicate the final deadline for portfolio submission to all students to ensure timely and complete submissions.

   b. Learners will submit their completed portfolios either as a physical or through the school's online submission system.

   c. Ensure the portfolio includes all required elements: practical works, project works, discussion, poster, presentation, research, experiments, etc.

   d. Learners should organise their portfolios clearly and logically, with each component clearly labeled and easy to access.

   e. For digital submissions, learners should upload their portfolios as a single file or in clearly marked folders within the online portal.

6. **Sample Portfolio Assessment Marking scheme**

Learner's works	Score
Practical	5 marks
Discussion	3 marks
Project work	5marks
Poster	2 marks
Presentation	5 marks
Research	5 marks
Experiments	5 marks
Total	**30 marks**

7. **Sample feedback strategy**

   a. Schedule periodic check-ins to discuss progress, set goals, and adjust strategies as needed.

   b. Utilise both formative and summative feedback to guide students' development and ensure they understand how to enhance their work continuously.

APPENDIX B: GROUP PROJECT

Structure

The group project on the topic should have the topic boldly typed, the names of all group members, topic and the date of submission on the cover page. The write up should have the table of contents which must contain an introduction, the sub topics within the main topics with diagrams where necessary and references.

Mode of administration

Assign the task ahead of time and give learners the opportunity and time to find information from multiple sources.

Sample Rubrics

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Content Knowledge	Demonstrates a thorough understanding of electric fields and their applications in technology. Information is accurate, detailed, and supported by evidence.	Demonstrates good understanding of electric fields and their applications with minor inaccuracies or missing details.	Demonstrates partial understanding with noticeable gaps or misconceptions in the explanation of electric fields.	Demonstrates little or no understanding of electric fields or the topic is unclear and unsupported.
Project Organization	Project is logically organised with a clear introduction, body, and conclusion. Ideas flow seamlessly.	Project has a logical structure, but some transitions between ideas are unclear.	Organization is inconsistent or somewhat unclear, making it hard to follow at times.	Project lacks organisation, making it difficult to understand the key ideas presented.

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Technical Application	Clearly explains and demonstrates real-world examples or technological applications of electric fields. Includes diagrams, models, or experiments effectively.	Provides good examples of applications with minor flaws in explanations or visuals.	Provides limited examples of applications. Diagrams or visuals are minimal or unclear.	Provides no examples or poorly explains the applications of electric fields. No visuals provided.
Creativity and Innovation	Project is highly creative, original, and innovative in presentation or ideas.	Project shows some creativity and originality in ideas or presentation.	Limited creativity or originality; presentation lacks engaging elements.	Little to no effort in creativity; project is basic and lacks originality.
Presentation Skills	Presentation is clear, confident, and engaging. Eye contact, voice projection, and use of visuals are excellent.	Presentation is clear and confident but slightly lacks engagement or visuals.	Presentation is somewhat unclear or lacks confidence. Limited use of visuals or engagement.	Presentation is unclear, unconfident, and unengaging. Visuals or aids are not effectively used.

Total score 20 marks

Feedback

Use the items in the rubrics to provide targeted feedback highlighting areas where learners will need improvement.

SECTION 2: MEASUREMENT OF HEAT

Strand: Energy

Sub-Strand: Heat

Learning Outcome: *Design experiments with available resources in the laboratory to determine the specific heat capacities of liquids and solids and also to determine latent heat of fusion of a liquid.*

Content Standard: Demonstrate knowledge and understanding of heat transfer from substances and recognise its importance in the choice of materials as good or bad conductors.

Hint

Mid-Semester Examination for the first semester is in Week 6. Refer ***to Appendix C*** *at the end of this section for Table of specification.*

INTRODUCTION AND SECTION SUMMARY

This section explores essential concepts in thermodynamics, focusing on heat capacity, specific heat capacity, and latent heat, which are fundamental to understanding how substances interact with and transfer thermal energy.

The weeks covered by the section are:

Week 5: Specific heat capacity

Firstly, heat capacity and specific heat capacity are explained. Substances can be classified based on their thermal conductivity, distinguishing between good conductors that readily transfer heat and poor conductors that resist heat transfer.

The section then guides learners through calculating specific heat capacities of substances. Techniques for measuring the specific heat capacity of a solid and liquid are described, supported by instructional videos that demonstrate the experimental procedures.

Week 6: Latent heat

Moving on, the concept of latent heat is introduced, covering latent heat of fusion and vaporisation. These phenomena describe the energy absorbed or released during phase transitions, such as melting and boiling.

To deepen understanding, the section includes practical demonstrations through videos on how to experimentally determine latent heat values. These videos illustrate experimental setups and procedures for measuring latent heat of fusion and vaporisation, providing visual aids to complement theoretical knowledge.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Teaching specific heat capacity and latent heat effectively involves a multifaceted approach that integrates discussions, experiments, collaborative problem-solving, and the use of educational videos to enhance comprehension and engagement.

Through guided discussions, learners should explore how materials like metals and non-metals differ in their ability to conduct heat, linking these properties to everyday examples such as cooking utensils and insulating materials.

Hands-on experiments are crucial for reinforcing these concepts. Starting with basic setups using controlled heat sources, learners should measure temperature changes and mass to calculate specific heat capacities of various substances. If the equipment is available, they could progress to more intricate experiments involving mixtures. Substances undergoing phase changes, such as melting ice or boiling water, can be easily investigated allowing learners to directly observe the principles of latent heat and the effect of phase change on temperature.

Integrating educational videos enhances learning by providing visual demonstrations and real-time examples. Videos can showcase thermal conductivity experiments with different materials, simulations of heat transfer processes, or animations explaining the concept of latent heat during phase changes.

Collaborative problem-solving activities further deepen understanding. Learners work together to analyse experimental data, calculate specific heat capacities, or design experiments to investigate factors influencing latent heat values.

ASSESSMENT SUMMARY

Effective assessment strategies for specific heat capacity and latent heat should integrate theoretical explanations, practical calculations, and experimental procedures to ensure a comprehensive understanding of these key thermal concepts.

To assess specific heat capacity, multiple-choice and short-answer questions are effective for testing learners' grasp of the concept of good or bad conductors of heat.

Problem-solving tasks that require learners to compute the specific heat capacities of different substances using given data are essential. These tasks should include real-life scenarios to evaluate learners' ability to apply these calculations practically, such as determining the heat required to change the temperature of a substance in everyday situations. Learners should be provided with simple examples which are accessible to all, as well as more complicated examples to challenge the most able.

Designing laboratory experiments where learners determine the specific heat capacity of a solid or liquids allows for practical application of theoretical knowledge. These assessments should focus on learners' abilities to follow experimental procedures accurately, take precise measurements, and perform necessary calculations.

WEEK 5

Learning Indicators

1. *Explain specific heat capacity and classify substances into good and bad conductors of heat*
2. *Calculate the specific heat capacities of substances*
3. *Describe how to determine the specific heat capacity of a solid using a liquid of a known specific heat capacity*

FOCAL AREA 1: SPECIFIC HEAT CAPACITY

When a dishwasher door is opened a few minutes after the end of the washing cycle, you will find the ceramics and the heavy metal items will be completely dry. However, anything made of plastic will still be wet. This happens because plastic has a relatively low specific heat capacity, which means that it does not retain as much thermal energy as the other material items and hence is not able to evaporate off the water droplets as quickly.

Heat capacity, C, is the quantity of heat Q transferred when changing (raising or lowering) the temperature of a body, θ, by 1 K (or 1 °C).

Mathematically,

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

The SI unit of heat capacity is JK^{-1}

Specific heat capacity, c, of a substance is the quantity of heat Q transferred when changing the temperature, θ, of 1 kg of the substance by 1 K or 1 °C.

OR

Specific heat capacity, c, is the heat capacity, C, per unit mass, m, of a substance.

Mathematically,

$c = \frac{C}{m}$

but $C = \frac{Q}{\theta}$

$\Longrightarrow c = \frac{Q}{m\theta}$

The SI unit of specific heat capacity is $J\ kg^{-1}\ K^{-1}$

The temperature increase of a material when energy is supplied to it depends on its specific heat capacity, *c*. The greater a material's specific heat capacity, the more energy is required for its temperature to increase by a given amount. The specific heat capacities of various materials are shown in the table below.

Type of material	material	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
Non metals	Water	4186
	Ice	2090
	Air	1005
Metals	Lead	128
	Aluminium	900
	Copper	385
	Iron	450

The table shows that non-metals generally have a higher specific heat capacity than metals. Also, water has a very high specific heat capacity compared to other materials. Its value is 4186 $Jkg^{-1}K^{-1}$, meaning that 4186 J of energy is required to heat up 1 kg of water by 1 K. It takes a lot of energy to heat up water and it takes a long time to cool down.

The specific heat capacity of solids and liquids can be determined experimentally by various methods e.g., method of mixture, cooling method, electrical method etc.

Experiment to determine the specific heat capacity of a solid by method of mixtures

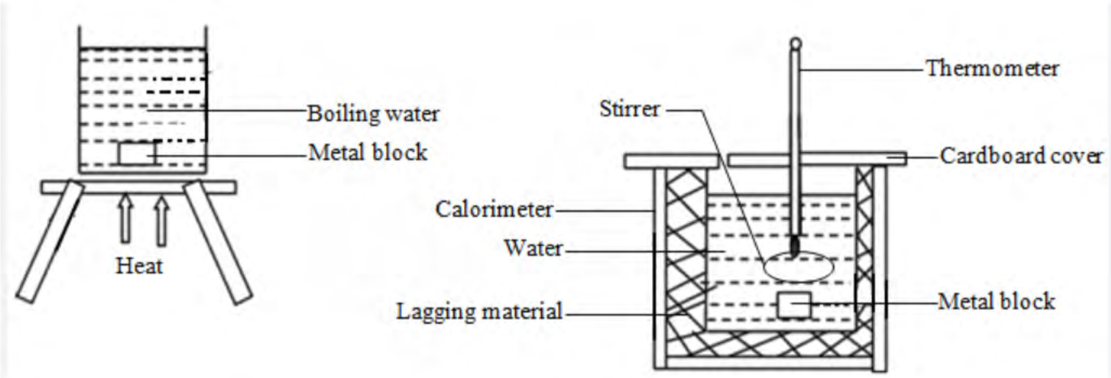


Figure 19: *Determination of the specific heat capacity of a solid by method of mixtures*

1. Weigh an empty calorimeter with its stirrer and record its mass m_c.
2. Fill the calorimeter up to ⅔ with cold water and weigh again.
3. Record the mass of the water and calorimeter m_{cw}.
4. Replace the calorimeter in its jacket.
5. Measure and record the initial temperature of water and calorimeter, θ_i.
6. Measure and record the mass m_s, of the solid.

7. Attach a thread to the solid and place it inside a separate beaker of water.
8. Heat the water and solid.
9. Measure and record the final temperature θ_s.
10. Transfer the solid into the lagged calorimeter.
11. Stir gently until a final steady temperature θ_f, is attained.
12. Read and record θ_f.
13. The mass of water, $m_w = m_{cw} - m_c$.
14. Determine fall in temperature as $\theta_s - \theta_f$.

Assume there is no heat lost to the surrounding,

[*Heat lost by solid*] = [*Heat gained by cold water*] + [*Heat gained by calorimeter*]

$$m_s c_s(\theta_s - \theta_f) = m_w c_w(\theta_f - \theta_i) + m_c c_c\left(\theta_f - \theta_i\right)$$

$$m_s c_s(\theta_s - \theta_f) = \left(m_w c_w + m_c c_c\right)\left(\theta_f - \theta_i\right)$$

$$c_s = \frac{\left(m_w c_w + m_c c_c\right)\left(\theta_f - \theta_i\right)}{m_s c_s(\theta_s - \theta_f)}$$

c_s can be calculated.

Specific heat capacity is crucial in various fields, improving efficiency, safety, and functionality:

1. **Climate Science**: Oceans' high specific heat capacity stabilises global temperatures and influences weather patterns.
2. **Cooking**: Materials like copper and aluminium, with low specific heat capacities, heat up and cool down quickly, enhancing cooking efficiency. Food storage systems are designed using knowledge of specific heat capacities.
3. **Construction**: Building materials with high specific heat capacities maintain stable indoor temperatures, reducing energy costs.
4. **Industry**: Precise temperature control in metalworking and chemical reactions relies on understanding specific heat capacities.
5. **Automotive**: Effective engine cooling and battery management in electric vehicles depend on coolants with high specific heat capacities.
6. **Environmental science**: Studies energy balances and models ecological changes, aiding in renewable energy storage.
7. **Medical**: Cancer treatments and cryopreservation require precise temperature control based on specific heat capacities.

8. **Aerospace**: Thermal protection systems for spacecraft and temperature management of components rely on specific heat capacities.

LEARNING TASKS

1. Define heat capacity and specific heat capacity.
2. Calculate the specific heat capacities of substances.
3. Use the specific heat capacities of materials to classify them as good and bad conductors.
4. Apply the concept of specific heat capacity to real-world scenarios.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-based Learning**
   - **a.** Define heat capacity and specific heat capacity. Guide learners to establish the relationship that exist between heat capacity and the specific heat capacity; ask the learners to discuss this with their neighbours before feeding back in a class discussion.
   - **b.** Facilitate a class discussion with learners to identify reasons for differences in temperature rise of substances heated for the same duration and have them distinguish between good and poor conductors of heat.
   - **c.** Let learners conduct research to explore real-world applications of specific heat capacity in industries such as manufacturing, construction, and energy efficiency, presenting findings on how materials with varying specific heat capacities contribute to these sectors.
   - **d.** Guide learners to also research multiple methods on the determination of specific heat capacity, analyse their relative benefits and drawbacks.
2. **Project-based learning**
   - **a.** Let learners measure and compare the time it takes for equal masses of different materials, initially at the same temperature, to reach the same final temperature when subjected to the same heat source, noting the materials that will heat up faster. Ask learners to rank the materials from lowest to highest specific heat capacity.
   - **b.** Have learners watch videos demonstrating experimental methods like the mixtures method, cooling curve method, and electrical method for determining specific heat capacities of liquids and solids.

Figure 20: *Video on determination of specific heat capacity of solid by method of mixtures*

c. Guide learners to a method that they have watched or researched to determine the specific heat capacities of liquids and solids, based on the resources available.

Figure 21: *Video on determination of specific heat capacity of water by electrical method*

2. **Problem-based learning**
   a. Provide learners with a series of differentiated questions using the heat capacity and the specific heat capacity formulae.
   i. A worked example demonstrating the use of each formula should be provided.
   ii. The problems should become increasingly difficult, with the most challenging problems requiring the learners to identify quantities in an experimental set up such as the method of mixtures in order to calculate c. Learners could also be challenged by giving them an unfamiliar experiment with enough background information and data to calculate specific heat capacity (for example, a beaker of a liquid being heated using an electrical heater with known values of voltage, current and time).

KEY ASSESSMENT

Level 1

1. Define the specific heat capacity of a material.
2. A material with a high specific heat capacity heats up quickly. (True/False)

Level 2

1. Using ideas about heat capacity, explain why water is often used as a coolant in engines.
2. Calculate the heat required to raise the temperature of 2 kg of water from 20°C to 100°C (specific heat capacity of water is 4.18 J/g°C). Hint: be careful with your units!

Level 3: Describe one way in which you could measure the specific heat capacity of an unknown metal.

Level 4

1. Conduct research on the use of specific heat capacity in climate control systems. Prepare a detailed report and presentation explaining its importance in designing efficient systems.
2. Describe one way in which you could measure the specific heat capacity of an unknown metal.

Hint

*The recommended mode of assessment for week 5 is **poster**. Use the level 4 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 76 for more information on how to carry out poster.*

WEEK 6

Learning Indicator: *Explain latent heat of fusion and vaporisation and specific latent heat of fusion and vaporisation*

FOCAL AREA 1: LATENT HEAT

Latent heat is the quantity of heat absorbed or released when a substance changes its physical state at constant temperature.

Types of latent heat

1. **Latent heat of fusion**: This is the amount of heat required to change a substance from solid to liquid at its melting point. For example, ice melting into water requires a specific amount of energy without changing the temperature of the substance.
2. **Latent heat of vaporisation**: This is the amount of thermal energy required to change a substance from liquid to gas at its boiling point. For instance, water evaporating into steam absorbs a specific amount of heat energy from its surroundings.

Specific latent heat is the amount of heat required to change the state of 1 kilogram of a substance without changing its temperature. It is typically categorised into:

1. **Specific latent heat of fusion (l_f):** The heat required to change 1 kilogram of a substance from solid to liquid (or vice versa) at its melting point.
2. **Specific latent heat of vaporisation (l_v):** The heat required to change 1 kilogram of a substance from liquid to gas (or vice versa) at its boiling point.

Mathematically, the specific latent heat (l) can be expressed as: $l = \frac{Q}{m}$

where

- l is the specific latent heat,
- Q is the total heat energy supplied or removed,
- m is the mass of the substance.

The unit of specific latent heat is Jkg^{-1}

The specific latent heat of fusion and vaporisation can be determined by various methods e.g., method of mixtures.

Experiment to determine the specific latent heat of fusion of ice by method of mixtures

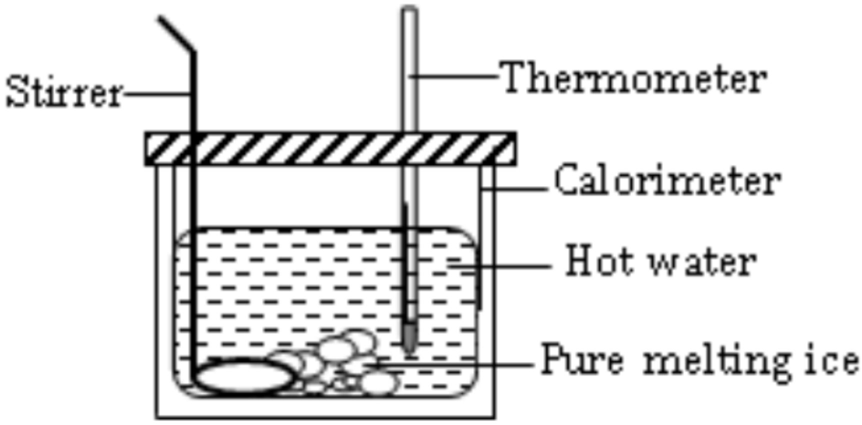


Figure 22: *Determination of the specific latent heat of fusion of ice by method of mixtures*

1. Weigh a calorimeter with its stirrer is and record its mass m_c.
2. Half-filled the calorimeter with water and let it remain still for about five minutes and record the temperature of the water θ_1.
3. Weigh the calorimeter again and determine the mass of water.
4. Dry some pieces of ice by blotting paper and add in small quantities.
5. Stir the water continuously until all the ice is melted.
6. Measure the final temperature of the mixture θ_2.
7. Re-weigh the calorimeter and its contents to determine the mass of the ice, m_i.
8. The heat lost on cooling the calorimeter and its contents is equal to the heat required to melt the ice and warm the water formed to the final temperature of the experiment, θ_2.

Calculations

$$[\textit{Heat gained by ice}] = [\textit{Heat lost by calorimeter and its contents}]$$

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

$$m_i\left(l_f + c_w \theta_2\right) = m_c c_c(\theta_1 - \theta_2) + m_w c_w(\theta_1 - \theta_2)$$

$$l_f = \frac{m_c c_c(\theta_1 - \theta_2) + m_w c_w(\theta_1 - \theta_2)}{m_i} - c_w \theta_2$$

$\therefore l_f$ is determined.

Some terms associated with phase change

1. **Melting:** The process by which a solid turn into a liquid when heat is applied. This occurs at the melting point of the substance.

2. **Freezing (Solidification):** The process by which a liquid turn into a solid when heat is removed. This occurs at the freezing point of the substance.
3. **Boiling:** Occurs when a liquid changes to a gas at its boiling point, throughout the entire liquid.
4. **Condensation:** The process by which a gas turns into a liquid when heat is removed. This occurs at the condensation point of the substance, which is the same as its boiling point.
5. **Sublimation:** The process by which a solid turn directly into a gas without passing through the liquid state. This occurs at certain conditions of temperature and pressure.
6. **Deposition:** The process by which a gas turns directly into a solid without passing through the liquid state. This is the reverse of sublimation.

Latent heat is crucial in various applications due to its ability to absorb or release significant amounts of energy during phase changes without changing temperature. Key applications include:

1. **Refrigeration and Air Conditioning:** Utilises latent heat for cooling and heating through refrigerant phase changes.
2. **Meteorology and Climate Science:** Drives weather patterns and storm formation through water vapour phase changes.
3. **Cooking:** Essential in processes like boiling, steaming, and freezing.
4. **Thermal Energy Storage:** Phase Change Materials (PCMs) store and release energy, used in building materials and electronics.
5. **Industrial Processes:** Used in distillation, metal casting, and welding.
6. **Power Generation:** Steam cycles in power plants rely on latent heat for efficiency.

LEARNING TASKS

1. Define latent heat of fusion and vaporisation.
2. Calculate specific latent heat of fusion and vaporisation.
3. Apply the concept of latent heat to real-world scenarios.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-based / Collaborative Learning**
   a. Guide learners to recall and discuss terms such as boiling, evaporation, melting, freezing, and other phase change phenomena

  i. This recall task could be made more interactive by asking the learners to stand up and 'behave like the particles in a solid'. Learners observing this should make comments and improvements to the model. The 'solid particles' would then be asked to behave as if they were 'melting', and then evaporating, etc, with their classmates giving them advice throughout.

b. Define latent heat of fusion and vaporisation, including giving learners the formulae for both. Guide learners to identify the relationship between the two quantities, as per the 'specific heat capacity' lesson.

c. Guide learners to research multiple methods on the determination of latent heat, analyse their relative benefits and drawbacks.

  i. Learners could individually research multiple methods themselves, creating a 'pros and cons summary at the end. Alternatively, each group of 3-4 learners could be assigned a method to research and present to the class; subsequently the teacher could facilitate a discussion regarding which method would be preferred in various scenarios.

d. Let learners research and present on real-world applications of latent heat, exploring its significance in industries such as HVAC systems (Heating, Ventilation, Air conditioning systems), food preservation, climate control, and phase change materials in energy storage

2. Project-based Learning

a. If the equipment is available, let learners perform experiment to determine the specific heat capacities of liquids and solids using the method of mixtures (outlined in content above).

b. In the absence of the equipment, or to reinforce the concepts, use videos to demonstrate practically how to find specific latent heat.

Figure 23: *Determination of specific latent heat of fusion by method of mixtures*

c. If the equipment is available, provide learners with a kettle of water stood on some kitchen scales and a joulemeter. Learners should set the scales to zero whilst the kettle and water are sat on them. Begin boiling the kettle, with the lid removed, and measure the energy supplied and the reduction in mass after 5 minutes. Use these values to calculate l_v.

Figure 24: *Determination of specific latent hear of vaporisation by electrical method*

d. Conduct with learners an experiment where you compare the time it takes for ice cubes made of pure water and ice cubes with added salt (which lowers the freezing point) to melt in room temperature water. Ask learners to write a written explanation of their observations in terms of latent heat. learners should also summarise the practical application of this phenomena in food preservation and refrigeration.

3. Problem-based learning

a. Provide learners with a series of differentiated questions using the specific latent heat formula.

i. A worked example demonstrating the use of the formula should be provided.

ii. The problems should become increasingly difficult, with the most challenging problems requiring the learners to identify quantities in an experimental set up such as the method of mixtures in order to calculate l. Learners could also be challenged by giving them an unfamiliar experiment with enough background information and data to calculate latent heat (for example, a beaker of a liquid being boiled away using an electrical heater with known values of voltage, current and time).

KEY ASSESSMENT

Level 1: Define latent heat.

Level 2

1. Explain the difference between latent heat of fusion and latent heat of vaporisation.

2. Calculate the heat required to melt 500 g of ice at 0°C (latent heat of fusion of ice is 334 J/g).

Level 3: Describe one way in which you could measure the latent heat of vaporisation of water.

Hint

*The recommended mode of assessment for Week 6 is **mid-term examination**. Refer to **Appendix C** at the end of this section for Table of specification.*

Section 2 Review

Week 5 covered calculating and determining the specific heat capacities of materials and classifying substances based on their thermal conductivity. Specific heat capacity is a fundamental concept in thermodynamics, defined as the amount of heat required to raise the temperature of one kilogram of a substance by one degree Celsius (or Kelvin). This property is intrinsic to each material and is denoted by the symbol c.

Learners should have learned to categorise substances into good and bad conductors of heat. Good conductors, such as metals (e.g., copper, aluminium), have low specific heat capacities and transfer heat quickly. In contrast, poor conductors, or insulators (e.g., wood, plastic), have higher specific heat capacities and resist the transfer of heat. The practical aspect of the lesson should involve calculating the specific heat capacities of various substances.

Week 6 transitioned to the concepts of latent heat and specific latent heat of fusion and vaporisation. Latent heat is the heat absorbed or released by a substance during a phase change without changing its temperature. The specific latent heat is the amount of heat required to change the phase of one kilogram of a substance.

In both weeks, differentiated questioning and varying levels of support from the teacher should be employed to ensure all learners understand the concepts. Highly proficient learners should tackle complex problems involving multiple steps and real-world applications, such as calculating energy efficiency in thermal systems. Approaching proficient and proficient learners received additional support through simplified examples and one-on-one tutoring sessions.

By the end of these lessons, every learner should be proficient in conducting experiments to determine the thermal properties highlighted above, applying their knowledge in practical and theoretical contexts.

APPENDIX C: MIDSEMESTER EXAMNINATION

Structure

Twenty (20) Multiple-Choice Questions

Table of Specification for Midsemester One

WEEK	Learning Indicators	LEVEL 1	LEVEL 2	LEVEL 3	Level 4	Total
1	Resolve vectors into their components	2	2	1	-	**5**
2	State principle of flotation	-	1	-	-	**1**
3	Distinguish elastic deformation from plastic deformation	1	1	1	-	**3**
4	Calculate the energy stored in an elastic material	1	1	2	-	**4**
5	Calculate the specific heat capacities of substances	2	3	2	-	**7**
Total		**6**	**8**	**6**	**-**	**20**

SECTION 3: ELECTROSTATICS

Strand: Electric Fields, Magnetic Fields and Electronics

Sub-Strand: Electrostatics

Learning Outcomes

1. *Use the concept of electric fields to explain how charges interact.*
2. *Explain and analyse the structure and working principles of capacitors and calculate capacitance.*

Content Standards

1. Demonstrate knowledge and understanding of electric fields.
2. Demonstrate knowledge and understanding of the structure and operation of capacitors.

INTRODUCTION AND SECTION SUMMARY

This section provides a comprehensive overview of electrostatics and capacitance, both fundamental concepts in electricity.

The weeks covered by the section are:

Week 7: Electric fields and Coulomb's law of electrostatics

The section begins with an explanation of how electric fields are represented and their key characteristics. Following this, Coulomb's law is introduced to understand the electrostatic force acting on point charges, paving the way for calculations based on this law.

Week 8: Electric field strength and potential difference

Moving forward, the concept of electric field strength or intensity due to a point charge is explored, illustrating how to determine this crucial parameter in electrostatics. The section then defines potential difference and its relationship with electrical field intensity.

Week 9: Capacitors I

Capacitors are then introduced, detailing their structure and operation, including how they store electrical energy. Methods for calculating capacitance, both for parallel plate capacitors and arrangements in series and parallel, are covered in depth. The behaviour of capacitors in DC and AC circuits is also discussed, emphasising their role and characteristics in different types of electrical systems.

Week 10: Capacitors II

Finally, the section concludes with calculating the energy stored in a capacitor and with highlighting their practical implications in electrical engineering and technology.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Let Learners explore the representation and characteristics of electric fields through guided discussions and visual aids, such as diagrams illustrating field lines and their directional properties. Demonstrations, or videos of demonstrations, to find the shape of electric fields experimentally should be utilised.

Introduce Coulomb's law through interactive discussions and practical examples. Engage in calculations and observe simulations for learners to not only understand the mathematical formulation of Coulomb's law but also apply it to real-world scenarios such as the design of lightning rods.

Through experiments and simulations, let learners explore how to determine the electric field intensity and observe its variations with distance from the charge.

Use diagrams and physical models to allow learners to explore the structure and operating principles of a capacitor. Illustrate different capacitor configurations, such as parallel plate capacitors, and guide learners through calculating capacitance based on geometric and dielectric properties.

The effective capacitance of capacitors in series and parallel configurations should be explored through hands-on activities and problem-solving exercises.

ASSESSMENT SUMMARY

Assessment of the concept of an electric field should involve questions that test learners' ability to explain how electric fields are visualised using diagrams and their understanding of field characteristics (for example, multiple choice questions to select the correct electric field diagram for a particular configuration of charged objects).

Assessments on Coulomb's law should include numerical problems where learners calculate the electrostatic force between charges of given magnitudes and distances. Problem-solving exercises should also be given to learners to evaluate their ability to calculate electric field strength accurately and understand how it varies with distance and charge magnitude.

Understanding capacitor's structure, operation, and behaviour in circuits is essential. Assessment strategies should include descriptive questions on capacitor construction and function, as well as numerical problems to calculate capacitance and energy storage in capacitors.

Assessment tasks should also include problem-solving exercises where learners calculate the overall capacitance in different circuit arrangements and explain the rationale behind their calculations.

WEEK 7

Learning Indicators

1. *Explain and show how an electric field is represented and their characteristics*
2. *State Coulomb's law of electrostatics and calculate electrostatic force acting on the charges*

FOCAL AREA 1: ELECTRIC FIELDS

An electric field is a region around a charged particle or object within which other charged particles or objects experience a force. It represents how a charge influences the space around it.

Faraday introduced the concept of the electric field. He envisioned electric and magnetic fields as lines extending through space, which could exert forces on charges. Faraday's field lines helped visualise how forces act at a distance, and these lines are called electric field lines or electric lines of force.

Characteristics of electric field lines

Electric field lines are imaginary lines drawn in such a way that the tangent to any of them at any point gives the direction of the electric field at that point.

Drawing electric field lines involves following a set of rules that ensure the representation accurately reflects the properties of the electric field. Here are the key rules:

1. Electric field lines originate from positive charges and terminate on negative charges. In the case of an isolated charge, they extend to or from infinity.
2. The direction of the electric field line at any point is tangential to the line at that point and indicates the direction of the electric field vector.
3. The density of electric field lines is proportional to the magnitude of the electric field at that region. A stronger electric field is depicted by more closely spaced lines.
4. Electric field lines never intersect. If they did, it would imply two different directions for the electric field at a single point, which is impossible.
5. Electric field lines are perpendicular to the surface of a conductor at the surface.
6. The arrangement of electric field lines should respect the symmetry of the charge distribution. For example, around a single isolated charge, the lines should be radially symmetric.
7. Electric field lines are drawn as continuous curves, not broken lines, to indicate the continuous nature of the electric field.

8. For a positive point charge, the lines radiate outward uniformly. For a negative point charge, the lines converge inward uniformly.
9. In diagrams, field lines should be drawn such that they convey the overall shape of the field clearly. A sufficient number of lines should be drawn to represent the field accurately, but not so many that the diagram becomes cluttered.

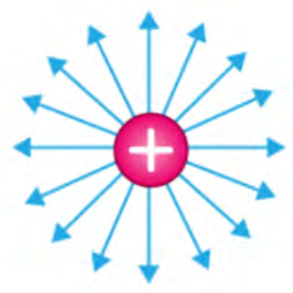


Figure 25: *Lines of force associated with a positively charged sphere in isolation*

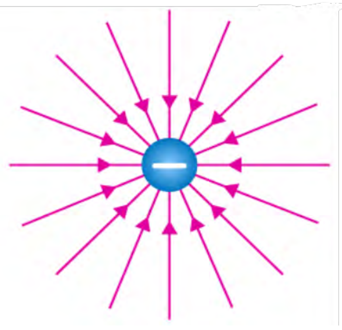


Figure 26: *Lines of force associated with a negatively charged sphere in isolation*

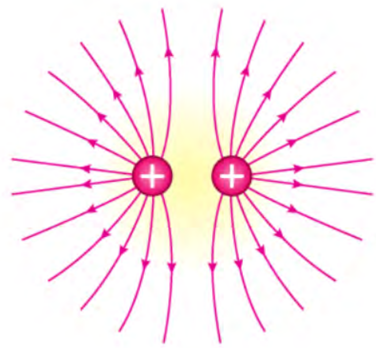


Figure 27: *Lines of force associated with two like point charges of equal amplitude*

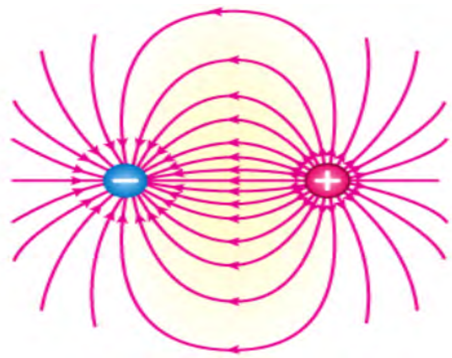


Figure 28: *Lines of force associated with two unlike point charges of equal amplitude*

LEARNING TASKS

1. Explain the concept of an electric field.
2. Describe the characteristics of an electric field, including direction and magnitude.
3. Illustrate electric field lines for different charge configurations.
4. Conduct an experiment to visualise electric field patterns.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-based Learning**
   a. Explain the concept of an electric field by introducing it as a region around a charged particle where other charged particles experience a force.

   i. Include videos or virtual simulations to enhance understanding.

   ii. Demonstrate the concept of an electric field by charging up an insulator (e.g., a balloon, by rubbing it on a jumper) and using it to pick up small pieces of paper (e.g. hole punches).

b. Describe the characteristics of an electric field, including direction (from positive to negative charges) and magnitude (force per unit charge). Use diagrams to illustrate these concepts.

2. Project-based Learning

a. Have learners watch a video demonstrating the visualisation of electric field patterns using semolina on an oil surface

Figure 29: *video demonstrating the visualisation of electric field patterns using semolina on an oil surface*

b. Guide learners through a project where they conduct an experiment to visualise electric field patterns using materials like semolina or iron filings. They should plan, execute, and analyse the experiment, then present their findings, highlighting the correlation between their illustrations and the experimental patterns.

3. Problem-based / Collaborative Learning

a. Discuss the patterns and the rules for drawing electric field lines (e.g., lines never cross, density represents strength), then provide learners with different charge configurations (e.g., single point charge/ dipole/ parallel plates/ a combination of these) and have them illustrate the electric field lines.

KEY ASSESSMENT

Level 1: Electric field lines point…

A. From negative to positive charges

B. From positive to negative charges

C. In random directions

D. In circular paths

Level 2: Explain how electric field lines represent the direction and strength of an electric field.

Level 4: Conduct research on the use of electric fields in technology. Prepare a detailed report and presentation explaining its importance in devices such as capacitors and electric field sensors.

FOCAL AREA 2: COULOMB'S LAW OF ELECTROSTATICS

Coulomb's law of electrostatics

Coulomb's law, a fundamental principle in electrostatics, describes the force between electrically charged particles. It was formulated by Charles-Augustin de Coulomb, a French physicist, in the late 18th century.

In the 18th century, scientists were exploring the nature of electricity and magnetism. Benjamin Franklin's experiments with electricity provided initial insights into the behaviour of charges. Coulomb was particularly interested in quantifying the force between electric charges.

Coulomb conducted a series of experiments between 1785 and 1789 to measure the force between charged objects. He used a torsion balance (a sensitive device involving a twisted wire) to measure the electrostatic force. Based on his experiments, Coulomb formulated a mathematical expression for the force between two-point charges.

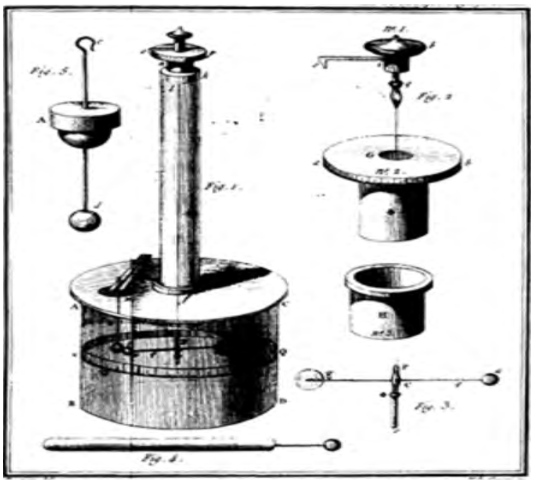


Figure 30: *A drawing of Coulomb's torsion balance, which he used to measure the electrical force between charged spheres*

Coulomb's law of electrostatics states that in a given medium, the force of attraction or repulsion F between two charges Q_1 and Q_2 is directly proportional to the product of the charges and inversely proportional to the square of their distance of separation r.

Mathematically,

$$F = k\frac{Q_1 Q_2}{r^2}$$

The constant of proportionality k is called *Coulomb's constant*. In SI units, the constant k has the value $k = 8.99 \times 10^9 \ \mathrm{Nm^2C^{-2}}$

The direction of the force is along the line joining the centres of the two objects. If the two charges are of opposite signs, Coulomb's law gives a negative result. This means that the force between the particles is attractive. If the two charges have the same signs, Coulomb's law gives a positive result. This means that the force between the particles is repulsive.

This fundamental principle underpins various practical applications in everyday life, including the operation of electrical appliances, electrostatic precipitators for pollution control, capacitors in electronics, static electricity phenomena, lightning protection systems, electrostatic painting, medical devices, and air purification technologies. Coulomb's law remains crucial in understanding and developing technologies across industries, influencing both design and operation of numerous devices and systems.

LEARNING TASKS

1. State Coulomb's law of electrostatics.
2. Identify the variables in Coulomb's law and their units.
3. Calculate the electrostatic force between two point-charges using Coulomb's law.
4. Solve problems involving multiple charges to find the net electrostatic force.
5. Conduct an experiment to verify Coulomb's law using charged objects and measure the forces involved.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-based Learning**
   - **a.** Begin with a detailed explanation of Coulomb's Law, discussing its historical context and significance in electrostatics. Define the terms involved (electric charge, distance, permittivity). Ask the learners to identify the units for each of the terms in the formula, and to use dimensional analysis to choose the correct SI unit for Coulomb's constant from a multiple-choice list.
   - **b.** Learners research or watch a video about Coulomb's torsion balance and the discovery of the relationship between electrostatic force, distance and charge.
2. **Problem-based Learning**
   - **a.** Provide a series of calculations of the electrostatic force between two-point charges using Coulomb's law, providing at least one step-by-step example.
   - **b.** To increase the level of challenge, provide learners with problems involving multiple charges to find the net electrostatic force.

3. **Project-Based / Collaborative Learning**
   a. In mixed ability groups, have learners design an experiment to verify the relationship between force and distance according to Coulomb's law using charged objects. They should outline how they would measure the forces between the objects, how they would attempt to maintain a constant charge on the objects at each distance interval, and how they would compare experimental results with theoretical predictions. (Note: learners should not be expected to have access to the necessary equipment to carry out the practical but should be assessed on their experimental design).

KEY ASSESSMENT

Level 1: State Coulomb's law of electrostatics

Level 2

1. Explain how Coulomb's Law can be used to calculate the force between two charged objects.
2. How does the electrostatic force change if one of the charges is doubled?

Level 3

1. Describe how you would experimentally verify Coulomb's Law using charged rods and a sensitive balance.
2. Calculate the electrostatic force between two charges of 2 μC and 3μC separated by a distance of 0.5 m in a vacuum.

   $k = 9.0 \times 10^9$ Nm^{2}C^{-2}
3. Calculate the electrostatic force between two-point charges A and B that are separated by 45 cm (about 1.48 ft) if the magnitude of A is 2q and that of B is q.

Level 4: Conduct research on the use of Coulomb's Law in technology. Prepare a detailed report and presentation explaining its importance in devices such as electrostatic precipitators and photocopiers.

Hint

*The recommended mode of assessment for week 7 is **computational task**. Use the level 3 question 3 as a sample question and the Teacher Assessment Manual and Toolkit page 39 for more information on how to carry out computational task assessment.*

WEEK 8

Learning Indicators

1. *Determine the electric field strength/intensity at a point due to a point charge*
2. *Define and calculate potential difference*

FOCAL AREA 1: ELECTRIC FIELD STRENGTH AND POTENTIAL DIFFERENCE

Electric field intensity

Electric field intensity (often referred to as electric field strength) is a measure of the force experienced by a unit positive charge placed in an electric field. It is a vector quantity, which means it has both magnitude and direction.

The **electric field intensity,** E, at a point in space is defined as the force F per unit positive charge Q placed at that point:

[[OMML-EQ-62D]]

The unit of electric field intensity is newtons per coulomb (NC^{-1}) or volts per meter (Vm^{-1})

Electric potential

Electric potential, often denoted by V, is a measure of the potential energy per unit charge at a point in an electric field. It gives us an idea of how much potential energy a charge would have at a specific location due to the electric field.

Electric potential is the work done (W) in moving a unit positive test charge (Q) from infinity to a point in an electric field.

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

The **electric potential difference** (also known as voltage) between two points in an electric field is the work done to move a unit positive charge from one point to the other.

The potential difference V between two points A and B is given by:

$$V_{AB} = V_A - V_B$$

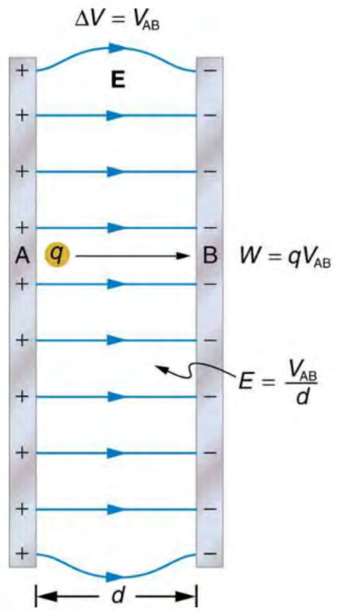


Figure 31: *Parallel conducting plates*

The relationship between V and E for parallel conducting plates is $E = \frac{V}{d}$. Note that $\Delta V = V_{AB}$ in magnitude. For a charge that is moved from plate A at higher potential to plate B at lower potential, a minus sign needs to be included as follows $-\Delta V = V_{AB} = V_A - V_B$.

The work done by the electric field in the figure above to move a positive charge q from A, the positive plate, higher potential, to B, the negative plate, lower potential, is

$$W = -q\Delta V$$

$$W = qV_{AB}$$

Work is $W = Fd\cos\theta$; here, $\cos\theta = 1$, since the path is parallel to the field, and so $W = Fd$. Since $F = qE$, we see that $W = qEd$. Substituting this expression for work into the previous equation gives

$$qEd = qV_{AB}$$

The charge cancels, and so the voltage between points A and B is seen to b

$$V_{AB} = Ed$$

$$E = \frac{V_{AB}}{d}$$

(Uniform E-field only)

where d is the distance from A to B, or the distance between the plates in the figure. Note that the above equation implies the units for electric field are volts per meter. We already know the units for electric field are newtons per coulomb; thus the following relation among units is valid

$1\ NC^{-1} = 1\ Vm^{-1}$

Differences between electric potential and electric field intensity

Electric potential	Electric field intensity
Work done per unit charge	Force per unit charge
Scalar quantity	Vector quantity
Measured in V or JC^{-1}	Measured in Vm^{-1} or NC^{-1}

Understanding electric field intensity and electric potential is crucial for many applications, such as designing circuits and electronic devices, understanding the behaviour of capacitors, and analysing electrostatic phenomena and electric fields.

LEARNING TASKS

1. Explain the concept of electric field strength and potential difference.
2. Calculate the electric field strength between two charged plates.
3. Calculate the potential difference between two points in an electric field.
4. Solve problems involving the relationship between electric field strength and potential difference in various configurations.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based / Collaborative Learning**
   - **a.** Introduce the concepts of electric field strength and potential difference. Ask learners to discuss and explain these concepts in their own words, and to share these with the class.
   - **b.** Guide learners through the derivation for the electric field strength between two parallel plates, $E = \frac{V}{d}$.
   - **c.** In groups, learners should sketch graphs of how both electric field strength and potential vary with distance in a) uniform and b) radial fields. Their sketches should be compared with the true graphs, and the teacher should explain how the shapes of the graphs relate to the relevant formulae.
2. **Problem-Based Learning**
   - **a.** Present learners with a real-world scenario that requires understanding electric field strength and potential difference, such as the design of a capacitor. Have learners explain the concepts and their significance in the scenario.
   - **b.** Provide learners with data on charged plates, including distances and potential differences. Have them calculate the electric field strength between the plates.
     - i. At least one worked example should be provided.

ii. Problems should be differentiated to become increasingly challenging for the most able learners.

c. Provide learners with problems where they calculate the potential difference between two points in an electric field.

i. At least one worked example should be provided.

ii. Problems should be differentiated to become increasingly challenging for the most able learners.

d. Provide more complicated examples of calculations involving both electric field strength and potential difference. For the most able learners, this could include graph analysis whereby the learner calculates electric field strength from a potential-distance graph and potential difference from a field strength-distance graph.

KEY ASSESSMENT

Level 1

1. Define electric field strength.

2. State two differences between electric field strength and potential difference.

Level 2: Calculate the electric field strength between two charged plates with a potential difference of 120 V and separated by a distance of 0.5 metres.

Level 3: Describe how you would solve a problem involving the calculation of the potential difference in a system with varying electric field strengths.

Hint

The recommended mode of assessment for Week 8 is ***homework****. Use the level 2 question as a sample question and the Teacher Assessment Manual and Toolkit page 46 for more information on how to carry out homework.*

WEEK 9

Learning Indicators

1. *Describe the structure and operation of capacitors*
2. *Determine the capacitance of a parallel plate capacitor*
3. *Determine the effective capacitance of a number of capacitors arranged in series and in parallel*

FOCAL AREA: CAPACITOR DESIGN AND CAPACITOR ARRANGEMENT

A capacitor is a device used for storing electrical charge or energy in an electric circuit. It is used in a variety of applications, such as to tune the frequency of radio receivers, eliminate sparking in automobile ignition systems, or store short-term energy for rapid release in electronic flash units.

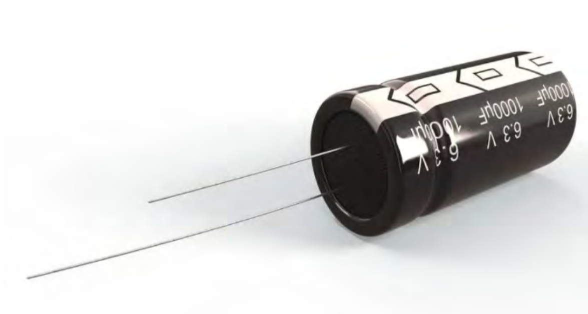


Figure 32: *Capacitor*

It consists essentially of two metal electrodes (plates) separated by air or some other insulating medium (known as a dielectric). Used in an electric circuit, the plates are connected to the positive and negative terminals of a battery or some other voltage source. When this connection is made, electrons are pulled off one of the plates, leaving it with a charge of $+Q$, and are transferred through the battery to the other plate, leaving it with a charge of $-Q$. The transfer of charge stops when the potential difference across the plates equals the potential difference of the battery. A charged capacitor is a device that stores energy that can be reclaimed when needed for a specific application.

The type of dielectric used in the construction of the capacitor is generally used to classify or name the capacitor. Some examples are ceramic capacitors, electrolytic capacitors, film capacitors, air capacitors etc.

Figure 33: *Circuit symbol for a capacitor*

Capacitance is defined as the ratio of the charge stored on the capacitor to the potential difference across the plates. Its SI unit is Farad (F)

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

Figure 34: *How to make a simple capacitor*

The Parallel-Plate Capacitor

The capacitance of a device depends on the geometric arrangement of the conductors. The capacitance of a parallel-plate capacitor with plates separated by a dielectric material depends on

1. *Plate Area*

The capacitance C is directly proportional to the plate area, A (C µ A)

2. *Distance between the plates*

The capacitance C is inversely proportional to the distance between the plates, d (Cµ$^1/_d$)

3. *Permittivity or dielectric constant*

The capacitance C is directly proportional to the permittivity of the medium of dielectric material, ε (C µ ε)

Mathematically,

$C \propto \frac{\varepsilon A}{d}$ Þ $C = k\frac{\varepsilon A}{d}$

$C = \frac{\varepsilon A}{d}$ (since k=1)

Grouping of Capacitors

Series grouping

Multiple capacitors are said be connected in series if 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.

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 35).

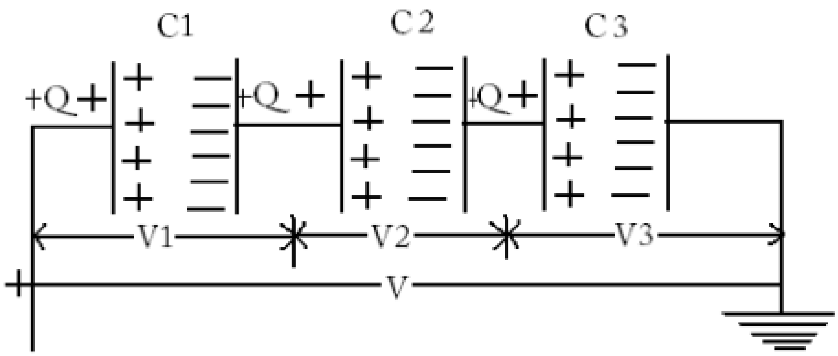


Figure 35: *Capacitors in series*

$V_1 = \frac{Q}{c_1},\ V_2 = \frac{Q}{C_2}, V_3 = \frac{Q}{C_3}$

The total pd, V, across the network

$V = V_1 + V_2 + V_3$

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

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

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

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

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

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

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

Therefore, the total capacitance decreases in series grouping.

Parallel grouping

Multiple capacitors are said to be connected in parallel if positive plate of each capacitor is connected to the positive terminal of battery and negative plate of each capacitor is connected to the negative terminal of 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 36).

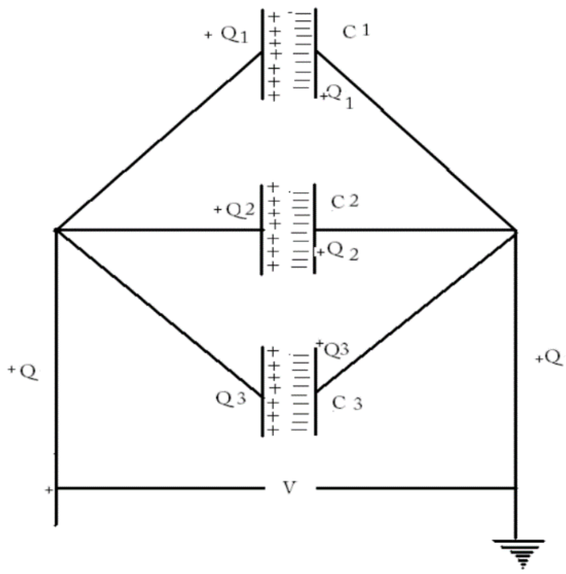


Figure 36: *Capacitors in parallel*

The sum of the separate charges is given by

$Q = Q_1 + Q_2 + Q_3$

But Q = CV

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

$CV = C_1V + C_2V + C_3V$

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

$C = C_1 + C_2 + C_3$

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 total capacitance increases in parallel grouping.

LEARNING TASKS

1. Describe the structure and function of capacitors.
2. Explain how the physical dimensions of a capacitor affect its capacitance.
3. Calculate the effective capacitance of capacitors connected in parallel and in series.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   a. Ask learners to stand up and 'behave like the electrons' in a circuit containing a capacitor, a switch and a battery. Talk the learners through the process by

which electrons build up on one side of the capacitor and are depleted from the other; ask them questions as you proceed through the description to help them to understand how their prior knowledge applies. E.g.,

"What is the charge on an electron? Which way will it travel around the circuit, given that the positive plate of the battery is over here?"

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

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

b. After the learners have completed their model (above), ask them to draw a diagram to summarise the knowledge that they have learned.

c. Give a brief lecture on the formula for the capacitance of a parallel plate capacitor. Use diagrams to show the structure of a parallel plate capacitor and how each variable affects the capacitance.

d. Give a brief lecture on the formulas for calculating the effective capacitance, use visual aids or a whiteboard to show how the formulas are applied.

2. Project-Based Learning

a. Have learners watch a video on how a simple capacitor can be built using aluminium foil and wax paper.

b. Provide aluminium foil, paper clips, wax paper, AA batteries, a multimeter and alligator clips. Have learners build a simple capacitor by layering aluminium foil and wax paper and connecting it to a battery, initially, and then to a multimeter to see how it stores and releases charge.

c. Provide capacitors of different values, a breadboard, wires, and a capacitance meter or multimeter with capacitance measurement capability. Have learners build circuits with capacitors in parallel and in series. Ask learners to measure the total capacitance of each configuration and compare their measurements with their calculations.

i. More able learner may be able to suggest why their calculated values may not agree with the experimental data.

d. Use interactive simulations (e.g., PhET Capacitor Lab) to explore how changing variables like plate area, distance between plates, and dielectric material affects the capacitance. Have learners perform virtual experiments by adjusting parameters and observing the changes in capacitance and ask learners to record their observations and analyse the data to draw conclusions about the relationships between the variables.

3. **Collaborative Learning**
   a. Assign research areas such as types of capacitors (e.g., ceramic, electrolytic), their specific applications, and how they differ in structure and function. Have each group present their findings, explaining the structure, function, and real-world applications of their assigned capacitor type.

4. **Problem-Based Learning**
   a. Provide worksheets with problems involving the calculation of capacitance for parallel plate capacitors with various configurations. Have learners work in pairs or small groups to solve the problems. Review the solutions as a class, discussing different approaches and common mistakes.
      i. At least one worked example should be provided.
      ii. Problems should be differentiated to become increasingly challenging for more able learners.

   b. Give learners worksheets with various problems involving capacitors in series and parallel. Have learners work in groups to solve the problems, encouraging them to discuss and explain their reasoning to each other. Review the solutions as a class, discussing any common mistakes and clarifying misunderstandings.
      i. At least one worked example should be provided.

      Problems should be differentiated to become increasingly challenging for more able learners.

KEY ASSESSMENT

Level 1

1. What is the primary function of a capacitor?
2. How does the physical size and separation of the plates affect the capacitance of a capacitor?

Level 2

1. Calculate the total capacitance of three capacitors with capacitances of 10 μF, 20 μF, and 30 μF arranged in series.
2. If the distance between the plates of a parallel plate capacitor is halved, how does this affect the capacitance?

Level 3: Explain why the total capacitance decreases when capacitors are arranged in series.

Level 4: Design a circuit with a total capacitance of 15 μF using a combination of 6 μF and 4 μF capacitors in both series and parallel configurations. Explain your design

Hint

*The recommended mode of assessment for week 9 is **questioning**. Use the level 2 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 30 for more information on how to use questioning assessment mode.*

WEEK 10

Learning Indicators

1. *Describe the behaviour of a capacitor in DC and AC circuits*
2. *Calculate the energy stored in a capacitor*

FOCAL AREA: BEHAVIOUR OF CAPACITORS AND ENERGY STORED

The behaviour of a capacitor varies significantly between DC (direct current) and AC (alternating current) circuits due to the mechanism of how capacitors store and release electrical energy.

Capacitor in DC Circuits

Charging: When a capacitor is connected to a DC voltage source, it begins to charge up. Initially, current flows through the circuit, and the voltage across the capacitor increases. The charging current decreases exponentially over time until the capacitor is fully charged to the supply voltage, and the current flow stops.

Discharging: When the capacitor is disconnected from the voltage source and connected to a load, it begins to discharge, releasing its stored energy. The voltage across the capacitor decreases exponentially over time, and the discharging current flows (also decreasing exponentially) until the capacitor is fully discharged.

Capacitor in AC Circuits

A capacitor charges up when the AC reaches its peak in an AC circuit and releases the charge when the AC decreases. This behaviour allows the capacitor to act like temporary storage that causes the current to lead voltage by 90 degrees.

Energy Stored

The energy stored in a capacitor is related to the amount of charge it holds and the voltage across its plates. The formula for the energy (E) stored in a capacitor is:

Þ $E = \frac{1}{2} C V^2$

Where, E is the energy stored in the capacitor (in Joules, J), C is the capacitance of the capacitor (in Farads, F), V is the voltage across the capacitor (in Volts, V).

Capacitors are versatile components used in various applications across electronics and electrical engineering. Key uses include:

1. **Energy Storage:** Stabilising power supplies and providing backup power.

2. **Signal Processing:** Filtering frequencies, coupling AC signals, and decoupling noise.
3. **Timing Applications:** Creating precise time delays and generating pulses in circuits.
4. **Power Factor Correction:** Improving efficiency in power systems.
5. **Motor Starters:** Enhancing the performance of AC motors.
6. **Electronic Tuning:** Adjusting frequencies in radio and RF circuits.
7. **Surge Protection:** Absorbing voltage spikes to protect components.
8. **Lighting:** Improving performance and reducing flicker in fluorescent lamps and LED drivers.
9. **Energy Harvesting:** Storing energy from renewable sources.
10. **Audio Applications:** Directing frequencies in speaker systems and filtering noise.
11. **Medical Devices:** Providing quick energy discharge in defibrillators.
12. **Communication Systems:** Facilitating modulation and demodulation.
13. **Computing:** Stabilizing power supply and reducing noise near ICs.

LEARNING TASKS

1. Describe the behaviour of a capacitor in DC and AC circuits.
2. Calculate the energy stored in capacitor.
3. Recognise the practical applications of capacitors in electronic devices and systems.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   - **a.** Explain the behaviour of capacitors in DC and AC circuits to the class. Use graphs, diagrams and animations to illustrate how capacitors behave differently in DC and AC circuits.
   - **b.** Give a brief lecture on the formula for the energy stored in a capacitor.
     - i. More able learners should be encouraged to look at a Q-V graph for a capacitor and should use this to derive the formula for the energy stored.
   - **c.** Instruct learners to research some examples of where and how capacitors are used (e.g., in power supplies, filters, timing circuits). Provide them with a blank table to fill in with some of the details of the application.

2. **Project-Based Learning**
   a. Provide capacitors, resistors, power supplies, and multimeters. Have learners build a simple DC circuit with a capacitor and resistor, observe the charging and discharging process, and measure the voltage across the capacitor over time. Let learners plot the voltage vs. time graph to show the exponential charging and discharging curves.
   b. Let learners use the measured voltage values and known capacitances to calculate the energy stored in the capacitor at different points using the formula.
   c. Have learners build series and parallel capacitor circuits. Let them measure the total capacitance and voltage, then calculate the energy stored in the overall circuit and let them discuss how the configuration (series vs. parallel) affects the total stored energy.
   d. Provide old electronic devices (e.g., radios, TVs, computers) that can be safely disassembled. Have learners disassemble the devices to locate and identify the capacitors. Discuss the role of each capacitor found and how it contributes to the device's function.

3. **Problem-Based Learning**
   a. Provide worksheets with problems involving energy calculations for capacitors with different capacitances and voltages. Have learners work in pairs or small groups to solve the problems. Review the solutions as a class, discussing different approaches and common mistakes.
      i. At least one worked example should be provided.
      ii. Problems should be differentiated to become increasingly challenging for more able learners.

KEY ASSESSMENT

Level 1

1. What happens to a capacitor in a DC circuit once it is fully charged?
2. What is the formula for calculating the energy stored in a capacitor?

Level 2: A capacitor stores 0.1 J of energy when charged to 10 V. What is its capacitance?

Level 3: Compare the energy stored in two capacitors, one with a capacitance of 20 μF charged to 10 V, and another with a capacitance of 10 μF charged to 20 V. Which capacitor stores more energy?

Level 4: Design a circuit that uses a capacitor to store 0.5 J of energy using a 9 V power supply. What capacitance should you choose for the capacitor?

Hint

*The recommended mode of assessment for Week 10 is **essay**. Use the level 4 question as a sample question and the Teacher Assessment Manual and Toolkit page 74 for more information on how to carry out essay tasks.*

Section 3 Review

Over the past four weeks, our journey through the fundamentals of electricity and capacitors has been both enlightening and foundational.

We began by exploring the concept of electric fields and their representation. An electric field, denoted by E, is a vector field that exerts a force on charged particles. It radiates outward from positive charges and inward towards negative charges, following the principles laid out by Coulomb's law. This law quantifies the force between two point charges Q_1 and Q_2, separated by a distance r, as, $F = k\frac{Q_1 Q_2}{r^2}$ where k is Coulomb's constant.

Moving forward, we delved into the practical implications of electric fields, particularly in calculating the electric field strength at a point due to a point charge Q. The formula $E = \frac{F}{Q}$ became instrumental in understanding how electric fields vary with distance and charge magnitude.

Closely tied to electric fields is the concept of potential difference (V), which we explored extensively in the eighth week. Potential difference measures the work done per unit charge to move a charge between two points in an electric field.

As we progressed into the ninth week, capacitors emerged as essential components in storing electrical energy. These devices consist of two conductive plates separated by an insulating material (dielectric). The capacitance C of a capacitor, which quantifies its ability to store charge, is given by $C = \frac{\varepsilon A}{d}$, where A is the area of the plates, d is the distance between them and is the permittivity of free space. Moreover, we explored how capacitors behave in different configurations. In series, the equivalent capacitance is inversely proportional to the sum of reciprocals of individual $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ while in parallel, it is simply the sum of the individual capacitances $C = C_1 + C_2 + C_3$. These configurations influence how capacitors interact with circuits, affecting their ability to store and release electrical charge.

Finally, in the tenth week, we examined the behaviour of capacitors in both DC and AC circuits. In DC circuits, capacitors charge and discharge according to the voltage applied, while in AC circuits, capacitors can act as filters, allowing alternating currents to pass while blocking direct currents.

Additionally, we delved into the calculation of energy stored in capacitors, which is crucial for understanding their practical applications. The energy stored (E) in a capacitor is given by $E = \frac{1}{2}CV^2$, where C is the capacitance and V is the voltage across the capacitor.

SECTION 4: PHOTOELECTRIC EFFECT AND RADIOACTIVITY

Strand: Atomic and Nuclear Physics

Sub-Strand: Atomic Physics

Learning Outcome: *Appreciate the application of the photoelectric effect in operating automatic doors and security setups.*

Content Standard: Demonstrate knowledge and understanding of the photoelectric effect.

Strand: Atomic and Nuclear Physics

Sub-Strand: Nuclear Physics

Learning Outcome: *Recognise the amount of energy an atom can produce when there is a change in its mass.*

Content Standard: Demonstrate knowledge and understanding of the atom as an agent for energy production.

Hint

Remind learners of the ***end of semester examination*** *in Week 12. Refer to* ***Appendix D*** *at the end of this section for Table of specification to guide you to set the questions for the exams.*

INTRODUCTION AND SECTION SUMMARY

The study of modern physics encompasses some of the most groundbreaking discoveries that have reshaped our understanding of the natural world. This section introduces learners to key concepts such as the photoelectric effect, wave-particle duality, and radioactivity. Learners will explore how light behaves as a wave and particle, learn the laws governing radioactive decay, understand the concept of half-life, and discover how radiocarbon dating is used to determine the age of ancient specimens. Through engaging activities and practical experiments, learners will comprehensively understand these phenomena and their applications in technology, medicine, and archaeology.

The weeks covered by the section are:

Week 11: Photoelectric effect and wave-particle duality

Understanding the fundamental principles behind the photoelectric effect, the concept of photons, and how particles can exhibit wave-like and particle-like properties.

Week 12: Radioactivity

Using the radioactive decay law to describe and calculate the decay of unstable nuclei over time. Learning about the concept of half-life and its significance in predicting the behaviour of radioactive substances and applying the principles of radiocarbon dating to calculate the age of ancient bone specimens and other organic materials.

SUMMARY OF PEDAGOGICAL EXEMPLARS:

Teachers should employ a mix of interactive teaching opportunities, visual aids, group discussions, and hands-on activities to explain key concepts such as the photoelectric effect, wave-particle duality, and radioactivity.

Use animations, simple experiments with solar panels, and popcorn kernel demonstrations to illustrate basic principles. Encourage collaborative learning through group discussions and think-pair-share activities.

Create models of radioactive decay using dice or coins. Utilise experiential learning by involving learners in practical experiments and group problem-solving tasks.

Advanced learners should use computer simulations, research projects, and detailed experiments to explore practical applications like radiocarbon dating. Promote talk for learning through class presentations and peer feedback sessions.

Differentiation is achieved by providing progressively challenging tasks, varied calculation practices, and additional research opportunities. This approach ensures that all learners grasp essential concepts, can perform relevant calculations, and can apply their knowledge to real-world scenarios, with extra content available for gifted and talented learners.

ASSESSMENT SUMMARY

To evaluate learners' understanding of radioactivity and the wave-particle duality of light, teachers should use both formative and summative assessments. Formative assessments include regular quizzes, group discussions, and interactive activities to monitor ongoing progress and provide immediate feedback. Summative assessments involve homework, written exams, and practical exams to evaluate overall comprehension and skills.

Homework assignments might include research tasks about radioactive decay and the photoelectric effect. Worksheets and problem-solving tasks should feature multiple-choice, short-answer, and detailed explanation questions covering all topics. Practical exams could involve demonstrating light's wave-particle duality or simulating radioactive decay.

WEEK 11

Learning Indicators

1. *Explain the photoelectric effect and wave-particle duality*
2. *State the laws of photoelectric effect*
3. *Identify areas of application of photoelectric effect and how they are applied*

FOCAL AREA: PHOTOELECTRIC EFFECT AND WAVE-PARTICLE DUALITY

Wave-particle duality

Wave-particle duality is a fundamental concept in quantum mechanics, where light and other electromagnetic radiation behave as waves and, at other times, as particles. This concept was introduced by Louis de Broglie in 1924, who suggested that particles such as electrons have wave-like characteristics. This duality was experimentally confirmed through the double-slit experiment, which demonstrated that particles like electrons can create interference patterns, a property typically associated with waves. De Broglie's hypothesis earned him the Nobel Prize in Physics in 1929.

Figure 37: *Video explaining the wave-particle nature of light*

Just as particles sometimes demonstrate wave-like behaviour, waves sometimes demonstrate particle-like behaviour. One example of this is the photoelectric effect.

The photoelectric effect is a phenomenon in which electrons are ejected from a metal surface when exposed to light of sufficient frequency. Heinrich Hertz first observed this effect in 1887 during his experiments on electromagnetic waves. However, Albert Einstein in 1905 provided a theoretical explanation for this phenomenon, for which he received the Nobel Prize in Physics in 1921.

Einstein proposed that light is composed of discrete packets of energy called photons. When photons strike a metal surface, they transfer their energy to electrons, causing the electrons to be ejected if the photon's energy exceeds the metal's work function (the energy needed to release an electron). The effect itself was not new, as Thomas Edison had already discovered thermionic emission in 1883, a process that required heating materials to high temperatures.

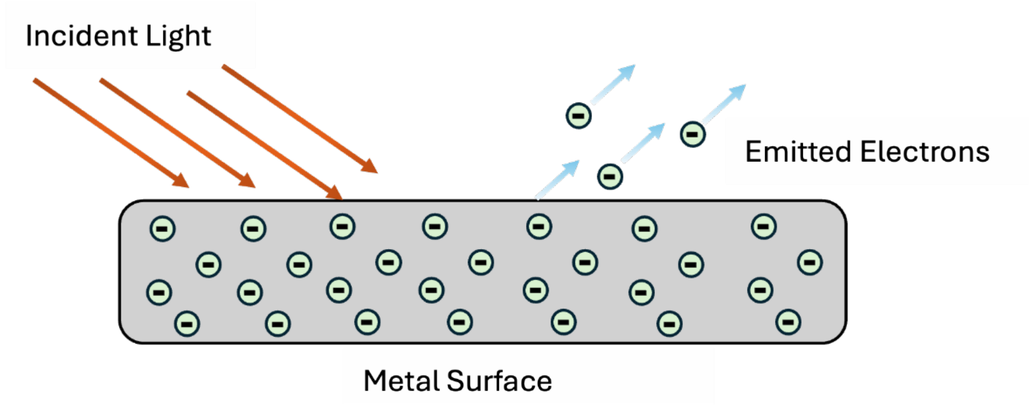


Figure 38: *A two-dimensional depiction of the incident light striking a metal surface and electrons ejected from it after absorbing energy from the incident radiation.*

Einstein postulated that the photoelectric effect is a beam of light consisting of small energy packages called photons or quanta. The energy E of a photon is equal to Planck's constant, h, multiplied by the frequency of the wave, f. From the relationship between frequency f, speed of light c and wavelength l, $f = \frac{c}{\lambda}$ for electromagnetic waves in vacuum, the energy of a photon is:

$$E = hf = \frac{hc}{\lambda}$$

where h = 6.63×10^{-34} Js.

Albert Einstein's explanation of the photoelectric effect established several important laws.

1. Light must have a certain minimum (threshold) frequency to eject electrons from the metal surface.
2. The emission of electrons occurs almost instantaneously when light above the threshold frequency strikes the metal surface. This instantaneous emission implies that the energy transfer from photons to electrons happens without any observable delay.
3. The kinetic energy of the ejected electrons is proportional to the frequency of the incident light and is independent of the light's intensity. This means that increasing the frequency of the incident light increases the kinetic energy of the ejected electrons while increasing the light's intensity only increases the number of ejected electrons, not their energy.
4. The number of electrons ejected is proportional to the intensity of the incident light, provided the frequency is above the threshold. Thus, a brighter light source (higher intensity) results in more electrons being emitted, but only if the light's frequency is sufficient to overcome the work function of the metal.

Applications of the Photoelectric Effect

The photoelectric effect has numerous practical applications in modern technology. One of the most common applications is photocells, or photoelectric sensors, which convert light into electrical energy. These sensors are widely used in solar panels, automatic doors, and light meters. Solar panels, for example, harness the photoelectric effect to generate electricity from sunlight, providing a renewable energy source.

Photomultiplier tubes, another application, amplify the photoelectric effect to detect low light levels. These tubes are essential in scientific instruments, medical imaging, and night vision devices due to their high sensitivity, which allows them to detect single photons.

Photoelectron spectroscopy is a technique that uses the photoelectric effect to study the energy levels of electrons in materials. This technique helps understand the electronic structure of atoms and molecules and is widely used in chemistry, physics, and materials science to analyse surfaces and thin films.

Digital cameras and charge-coupled devices (CCDs) also rely on the photoelectric effect to capture images by converting light into electrical signals. These devices are crucial in imaging technology, enabling high-resolution photographs and videos. The photoelectric effect's role in CCDs allows for the precise detection of light and image capture, foundational for modern digital photography and various imaging applications.

Figure 39: *Instead of a photographic film, a digital camera uses a CCD to capture images*

LEARNING TASKS

1. Explain the basic concepts of the photoelectric effect and wave-particle duality.
2. State and explain the laws of the photoelectric effect.
3. Design and conduct an experiment or research project to explore the applications of the photoelectric effect in technology.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-based Learning**

   a. Explain the concept of wave-particle duality to learners, using videos and other visual aids to enhance your explanations. Ensure that the learners are given an example of an experiment which demonstrates the wave-like nature of electrons (e.g., the double slit experiment). Show them images of the pattern produced and a comparable image of the interference pattern produced by water waves to strengthen your point.

   b. Explain the concept of the photoelectric effect to learners, again using images and videos to help the learners to envisage the process. Guide learners to identify the 4 laws of the photoelectric effect. Introduce the photoelectric effect formula.

   c. Assign a research project on an application of the photoelectric effect. Guide learners in designing experiments or simulations to gather data. For example, they could research how different materials affect solar panels' efficiency or the photoelectric effect's role in medical imaging devices. Provide a structured template for their research proposal, including sections on objectives, methodology, expected outcomes, and potential implications.

   d. Have learners present their findings in a research paper and a class presentation. Ensure their research papers include background information, experimental or simulation data, analysis, and conclusions. During the class presentation, please encourage learners to use visual aids such as slides, charts, and videos to explain their findings. Facilitate a Q&A session where peers can ask questions and provide feedback, fostering a collaborative learning environment.

   e. Conduct a group discussion where learners can ask questions and clarify concepts. Use guided questions to help learners understand key points, such as "What happens when the frequency of light increases?" and "Why do we see wave patterns in the double-slit experiment with electrons?"

   f. Summarise key points using flashcards and highlighted keywords. Create flashcards for terms like "photoelectric effect," "photon," "threshold frequency," and "wave-particle duality." Use these flashcards to quiz learners at the end of the session.

2. **Project-Based Learning**

   a. Using computer simulations to model the photoelectric effect, allow learners to adjust variables and predict outcomes. Guide them in changing parameters such as light frequency, intensity, and metal type. Have learners predict the outcomes based on their understanding of the photoelectric effect and then run the simulations to confirm their predictions.

i. Compare predictions with actual results, facilitating a discussion on discrepancies and underlying principles. Please encourage learners to document the differences between their predictions and the simulation results. Discuss possible reasons for these discrepancies and what they reveal about the underlying principles of the photoelectric effect.

b. Set up a simple experiment using a small solar panel to demonstrate the conversion of light into electrical energy. Divide learners into mixed-ability groups and give each group a solar panel, a light source (like a flashlight), and a voltmeter. Have learners measure the voltage output of the solar panel when exposed to light of different intensities and angles. Discuss their observations and relate them to the photoelectric effect.

c. Conduct a lab experiment to measure ejected electrons' threshold frequency and kinetic energy. Set up a controlled lab environment where learners can use a photocell, a light source with adjustable frequency, and measuring instruments (voltmeter and ammeter). Provide step-by-step instructions and a lab worksheet to guide them through the experiment. Have learners record their data, plot graphs, and analyse their results. Facilitate a discussion on how their findings support the laws of the photoelectric effect.

3. Problem-Based Learning

a. Work through example problems on the board, using concept maps to explain calculations of threshold frequency, kinetic energy, and the number of ejected electrons.

b. Provide additional practice problems for individual or pair work. Create worksheets with problems of varying difficulty. For instance, start with simple calculations of the energy of photons and then move to more complex problems involving the work function and kinetic energy of ejected electrons.

i. More able learners should be able to analyse graphs of photoelectron kinetic energy against light frequency to find a) the threshold frequency, b) the work function and c) Planck's constant.

KEY ASSESSMENT

Level 1: Define wave-particle duality.

Level 2: Calculate the kinetic energy of an electron ejected from a metal surface if the incident light has a frequency of 6×10^{14} Hz and the work function of the metal is 3 eV. How is this calculation relevant to the design of photoelectric sensors in devices like security systems?

Level 3: Compare the outcomes of shining light of high intensity but below the threshold frequency versus light of low intensity but above the threshold frequency on a metal surface. How do these principles apply to the efficiency of photovoltaic cells?

Level 4: Develop a research proposal to investigate new materials for more efficient photoelectric devices. Include objectives, methodology, and expected outcomes. Discuss how this research could impact careers in material science and engineering.

Hint

*The recommended mode of assessment for Week 11 is **discussion**. Use the level 3 question as a sample question and the Teacher Assessment Manual and Toolkit page 52 for more information on how to carry out discussion.*

WEEK 12

Learning Indicators

1. *State the radioactive decay law*
2. *Calculate the half-life of a radioactive sample*
3. *Calculate the age of bone specimen*

FOCAL AREA: RADIOACTIVITY

Radioactivity is the spontaneous emission of particles or electromagnetic waves due to the decay of unstable atomic nuclei. This phenomenon was first discovered by Henri Becquerel in 1896 while investigating phosphorescence in uranium salts. Later, Marie Curie and Pierre Curie conducted pioneering research on radioactivity, leading to the discovery of radium and polonium. For their work on radioactivity, Marie Curie received two Nobel Prizes: one in Physics in 1903 and another in Chemistry in 1911.

Radioactive decay involves the transformation of an unstable nucleus into a more stable one, releasing energy (and/or matter) in the form of alpha particles, beta particles, or gamma rays.

The radioactive decay law describes the rate at which unstable nuclei decay over time. It states that the number of undecayed nuclei decreases exponentially with time. Mathematically, it is expressed as:

$$N(t) = N_o e^{-\lambda t}$$

where:

$N(t)$ is the number of undecayed nuclei at time t.

N_0 is the initial number of undecayed nuclei.

λ is the decay constant, unique to each radioactive substance.

t is the elapsed time.

Half-life is the time required for half of the radioactive nuclei in a sample to decay, or the time taken for the Activity (number of decays per second) of a sample to half. It is a constant property for a given isotope and is independent of the initial amount of substance. The relationship between the half-life ($t_{1/2}$) and the decay constant (λ) is given by:

$$t_{\frac{1}{2}} = \frac{\ln(2)}{\lambda} = \frac{0.693}{\lambda}$$

Half-life is a crucial concept in understanding the long-term behaviour of radioactive substances and is widely used in fields such as archaeology, geology, and medicine.

The age of a bone specimen can be determined using radiocarbon dating, a method that measures the remaining amount of carbon-14, a radioactive isotope of carbon, in the specimen. Carbon-14 is continuously formed in the atmosphere and incorporated into living organisms. Upon death, the uptake of carbon-14 stops, and the existing carbon-14 decays over time. By measuring the remaining carbon-14 and comparing it to the initial amount, the age of the specimen can be calculated.

The radioactive decay law above can be rearranged to give the formula used in radiocarbon dating:

$$t = \frac{ln\left(\frac{N_0}{N(t)}\right)}{\lambda}$$

Where:

1. t is the age of the specimen.
2. N_0 is the initial amount of carbon-14.
3. $N(t)$ is the remaining amount of carbon-14.
4. λ is the decay constant of carbon-14.

LEARNING TASKS

1. Describe the basic concepts of radioactive decay and half-life.
2. Apply the radioactive decay law and calculate the half-life.
3. Determine the age of a bone specimen using radiocarbon dating.

Figure 40: *Video explaining radioactive decay*

PEDAGOGICAL EXEMPLARS

1. **Enquiry-based Learning**

   a. Introduce learners to alpha, beta and gamma radiation. Explain their structure and the effect that they have on the structure of the nucleus that they are emitted from.

   b. Use animations and videos to visually explain the process of radioactive decay and the concept of half-life. Show how an unstable nucleus emits particles and how the number of undecayed nuclei decreases over time.

c. Conduct a group discussion where learners can ask questions and clarify concepts. Use guided questions such as "What is radioactive decay?" and "How do we measure half-life?"

d. Summarise key points using flashcards and highlighted keywords. Create flashcards for terms like "radioactive decay," "half-life," and "decay constant." Use these flashcards to quiz learners at the end of the session.

e. Assign a research project on the application of radiocarbon dating in archaeology. Guide learners in designing experiments or simulations to gather data. For example, they could research how radiocarbon dating has been used to date ancient artefacts or human remains. Provide a structured template for their research proposal, including sections on objectives, methodology, expected outcomes, and potential implications.

i. Have learners present their findings in a class presentation. During the class presentation, encourage learners to use visual aids such as slides, charts, and videos to explain their findings. Facilitate a Q&A session where peers can ask questions and provide feedback, fostering a collaborative learning environment.

2. Project-Based Learning

a. Demonstrate a simple experiment using popcorn to simulate radioactive decay. Heat the corn kernels and observe how the number of unpopped corn kernels decreases over time, relating this to the concept of half-life.

b. Use computer simulations to model radiocarbon dating. Introduce learners to simulation software or online platforms that simulate the decay of carbon-14 and the dating process. Guide them in entering different initial amounts of carbon-14 and observing the decay over time.

i. Compare predictions with actual results, facilitating a discussion on discrepancies and underlying principles. Encourage learners to document any differences between their predictions and the simulation results. Discuss possible reasons for these discrepancies and what they reveal about the underlying principles of radiocarbon dating.

c. Conduct a lab activity to model radioactive decay using dice or coins. Each learner rolls a set of dice with a predetermined number representing "decayed" nuclei. After each roll, the "decayed" dice are removed, and the remaining dice are rolled again. Learners record the number of remaining "undecayed" dice after each roll and plot the results to visualise the decay process and calculate the half-life. Facilitate a discussion on how this model illustrates the randomness of radioactive decay and the concept of decay constant.

3. **Problem-Based Learning**
   a. Work through example problems on the board, using concept maps to explain the radioactive decay law and half-life calculations. Use visual aids like graphs and charts to show the exponential decay curve and the concept of half-life.
   b. Provide additional practice problems for individual or pair work. Create worksheets with problems of varying difficulty, starting with simple decay calculations and progressing to more complex half-life problems.
   c. Use quizzes and interactive problem-solving tasks to reinforce understanding. Implement activities like "Kahoot!" quizzes or online interactive simulations where learners can practice decay calculations and half-life problems.

KEY ASSESSMENT

Level 1: State the relationship between the decay constant and half-life.

Level 2: Explain how the concept of half-life is used in medical diagnostics, such as radioactive tracers.

Level 3: A sample containing $1x10^{10}$ radioactive nuclei has a half-life of 5 years. What percentage of the nuclei will have decayed after 40 years?

Level 4: Discuss the potential of radiocarbon dating in advancing our understanding of historical timelines. Include an analysis of current limitations and future possibilities.

Hint

*The recommended mode of assessment for week 12 is **end of semester examination**. Refer to **Appendix D** at the end of this section for Table of specification which will guide you to set the items.*

SECTION 4 REVIEW

Over the past few weeks, we explored radioactivity and the wave-particle duality of light.

For wave-particle duality, learners were introduced to light's dual nature, with key experiments like the photoelectric effect illustrating this concept. Practical applications such as solar panels and optical devices were discussed to show relevance in technology

In radioactivity, learners learned about modelling radioactive decay using dice or popcorn to understand half-life and decay rates. Discussions included practical applications such as radiocarbon dating.

Beginners should have a basic understanding of radioactive decay, half-life, and wave-particle duality. Intermediate learners should understand radioactive decay's detailed modelling, calculate half-lives, and understand experiments demonstrating light's dual nature. Advanced learners should be capable of advanced calculations, in-depth modelling of radioactive decay, and exploring the applications of wave-particle duality in modern technology.

Differentiation ensured all learners achieved a thorough understanding, with beginners gaining foundational knowledge, intermediate learners engaging in practical applications, and advanced learners exploring complex aspects and real-world applications. This approach prepared learners to apply these concepts in various scientific and technological contexts.

APPENDIX D: END OF SEMESTER EXAMINATION

STRUCTURE

SECTION A – 40 Multiple Choice Questions – 45mins (for 40 marks)

SECTION B -1hr 15mins (60 Marks)

Part 1 – 6 Questions; Answer All [Simple DoK Level 1 and 2 questions for 15 marks]

Part 2 – 4 Questions; Answer 3 [DoK Level 2 and 3 questions for 45 marks]

Table of Specification

WEEK	Learning Indicator	Type of Question	DoK Level				Total
			1	2	3	4	
1	Check the validity of equations. Establish the relationship between quantities. Determine the resultant of two vectors.	MCQ	1	2	1		4
		Essay	-	1	-		1
2	State Archimedes' principle. State principle of flotation.	MCQ	1	1			2
		Essay	-	-	1		1
3	Distinguish elastic deformation from plastic deformation.	MCQ	1	1	1		3
		Essay	1	-	-		1
4	State Hooke's law. Calculate Young's modulus.	MCQ	2	1	1		4
		Essay	-	1	-		1
5	Calculate the specific heat capacities of substances. Describe how to determine the specific heat capacity of a solid using a liquid of a known specific heat capacity.	MCQ	2	2	2		6
		Essay	-	-	-		
6	Explain latent heat of fusion and vaporisation and specific latent heat of fusion and vaporisation.	MCQ	1	2	1		5
		Essay	-	-	1		1
7	Explain and show how an electric field is represented and their characteristics. State Coulomb's law of electrostatics and calculate electrostatic force acting on the charges.	MCQ	1	2	1		4
		Essay	-	-	1		1
8	Determine the electric field strength/intensity at a point due to a point charge. Define and calculate potential difference.	MCQ	-	1	1		2
		Essay	-	1	-		1

9	Describe the structure and operation of capacitors. Determine the capacitance of a parallel plate capacitor. Determine the effective capacitance of a number of capacitors arranged in series and in parallel.	MCQ	1	1	-		**3**
		Essay	-	-	1		**1**
10	Describe the behaviour of a capacitor in DC and AC circuits. Calculate the energy stored in a capacitor.	MCQ	-	2	1		**3**
		Essay	1	-	-		
11	Explain the photoelectric effect and wave-particle duality. State the laws of photoelectric effect. Identify areas of application of photoelectric effect and how they are applied.	MCQ	1	1	1		**3**
		Essay	1				**1**
12	State the radioactive decay law. Calculate the age of bone specimen.	MCQ	1	1	1		**3**
		Essay					
Total			**15**	**20**	**15**		**50**

SECTION 5: PROJECTILES, FRICTION, CIRCULAR MOTION

Strand: Mechanics and Matter

Sub-Strand: Kinematics

Learning Outcome: *Use projectiles to explain the performance of athletes in some field events.*

Content Standard: Demonstrate knowledge and understanding of projectile as two dimensional motion.

Strand: Mechanics and Matter

Sub-Strand: Dynamics

Learning Outcomes

1. *Use the concept of circular motion to explain how the earth is kept in its path.*
2. *Explain how friction affects our daily life.*

Content Standards

1. Demonstrate knowledge and understanding of circular motion.
2. Demonstrate knowledge and understanding of friction.

Hint

*Learners should be assigned **Individual Projects** in Week 14 on stationary waves and present their research findings in Week 20. Refer to **Appendix E** at the end of this section for more information on the project.*

INTRODUCTION AND SECTION SUMMARY

This section delves into the fundamental concepts of projectile motion, friction, and circular motion, providing key insights into how objects move and interact with forces in various contexts.

The weeks covered by the section are

Week 13: Projectiles

First, projectile motion is explained, detailing how objects launched into the air follow a specific path under gravity. This includes calculating essential quantities such as time to reach maximum height, maximum height, time of flight, and range. Examples from sports like basketball and javelin throw illustrate practical applications.

Week 14: Friction

Next, friction is explored, distinguishing between static friction (preventing motion) and dynamic friction (opposing motion). The laws of friction, along with its advantages, disadvantages, and methods to reduce it (e.g., lubrication), are discussed. Determining the coefficient of friction provides a quantitative measure of the force between surfaces

Week 15: Circular motion

Circular motion, where objects follow a circular path, is examined through examples like spinning wheels and planetary orbits. Key parameters such as period, frequency, angular displacement, angular velocity, angular acceleration, and centripetal force are defined and explained.

Week 16: Application of circular motion

The practical application of these principles is highlighted in the banking of roads, explaining how proper banking angles help vehicles navigate curves safely. Additionally, the section explains the purpose and applications of a centrifuge and describes the motion of a conical pendulum, illustrating rotational dynamics.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Start with defining projectiles and explaining their parabolic trajectories influenced by gravity and initial velocity. Use examples from sports like basketball and javelin throw. Progress to calculating key quantities such as time to reach maximum height, maximum height, time of flight, and range, reinforcing these concepts through problem-solving sessions.

Introduce friction and its role in opposing motion, using everyday examples to distinguish between static and dynamic friction. Explain the laws of friction and discuss its advantages and disadvantages. Demonstrate methods to reduce friction and conduct experiments to determine the coefficient of friction.

Explain circular motion with real-life examples. Use visual aids and simulations to illustrate key concepts of angular displacement, centripetal force etc. Calculate centripetal force and related quantities through collaborative activities.

Discuss why roads are banked to provide necessary centripetal force, reducing reliance on friction. Derive the formula for the optimal banking angle and solve related problems through collaborative activities.

Explain the purpose and operation of a centrifuge in separating substances and also describe the motion of a conical pendulum using diagrams, videos and demonstrations to illustrate the forces involved.

ASSESSMENT SUMMARY

Use short-answer and essay questions to assess learners' understanding of projectile motion, including the factors influencing it and its characteristics. Similarly, the nature of friction and the principles of circular motion can be assessed from written, descriptive work.

Provide exercises that require learners to calculate key quantities related to projectile motion, friction, centripetal force, centripetal acceleration, angular velocity, and period, testing their ability to apply the relevant formulas. Include tasks that require learners to derive the formula for the optimal banking angle for a given speed and radius and solve problems involving these calculations.

Include laboratory experiments where learners determine the coefficient of friction for different materials and calculate quantities related to circular motion.

Give a project where learners will research and understand what a centrifuge is, its purpose, and its applications in various fields such as medicine, industry, and research.

WEEK 13

Learning Indicators

1. *Identify games and sports where projectiles are seen*
2. *Determine the time taken by the projectile to reach the maximum height and the magnitude of the maximum height*
3. *Determine the range of a projectile*

FOCAL AREA: PROJECTILES

A projectile is any object that is thrown or propelled into space and is influenced only by gravity. When an object moves through the air without any propulsion and solely under the influence of gravity, it follows a curved path known as a parabolic trajectory. This motion is described as projectile motion. There are also other forces like air resistance that act on a projectile, but their impact on it is minimal compared to gravity and so they are often ignored in simple models.

The study of projectiles dates to ancient times, with significant contributions from scientists like Galileo Galilei and Isaac Newton. Galileo was one of the first to mathematically describe the motion of projectiles, showing that their paths are parabolic. Isaac Newton's laws of motion further provided the foundation for understanding how projectiles behave. Galileo's experiments with inclined planes and Newton's formulation of the laws of motion laid the groundwork for the modern understanding of projectile motion.

Components of Velocity of Projectiles

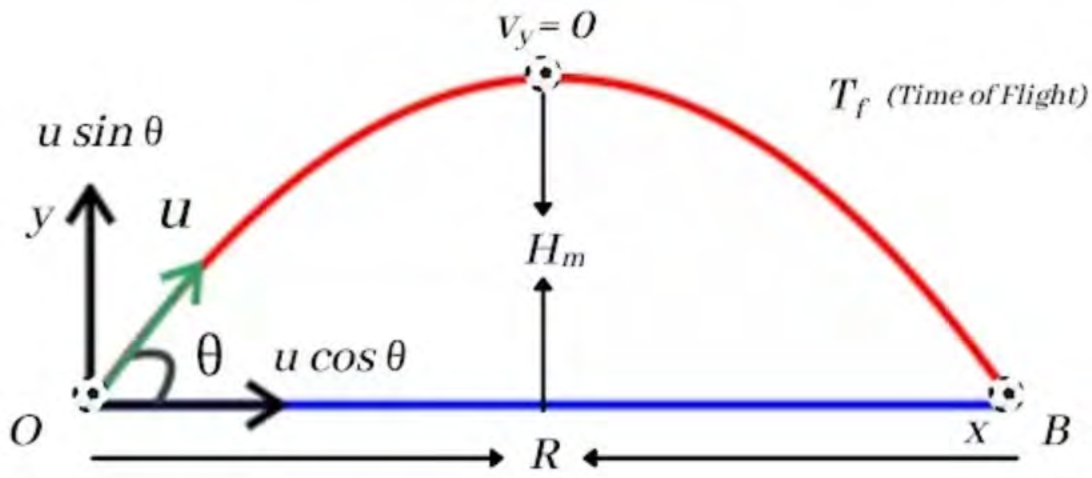


Figure 41: *The diagrammatic representation of the projectile motion of a projectile*

In a projectile motion, there are two components of velocity: velocity along the horizontal direction (or x-direction), and velocity along the vertical direction (or y-direction). They can be found with the help of the equations of motion.

Velocity in the horizontal direction

The horizontal component of the velocity remains the same at every point during the flight. This is because the acceleration of free fall due to gravity does not act in the horizontal direction.

Acceleration in the horizontal direction (a_x) = 0

Constant velocity in the horizontal direction: $u_x = u\cos\theta$

Horizontal distance: $x = (u\cos\theta)t$

Velocity in the vertical direction

Taking the upwards direction as positive:

Acceleration in the vertical direction (a_y) = −g

Initial velocity in the vertical direction: $u_y = u\sin\theta$

From equations of motion

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

Final velocity at any time t in the vertical direction:

$v_y = u\sin\theta - gt$

$v_y^2 = (u\sin\theta)^2 - 2gy$

Vertical distance:

$y = \left(u\sin\theta\right)t - \frac{1}{2}g\,t^2$

Quantities Associated with Projectiles

To understand projectile motion, we need to determine several key quantities:

1. **Time taken to reach maximum height (t):** The time it takes for a projectile to reach its highest point.

   $v = u\sin\theta - gt$

   at maximum height ($v = 0\ m\,s^{-1}$)

   $0 = u\sin\theta - gt$

   $t = \frac{u\sin\theta}{g}$

2. **Time of flight (t_f):** This is the total time the projectile remains in the air, from launch to landing. It is twice the taken to reach maximum height.

   $t_f = \frac{2u\sin\theta}{g}$

3. **Range (R):** The range is the horizontal distance a projectile travels during its flight.

   Horizontal distance

   $x = (u\cos\theta)t$

   Time of flight

   $t = \frac{2u\sin\theta}{g}$

   Then

   $R = (u\cos\theta)\,\frac{(2u\sin\theta)}{g}$

   $R = \frac{u^2 2\sin\theta\cos\theta}{g}$

   $R = \frac{u^2 \sin 2\theta}{g}$

   Range is maximum when

   $\sin 2\theta = 1$

   $\theta = 45°$

   Then the maximum range

   $R_{max} = \frac{u^2}{g}$

4. **Maximum height (H):** The highest point reached by the projectile can be determined using the initial vertical velocity and gravity:

   Vertical distance

   $y = \left(u\sin\theta\right)t - \frac{1}{2}g\,t^2$

   Time taken to reach maximum height

   $t = \frac{u\sin\theta}{g}$

   $H = (u\sin\theta)\frac{u\sin\theta}{g} - \frac{1}{2}g\left(\frac{u\sin\theta}{g}\right)^2$

   $H = \frac{u^2\sin^2\theta}{g} - \frac{u^2\sin^2\theta}{2g}$

   $H = \frac{u^2\sin^2\theta}{2g}$

NOTE:

Learners do not need to know these algebraic equations by heart but rather should be encouraged to apply the equations of motion to a variety of examples with an understanding of how to identify key values at various points in the *motion of a projectile (e.g. that the vertical velocity is zero at the maximum height).*

Application of Projectiles

Projectile motion is seen in various fields and everyday activities. In sports, understanding projectile motion is crucial in optimising the trajectory of balls in games like basketball, football, and golf. Engineers apply the principles of projectile motion when designing ballistic missiles, fireworks, and vehicles for space exploration. Military applications include calculating the trajectories of projectiles for targeting and defence systems. In daily life, throwing a ball, launching a rocket, or even the water from a garden hose can all be described as projectiles.

Examples in Daily Life

1. **Sports:** Athletes use principles of projectile motion to improve performance in throwing events, jumps, and ball sports.
2. **Transportation:** Engineers design the trajectories of vehicles, especially in aerospace, using projectile motion principles.
3. **Entertainment:** Animators and game developers apply these principles to create realistic movements in animations and video games.

LEARNING TASKS

1. Define a projectile.
2. State examples of projectiles in sports.
3. Determination of the components of velocity of projectiles.
4. Determination of the time taken to reach maximum height, time of flight, maximum height and range.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   a. Start with a brief explanation of the basic physics of projectiles, including initial velocity, angle of projection, and acceleration due to gravity. Ensure that you explain that, as displacement, velocity and acceleration are vectors, a negative sign should be used for quantities in the 'downwards' direction.
   b. Ask learners to discuss in pairs and subsequently list sports they know and identify the objects that act as projectiles. Select some pairs to feedback their list to the class and ask other learners to comment if they disagree with an item on the list. Continue the discussion by using pictures or videos to show examples

of projectiles in sports like basketball, football, and archery. With videos, pause at key moments to discuss how the objects are moving and why they are considered projectiles. Engage learners in identifying and describing the path of the projectiles.

c. Explain the resolution of velocity into horizontal and vertical components and how to calculate these components. Use diagrams to illustrate this, as well as how the horizontal component remains constant while the vertical component changes due to gravity.

d. Ask learners to recall the equations to motion and to feedback to you; write the equations on the board as they are mentioned and then use them to work through example problems on the board, showing step-by-step calculations on the time taken to reach maximum height, total time of flight, maximum height and range of a projectile.

2. **Project-Based Learning**

a. Perform a simple demonstration using a ball or small object to show projectile motion. Ask learners to describe their observations.

b. Provide projectiles, launchers (e.g., a small catapult or slingshot), rulers, protractors, and stopwatches. Have learners launch projectiles at various angles and measure key quantities like time to reach maximum height, time of flight, maximum height, and range. Learners should be encouraged to consider the measures that they will take to measure accurate values (a good idea is to film the projectile in slow-motion with a slop-clock and vertical/horizontal rulers in the shot). Learners may use their measurements to calculate the initial velocity of the projectile.

c. Use simulations to allow learners to change variables and measure outcomes. For example, set a virtual projectile to different initial velocities and angles, and measure the resulting time of flight and range. Compare the simulation results with theoretical calculations and discuss any discrepancies.

Figure 42: *PhET interactive simulations on projectile*

3. **Collaborative Learning:** Let learners, in groups, create a poster or collage of different sports showing the projectiles used in each. Display the posters in the classroom and have a gallery walk where learners explain their posters to their peers.

4. Problem-Based Learning

a. Let learners employ their knowledge in trigonometric ratios and Pythagoras's theorem to derive the components of the velocity of a projectile when it is launched at an angle to the horizontal.

b. Provide problems that involve calculating the components of the velocity of a projectile, time to reach maximum height, time of flight, maximum height, and range for different projectile scenarios. Have learners work individually, in pairs or small groups to solve the problems. Go over the solutions as a class, discussing different methods and common mistakes.

i. At least one worked example should be provided.

Problems should be differentiated to become increasingly challenging for more able learners.

KEY ASSESSMENT

Level 1

1. Define a projectile.

2. List two objects each which may be considered as projectile in sports.

Level 2: Determine the range of a golf ball hit with an initial speed of 40 ms^{-1} at an angle of 20° to the horizontal ($g = 10\ ms^{-2}$).

Level 3: Analyse how varying the initial velocity and the angle of projection affects the maximum height and range of a projectile.

Hint

*The recommended mode of assessment for week 13 is **questioning**. Use the level 1 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 30 for more information on how to use questioning.*

WEEK 14

Learning Indicators

1. *Identify some effects and applications of friction*
2. *Determine the coefficient of friction*

FOCAL AREA: FRICTION

Friction is the force that tends to prevent movement or slow the motion of two more bodies sliding over each other. For example, when you try to push a book along the floor, friction makes this difficult. Friction always acts in the opposite direction to the movement of the object i.e. it opposes the motion of an object. Friction always acts to decelerate a moving object.

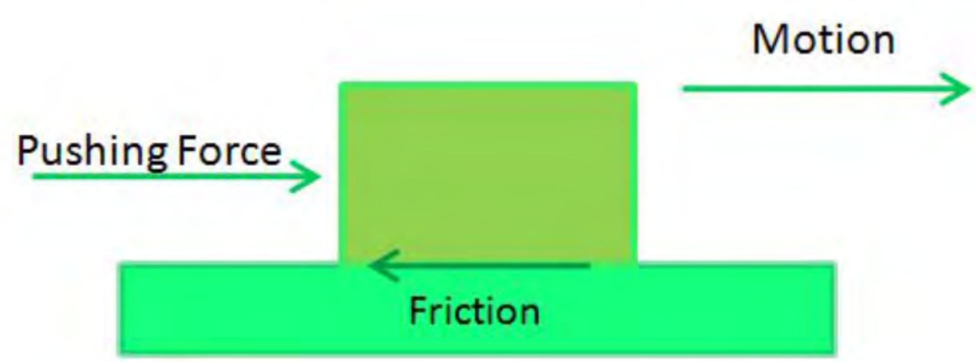


Figure 43: *Friction*

Static friction occurs when the objects are not moving relative to each other, while dynamic friction (also known as kinetic or sliding friction) occurs when the objects are sliding past each other. Static friction is usually greater than dynamic friction because it takes more force to start moving an object than to keep it moving. When you push a book across a table, the resistance you feel is due to sliding (dynamic) friction. Once the book starts moving, this frictional force remains relatively constant, opposing the motion.

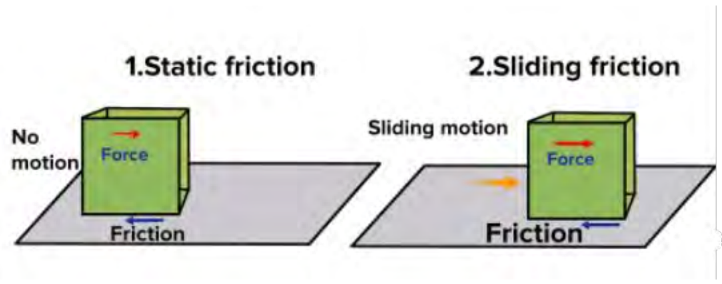


Figure 44: *Static and Sliding Friction*

When you apply a force to a body, it will not move until the applied force exceeds the static friction. As soon as the applied force equals the static friction, the body will start to move.

The frictional force F depends on the following factors:

1. The coefficient of friction (μ) which depends on the nature of the surface
2. The normal / reaction force (R)

   $F = \mu R$

The frictional force does not depend on:

1. The surface area in contact
2. The relative velocity or speed of motion.

Some Applications of Friction

1. Walking/ running on the ground.
2. Application of brakes of vehicles.
3. Sharpening of cutting tools.

Disadvantages of Friction

1. Reduces efficiency of machines
2. Causes wear and tear in machines.
3. Causes heating of machine parts.
4. Undesirable noises in working machines.

Methods of Reducing Friction

Friction can be reduced by

1. Making the surface smooth by polishing.
2. Applying lubricants (like oil or grease) to the rubbing surface.
3. Using wheels to move objects.
4. Using ball bearing between moving parts of machine.

Experiment to Measure the Force of Static and Dynamic Friction Using a Spring Scale (Newtonmeter) and Various Surfaces

Materials needed

Spring scale (Newtonmeter), various surfaces (e.g., wood, metal, plastic, sandpaper, carpet), object to pull across surface (e.g., block of wood, book or metal object), weights to place on top object (optional, for varying mass), ruler or measuring tape, notebook and pen for recording data.

Procedure

1. Put the object on the first surface to be tested.

2. Attach the spring scale (Newtonmeter) to the object securely.
3. Slowly pull the spring scale horizontally. Increase the force gradually until the object just starts to move.
4. Note the maximum force reading on the spring scale just before the object starts moving. This is the force of static friction.
5. After the object starts moving, keep pulling it with the spring scale at a constant speed.
6. Observe and record the force reading on the spring scale while the object is moving at a steady speed. This is the force of dynamic friction.
7. Repeat the above steps with different surfaces to compare the frictional forces.
8. You can also place different weights on the object to see how mass affects frictional force for a particular surface.
9. Use the recorded forces to calculate the coefficient of friction (μ) using the formula:

   $\mu = \frac{F}{R}$

   Where F is the frictional force (static or dynamic; perform two separate calculations), and R is the normal force (weight of the object).
10. Write a conclusion as to which surface provides the most friction and which provides the least, explaining the result if possible.
11. If you have also performed an experiment to vary the mass for a particular surface, write a conclusion as to the effect of mass on a) static and b) dynamic friction.

Figure 45: *Video on using spring scale to measure frictional forces*

LEARNING TASKS

1. Define friction.
2. Distinguish between static and dynamic friction.
3. State the factors that affect friction.
4. State applications, disadvantages and methods of reducing friction.
5. Determine the coefficients of static and dynamic friction.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
    - **a.** Start with a discussion about friction, asking learners to share examples from their daily lives.
    - **b.** Explain the fundamental concepts of friction, including the differences between static and dynamic (kinetic) friction. Introduce the equation governing friction $F = \mu R$ and discuss the meaning of the coefficient of friction (μ).
    - **c.** Show videos that illustrate different types of friction in action (e.g., a car skidding, a person sliding down a slide).
    - **d.** Explain the advantages of friction, such as enabling walking, gripping objects, and braking in vehicles. Have learners identify and discuss scenarios in everyday life where friction is advantageous and then facilitate a class discussion to share these ideas.
    - **e.** Explain the disadvantages of friction, including wear and tear on materials, energy loss, and reduced efficiency. Have learners think of examples where friction causes issues and discuss possible solutions. Facilitate a class discussion to share these ideas.
    - **f.** Introduce methods to reduce friction, such as lubrication, using smooth surfaces, and using ball bearings. If possible, organize visits to industries where friction reduction is critical, such as mechanic shop. Invite engineers or scientists to talk about how they manage friction in their fields.
2. **Project-Based Learning**
    - **a.** Perform a simple demonstration using objects (like a block on a surface) to show static friction (when the object does not move) and dynamic friction (when the object is in motion).
    - **b.** Conduct experiments where learners can measure the force of static and dynamic friction using a spring scale and various surfaces. Have learners compare the frictional forces on different materials (e.g., rubber, wood, metal) and analyse their results.
    - **c.** Use interactive simulations (e.g., PhET Forces and Motion) to explore friction. Learners can adjust variables like surface type and weight to see the effects on friction. Allow learners to simulate the movement of objects and measure static and dynamic friction forces.
    - **d.** Show demonstrations of friction reduction techniques, like applying oil to a surface or using ball bearings.

3. **Problem-Based Learning**
   a. Provide a variety of problems that require calculating frictional forces, coefficients of friction, and analysing different scenarios.
      i. At least one worked example should be provided.
      ii. Problems should be differentiated to become increasingly challenging for more able learners.

KEY ASSESSMENT

Level 1: Describe the difference between static friction and dynamic friction.

Level 2: A box is pushed across a floor with a constant force. How would you determine the coefficient of dynamic friction between the box and the floor? Ensure that you mention the equipment that you would need and how it would be used.

Level 3: Given a block at rest on a surface with a coefficient of static friction of 0.4, calculate the force required to start moving the block if its weight is 50 N. How does this force compare to the force required to keep the block moving if the coefficient of dynamic friction is 0.3?

Level 4

1. Investigate the role of friction in sports. Present your findings in a detailed report, including potential future advancements and career opportunities in sports engineering.
2. Speak for or against the motion "Friction is bad".

Hint

*The recommended mode of assessment for week 14 is **Individual Projects** on stationary waves and present their research findings in Week 20. Refer to **Appendix E** at the end of this section for more information on the project.*

WEEK 15

Learning Indicators

1. *Explain circular motion and give some examples of circular motion*
2. *Explain and calculate centripetal force*

FOCAL AREA: CIRCULAR MOTION

Circular motion refers to the movement of an object along a circular path, where its distance from a fixed point remains constant. In this type of motion, the object continuously changes direction while maintaining a constant speed, resulting in a uniform circular motion if the speed remains unchanged or non-uniform circular motion if the speed varies. Some examples of circular motion are satellite that revolves around the earth, a string tied to a stone at one end and whirled around, an automobile rounding a curve etc.

An object will display uniform circular motion if the resultant force acting on it is perpendicular to its instantaneous velocity at all points of its path.

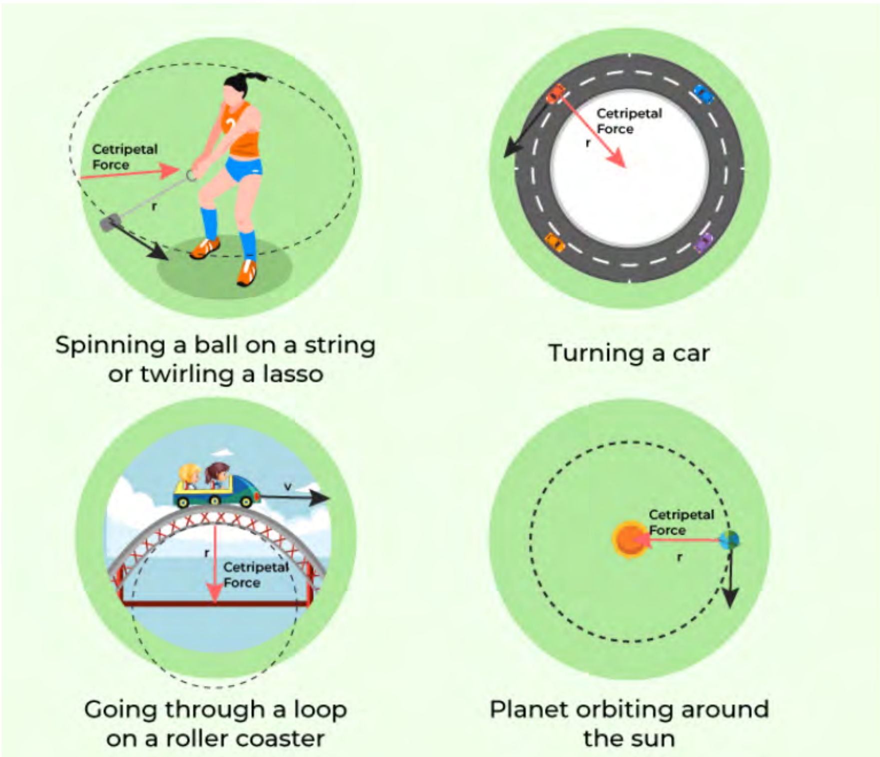


Figure 46: *Images of some examples of circular motion*

Angular Displacement

Angular displacement (θ) can be defined as the angle that object has gone through in a circular path during a particular period. Angular displacement is a vector quantity. The SI unit of the angular displacement is radians.

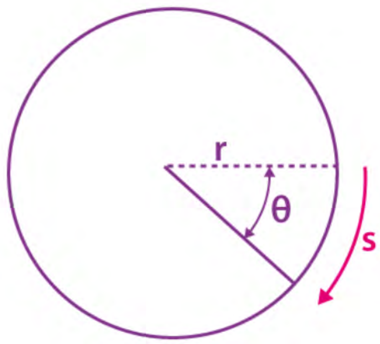


Figure 47: *Schematic diagram of circular motion*

$\theta = \frac{s}{r}$

$s = \theta r$

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 (sometimes called angular frequency) is the rate at which the angular displacement of a body in a circular path changes with time. It is a vector quantity and is denoted by ω. Its SI unit is $rads^{-1}$.

$\omega = \frac{\theta}{t}$

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 and linear velocity is

$v = \omega r$

Angular Acceleration

Angular acceleration is the rate of change of angular velocity of a body undergoing circular motion with time. It is a vector quantity and is denoted by α. Its SI unit is $rads^{-2}$.

$\alpha = \frac{\omega}{t}$

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

Centripetal force is the force that keeps an object moving in a circular path, directed towards the centre of the circle around which the object is moving. This force is essential because, without it, an object would move in a straight line due to its inertia, according to Newton's first law of motion.

Example: In the case of a car turning around a curve, the friction between the tires and the road provides the centripetal force required to keep the car moving in a curved path.

Centripetal force is given by

$F_c = \frac{mv^2}{r}$

where m is the mass of the object, v is the linear velocity of the object, r is the radius of the circular path.

Imagine tying a ball to a string and whirling it around in a circle. The string pulls the ball towards the centre, providing the centripetal force necessary to keep it moving in a circular path. If the string breaks, the ball will fly off tangentially to the circle because the centripetal force is no longer acting on it.

Understanding centripetal force is crucial in various fields, such as engineering, astronomy, and amusement park design, where the principles of circular motion are applied.

LEARNING TASKS

1. Describe circular motion.
2. State examples of circular motion.
3. Define key parameters such as period, frequency, angular displacement, angular velocity, angular acceleration and centripetal force.

4. Explain the concept of centripetal force and how it acts on objects in circular motion.
5. Calculate centripetal force, centripetal acceleration, angular velocity, and period.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**
   a. Ask learners to discuss everyday examples of objects that move in circles. Ask some learners to share their examples with the class.
   b. Explain key concepts and definitions: angular displacement, angular velocity, angular acceleration, and centripetal force. Use visual aids, such as a large diagram of an object moving in a circular path, to help learners to understand the terms listed.
   c. Show videos or animations of different types of circular motion like spinning amusement park rides or satellite orbits.
   d. Derive the equations for angular displacement, angular velocity, angular acceleration, and centripetal force. Go through some worked examples with the class using the relationships derived.
2. **Project-Based Learning**
   a. Use a rotating platform or a turntable to demonstrate circular motion. Measure and calculate angular displacement, angular velocity, frequency, and period using a stopwatch and ruler.
   b. Swing a small object tied to a string in a circular path to illustrate centripetal force. Measure the radius and the time for several revolutions to calculate period, frequency, angular velocity, and centripetal force.
   c. Utilise online simulations (e.g., PhET Interactive Simulations) where learners can manipulate variables like radius, mass, and speed to see how they affect centripetal force and velocity. Allow learners to observe and analyse the effects of changing different parameters on circular motion
3. **Problem-Based Learning:** Provide a variety of problems for learners to solve, focusing on calculating angular velocity, angular acceleration, frequency, period and centripetal force. Include both theoretical problems and practical, real-world scenarios. Problems should be differentiated.

KEY ASSESSMENT

Level 1: Define angular velocity.

Level 2: A car is moving in a circular track with a radius of 50 meters and completes one lap in 20 seconds. Calculate the car's angular velocity.

Level 3

1. Evaluate the impact of doubling the period of rotation on the angular velocity and linear velocity of an object in circular motion.
2. Evaluate the impact of incorrect banking angles on road safety and propose measures to mitigate risks in your community

Hint

*The recommended mode of assessment for week 15 is **simulation**. Use the level 3 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 54 for more information on how to use simulation.*

WEEK 16

Learning Indicators

1. *Explain banking and skidding*
2. *Calculate maximum and minimum tension in a string*

FOCAL AREA 1: BANKING AND SKIDDING

The likelihood of skidding can often be reduced by banking the road. Banking of roads is the process in which the outer edges are raised through certain angle to provide the vehicles with the necessary centripetal force so that they take a safe turn; it increases the centripetal force at a given radius compared to an unbanked road.

Figure 48: *Banked road curve*

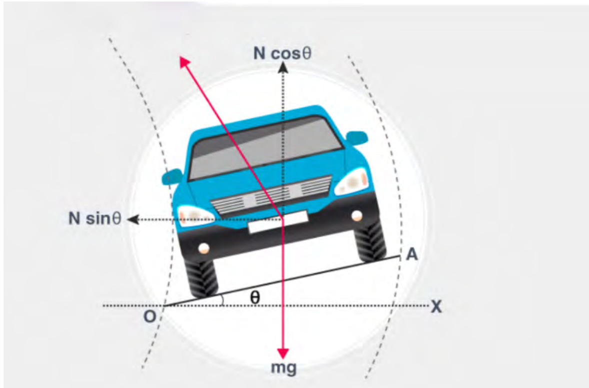


Figure 49: *Image of car negotiating a turn*

Consider Figure 49, showing the forces acting on a car on a banked curve. N is the normal reaction force, shown by the red arrow pointing diagonally upwards and to the left (perpendicular to the road surface).

Resolving horizontally

$F = N\,sin\theta$ but, as this is an example of circular motion, $F = \frac{mv^2}{r}$

(because the force $Nsin\theta$ points to the centre of the bend it provides the centripetal force)

$Nsin\theta = \frac{mv^2}{r}$ ....(1)

Resolving vertically

$Ncos\theta = mg$....................................(2)

Dividing (1) by (2)

$$\frac{Nsin\theta}{Ncos\theta} = \frac{\frac{mv^2}{r}}{\frac{mv^2}{r}}$$

$$\frac{sin\theta}{cos\theta} = \frac{v^2}{rg}$$

$$\tan\theta = \frac{v^2}{rg}$$

This relationship can be rearranged to give v, the maximum velocity at which a vehicle can navigate a bend, before skidding.

Centrifuge

A centrifuge is a device that uses centrifugal force (the apparent outward force on a mass when it is rotated) to separate components of a mixture based on their density. When the mixture is spun at high speeds, the denser components move outward to the bottom or outer edge of the container, while the less dense components remain closer to the centre.

Figure 50: *Tubular Centrifuge*

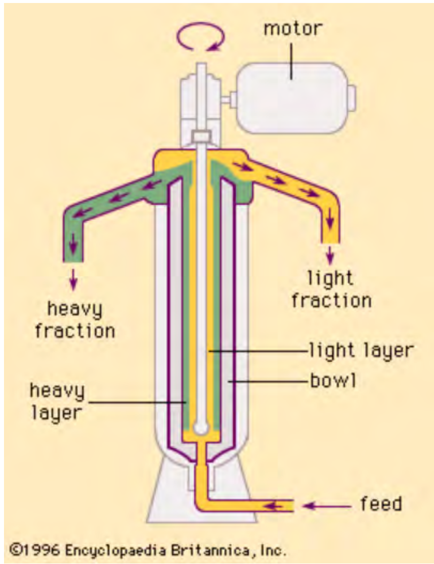


Figure 51: *Schematic diagram of centrifuge*

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.

e. *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.

LEARNING TASKS

1. Explain why roads are banked and how banking helps vehicles negotiate curves safely.
2. Derive and use the formula for the optimal banking angle for a given speed and radius of the curve and solve problems involving the calculation of banking angles.
3. Explain what a centrifuge is and its purpose in various applications.

PEDAGOGICAL EXEMPLARS

1. **Enquiry-Based Learning**

   a. Explain the concept of banking of roads and its purpose in helping vehicles negotiate bends safely. Let learners recall and discuss the forces acting on a car as it sits on a banked track and then remind them that the resultant of all of these forces must act towards the centre of the circle if the car is exhibiting uniform circular motion.

   b. Guide learners to deduce the formular $\tan\theta = \frac{v^2}{rg}$ where v is the maximum allowed speed, r is the radius of the circle, g is the acceleration due to gravity and θ is the banking angle.

   c. Show videos or conduct demonstrations of real-world applications, such as cars negotiating banked curves, laboratory centrifuges in action, and conical pendulums in swing rides, and discuss how these concepts are applied in real life.

   d. Explain the concept of a centrifuge and its uses in separating substances based on density.

2. **Project-Based Learning**
   - **a.** Use a model car and an inclined plane to demonstrate how a banked road helps a car negotiate a bend, measure the angle of the incline with a protractor, mark the path with chalk or tape, and explain how the incline reduces reliance on friction and provides the necessary centripetal force.
   - **b.** Construct a simple centrifuge using a salad spinner or paper to spin test tubes with different liquids. Observe separation due to centrifugal force.

Figure 52: *Video on using paper as centrifuge*

3. **Problem-Based Learning:** Provide learners with worksheets containing differentiated problems related to calculating banking angles for different scenarios (e.g., vehicle speed, curve radius). Have learners work independently or in small groups to solve the problems.
4. **Collaborative Learning:** Form mixed-ability groups, assign each group an area, such as the physics of banked roads or the use of centrifuges in medicine. Have learners research their topics and prepare presentations.

KEY ASSESSMENT

Level 1

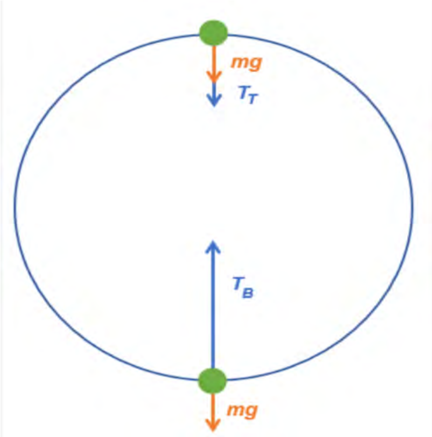
1. Why is banking necessary for curved roads?
2. Describe the motion of a conical pendulum

Level 2: Calculate the banking angle required for a vehicle traveling at 30 ms^{-1} around a curve with a radius of 80 m. [$g = 10\ ms^{-2}$]

Level 3: Evaluate the impact of incorrect banking angles on road safety and propose measures to mitigate risks.

FOCAL AREA 2: MAXIMUM AND MINIMUM TENSION IN A STRING

Consider an object of mass m attached to a string of length r and moving in a vertical circle. The forces acting on the object are gravity (mg) and the tension in the string (T).



At the top of the circle, the tension T_{top} and gravitational force mg both act downward. 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.

$$\therefore T_{max} = \frac{mv^2}{r} + mg$$

Conical Pendulum

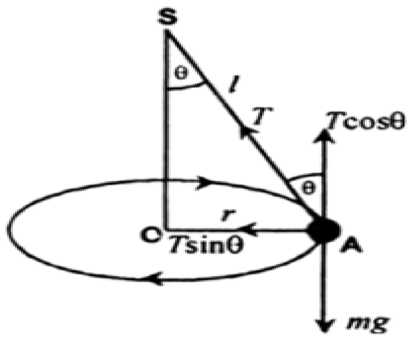
A conical pendulum is a type of pendulum where the bob (the weight at the end) moves in a horizontal circular path, tracing out a cone shape with the string.

The conical pendulum has had a long history, and it was first studied by Robert Hooke. He was a famous English scientist who studied the conical pendulum around 1660 as a model for the orbital motion of the planets. Later, inspired by Hooke's work on conical pendulums, Christian Huygens calculated its time period in 1673. He calculated the time period of the conical pendulum using the concept of centrifugal force which he introduced then.

Conical Pendulum Important Concepts and Tips for JEE (vedantu.com)

Time Period of a Conical Pendulum

Let consider a conical pendulum consisting of point heavy mass m attached with massless, flexible and inextensible string of length l. Let the pendulum be suspended from a rigid support S and the mass be whirled with constant speed v in a horizontal circle of radius r so that the string makes an angle θ with the vertical.



The different forces acting on the mass are:

1. Weight (mg) in vertically downward direction.
2. Tension, T, in the string along the line AS.

Resolve the components of T as shown in the figure above.

The component $T\cos\theta$ balances the weight mg of the mass and component $T\sin\theta$ provides the necessary centripetal force to whirl the mass. Thus

$T\cos\theta = mg$ ....(1)

$T\sin\theta = \frac{mv^2}{r}$ ....(2)

Dividing (2) by (1),

$$\frac{\frac{mv^2}{r}}{mg} = \frac{T\sin\theta}{T\cos\theta}$$

$$\frac{v^2}{rg} = \tan\theta$$

$v = \sqrt{rg\tan\theta}$ ....(3)

From figure, $r = l\sin\theta$

Substituting for r in equation (3),

$$v = \sqrt{l\sin\theta\, g\tan\theta} = \sin\theta\sqrt{\frac{gl}{\cos\theta}}$$

Time taken to complete one revolution of conical pendulum is

$$T = \frac{2\pi r}{v} = \frac{2\pi l \sin\theta}{v}$$

$$T = 2\pi\sqrt{\frac{l\cos\theta}{g}}$$

The principles of the conical pendulum have several real-life applications in various fields, particularly in engineering and mechanics. For example, many amusement park rides, such as swing rides or chair-o-planes, operate on the principles of a conical pendulum. The seats of these rides are attached to rotating arms, and as the ride spins, the seats swing outward and move in a circular path, creating a conical shape. The physics of the conical pendulum helps in designing these rides to ensure they operate safely and provide the desired motion for riders.

Figure 53: *Large Capacity Amusement Park Swing Rides*

LEARNING TASKS

1. Identify and analyse the forces acting on an object on a string moving in a circle in the vertical plane.
2. Derive and use formulas to calculate maximum and minimum tension in the string at different points in the motion
3. Identify real-world examples where tension in a string is a critical factor.
4. Describe the motion of a conical pendulum.

PEDAGOGICAL EXEMPLARS

1. **Talk for Learning**
   - **a.** Explain how tension in a string varies throughout the journey of an object moving in a circular path in a plane with a vertical component. Discuss scenarios where tension is at its maximum and minimum.
   - **b.** Guide learners to derive the mathematical relationship between tension, mass, gravity, velocity and radius for the top and bottom of the circular path.
   - **c.** Show videos or articles that demonstrate the importance of tension calculations in designing suspension bridges, elevator systems, or amusement park rides.
   - **d.** Explain the concept of a conical pendulum, where the bob moves in a horizontal circle due to the tension in the string.
2. **Problem-Based Learning:** Provide learners with differentiated worksheets containing problems on calculating maximum and minimum tension in various scenarios (e.g., pendulums, vertical circular motion).
3. **Project-Based Learning**
   - **a.** Hang a mass from a string and measure the tension using a spring balance. Demonstrate tension in a string during circular motion by swinging a mass in a vertical circle and identifying points of maximum and minimum tension (note that this is a fairly inaccurate demonstration due to the changing velocity of the mass moving in the circle).
   - **b.** Use an online or software-based physics simulation to model scenarios involving tension in a string. Have learners vary parameters such as mass, string length, and speed. Observe how changing these variables affects the tension in the string.
   - **c.** Use an online simulation to model a conical pendulum, allowing learners to adjust variables such as string length, pendulum bob mass, and rotation speed, observe their effects on motion and stability, and discuss the forces involved, focusing on how string tension provides centripetal force.

KEY ASSESSMENT

Level 1: Explain what is meant by maximum tension in a string.

Level 2: If a 5 kg mass is being whirled around in a circle at a linear velocity of $2ms^{-1}$ and at a radius of 0.4m, calculate the maximum and minimum tension in the string.

Level 3: Evaluate the importance of considering both maximum and minimum tension in designing a swing.

Hint

*The recommended mode of assessment for week 16 is **demonstration**. Use the level 2 question as a sample question and the Teacher Assessment Manual and Toolkit page 49 for more information on how to use demonstration.*

Section 5 Review

Week 13 began with projectiles, objects thrown into the air that follow a curved path under the influence of gravity. The motion of projectiles was explored, and their presence in various games and sports, such as basketball, soccer, and archery, was identified. Key quantities associated with projectiles were determined, including the time to reach maximum height, maximum height itself, time of flight, and range. By mastering these concepts, learners should learn to analyse and predict the motion of projectiles in different contexts, enhancing problem-solving skills in physics.

In week 14, the focus shifted to friction, a force that opposes motion between two surfaces in contact. A distinction was made between static friction, which prevents motion, and dynamic (kinetic) friction, which resists ongoing motion. The laws of friction were discussed, highlighting both its advantages, such as providing traction for walking, and disadvantages, like wear and tear on machinery. Methods of reducing friction, including lubrication and the use of smoother surfaces, were examined. Additionally, learners should learn to determine the coefficient of friction, a crucial parameter in calculating frictional forces in various scenarios.

Week 15 introduced circular motion, where objects move along a circular path. Examples of circular motion, such as a car turning on a curved road or a satellite orbiting Earth, were presented. Key parameters were defined, including the period (time for one complete cycle), frequency (number of cycles per unit time), angular displacement (angle covered), angular velocity (rate of change of angular displacement), angular acceleration (rate of change of angular velocity), and centripetal force (resultant force directed towards the centre of the circular path). The concept of centripetal force and its crucial role in maintaining circular motion was delved into. Learners also learned to calculate centripetal force, centripetal acceleration, angular velocity, and the period, solidifying their understanding of circular motion dynamics.

In week 16, practical applications of previous lessons were explored. The banking of roads was examined, understanding why roads are banked to provide the necessary centripetal force for vehicles to navigate curves safely. The formula for the optimal banking angle for a given speed and curve radius was derived.

The concept of a centrifuge was introduced, explaining its purpose in separating substances based on density differences through rapid rotation.

Finally, the maximum and minimum tension in a string was discussed, providing a deeper understanding of the forces at play in various physical systems. Additionally, the motion of a conical pendulum, a weight attached to a string that moves in a circular path, was described and the forces acting on it were analysed.

APPENDIX E: INDIVIDUAL PROJECT

Task: *Learners should be assigned individual projects on stationary waves and present their research findings in week 20.*

Structure

The individual project on the topic should have the topic boldly typed, the name of student, topic and the date of submission on the cover page. The write up should have the table of contents which must contain an introduction, the sub topics within the main topics with diagrams and charts where necessary and references.

Mode of administration

Assign the task ahead of time and give learners the opportunity and time to find information from multiple sources.

Rubrics/marking scheme

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Research and Understanding	Demonstrates a comprehensive understanding of stationary waves, explaining concepts (e.g., nodes, antinodes, harmonics) clearly and accurately.	Shows a good understanding of stationary waves; explanations are mostly accurate, with minor gaps in detail.	Demonstrates a basic understanding; explanations lack depth or have notable inaccuracies.	Limited understanding; explanations are unclear, missing key concepts, or largely inaccurate.
Evidence of Multiple Sources of Information	Effectively uses 3 or more credible sources, synthesising information clearly and integrating diverse perspectives (e.g., textbooks, online resources, articles).	Uses 2–3 credible sources; some evidence of synthesis, though sources are not fully integrated.	Relies on 1–2 sources, with limited synthesis or over-reliance on a single source.	Uses a single source or unreliable sources; lacks depth or diversity in research.

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Real-World Application of Stationary Waves	Identifies and explains multiple real-world applications (e.g., musical instruments, telecommunications, acoustics) with strong connections to theory.	Identifies and explains at least one real-world application, making clear but less detailed connections to theory.	Identifies a real-world application but lacks clarity or depth in connecting it to the theory.	No real-world application provided, or explanation is vague and disconnected from the theory.
Presentation	Presentation is clear, well-organised, and engaging; includes effective visuals (e.g., diagrams, charts) that enhance understanding.	Presentation is clear and organised; visuals are relevant but may not fully enhance understanding.	Presentation is somewhat organised but lacks clarity, visual appeal, or coherence.	Presentation is disorganised, incomplete, or poorly communicated; visuals are absent or ineffective.

Feedback

Use the items in the rubrics to provide targeted feedback highlighting areas where learners will need improvement.

SECTION 6: ELECTROMAGNETISM

Strand: Electric Fields, Magnetic Fields and Electronics

Sub-Strand: Electromagnetism

Learning Outcomes

1. *Explain the how current is affected by a magnetic field using rules and calculations.*
2. *Demonstrate the repulsive and attractive forces between parallel current-carrying conductors in a magnetic field.*
3. *Demonstrate knowledge of the relationship between the magnetic field and the electric field.*

Content Standards

1. Demonstrate knowledge and understanding in analysing the factors that affect the magnetic force on conductors carrying current in a uniform magnetic field.
2. Demonstrate knowledge and understanding of the forces set up between parallel conductors carrying current in a uniform magnetic field and its applications.
3. Demonstrate knowledge and understanding of the force exerted on a charged particle moving in electric and magnetic fields and its applications.

Hint

*The recommended mode of assessment for Week 18 is **mid-term examination**. Refer to **Appendix F** at the end of this section for Table of specification.*

INTRODUCTION AND SECTION SUMMARY

This section covers fundamental principles of electromagnetism, focusing on the force acting on charged particles and on the magnetic fields around current-carrying conductors. Learners will learn to calculate the force on a charged particle in a magnetic field, understand the force on a moving charged particle in an electric field, and describe the Lorentz force in crossed fields. Additionally, they will explore forces between parallel conductors, torque on rectangular coils, and the working principles of electric motors, moving coil galvanometers, and electromagnetic switches. Practical applications, such as mass spectrometers and cyclotrons, are highlighted to link theoretical concepts to real-world uses. By the end of this section, learners should be able to explain, calculate, and apply these principles and demonstrate practical skills in conducting relevant experiments. This section is interconnected with physics, engineering, and other sciences.

The weeks covered by the section are:

Week 17: Magnetic field around a current carrying conductor

This week covers the relationship between current, magnetic field strength, angle and force on a current-carrying conductor, as well as its applications in electric motors and other devices. Use the Fleming's Left Hand Rule mnemonic to predict the direction of force on a current-carrying conductor in a magnetic field.

Week 18: Magnetic field around a current carrying conductor

Learners will explore the forces acting between parallel conductors carrying current, the torque on a rectangular current-carrying coil in a magnetic field, and the structure and working principles of electric motors and moving coil galvanometers. They will also learn about the construction and applications of electromagnetic switches. The principles will be applied to understanding and designing devices such as electric motors, household appliances, and scientific instruments.

Week 19: Force on a charged particle

Learners will understand the factors affecting the force on a charged particle in a magnetic field, including the direction of the field, the direction of the particle, and the charge of the particle. They will learn to calculate the force using the formula $F=Bvq\sin(\phi)$. The force on a moving charged particle in an electric field will also be explored, along with the combined effects of electric and magnetic fields, known as the Lorentz force. Learners will study the use of these principles in devices such as mass spectrometers and cyclotrons.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Effective teaching strategies for these concepts include discussion-based learning, hands-on experiments, and collaborative projects. Teachers should engage learners with discussions using diagrams and real-life examples to explain electromagnetism principles. Hands-on experiments, such as building simple electric motors or demonstrating the Lorentz force, help learners visualize these concepts. Collaborative projects and computer simulations allow learners to explore charged particles' behaviour in electric and magnetic fields. Differentiation is crucial, offering scaffolding for complex ideas and tailored assignments for varied learning needs. Assessments should include formative quizzes and in-class activities, along with summative written and practical exams. Gifted learners can tackle advanced experiments and research projects, applying their knowledge innovatively.

ASSESSMENT SUMMARY

Assessments should include both formative and summative methods to gauge learners' understanding and skills. Formative assessments, such as quizzes, in-class activities, and Q&A sessions, monitor ongoing progress. Summative assessments, like problem sets, research assignments, written exams, and practical exams, evaluate overall comprehension and application. Teachers should conduct regular quizzes and provide immediate feedback during classwork. Homework assignments should reinforce lessons and offer varied problems. Written exams should mix multiple-choice, short answers, and calculation problems, while practical exams assess hands-on skills. Accurate recording and reporting of assessment results are essential for tracking progress. Comprehensive feedback and clear progress reports will help learners and parents understand performance and areas for improvement.

WEEK 17

Learning Indicators

1. *Describe the force exerted on a current-carrying conductor in a magnetic field*
2. *Discuss the factors that affect the magnitude of the magnetic force on a current-carrying conductor in a magnetic field*
3. *Discuss Fleming's left-hand rule*

FOCAL AREA 1: FORCE ON A CHARGED PARTICLE

The study of electromagnetism dates to the early 19th century when Hans Christian Ørsted discovered that electric currents create magnetic fields. This discovery was crucial in the development of the field of electromagnetism. André-Marie Ampère further contributed by quantifying the magnetic forces between electric currents, leading to the formulation of Ampère's Law. In 1831, Michael Faraday discovered electromagnetic induction, providing the foundation for understanding how electric and magnetic fields interact. These discoveries paved the way for modern applications of electromagnetism, including the operation of electric motors, generators, and various electronic devices.

When an electric current flows through a conductor, it generates a magnetic field around it. This phenomenon is well described by Maxwell's equations, specifically the fourth equation, which is the Ampère – Maxwell Law (Modified Ampère's Law). *Note that these formulae could be presented to the most able learners for extension work or further reading, but not all learners should be expected to meet them.*

Table 2: *Maxwell's Equations in both integral and differential form with their relevance*

Name	Integral form	Differential form	Explanation
Gauss' law of electricity	$\oint \vec{E} \bullet d\vec{a} = \frac{Q_{enc}}{\varepsilon_0}$	$\nabla \times \vec{E} = \frac{\rho}{\varepsilon_0}$	This equation tells us that electric charges create electric fields. The more charge you have, the stronger the electric field.

Name	Integral form	Differential form	Explanation
Gauss' law of magnetism	$\oint \vec{B} \bullet d\vec{a} = 0$	$\nabla \times \vec{B} = 0$	This equation states that there are no magnetic "monopoles." Unlike electric charges, which can be positive or negative, magnetic poles always come in pairs—north and south. You can't have a north pole without a south pole and vice versa.
Faraday's law of induction	$\oint \vec{E} \bullet d\vec{l} = -\int \frac{\partial \vec{B}}{\partial t} \bullet \partial \vec{a}$	$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	This law explains how a changing magnetic field can create an electric field. This is what happens in generators, where moving magnets near coils of wire produce electricity.
Modified Ampère's Law	$\oint \vec{B} \bullet d\vec{l} = \mu_0 I_{enc} + \mu_0 \varepsilon_0 \int \frac{\partial \vec{E}}{\partial t}$	$\nabla \times \vec{B} = \mu_0 \left(\vec{J} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$	This equation shows how a moving electric field or an electric current can create a magnetic field. This law revealed that light is a form of electromagnetic wave, linking electricity, magnetism, and optics together.

The shape and direction of a magnetic field (which point from north pole to south pole) produced by an electric field depend on the configuration of the conductor:

1. **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.

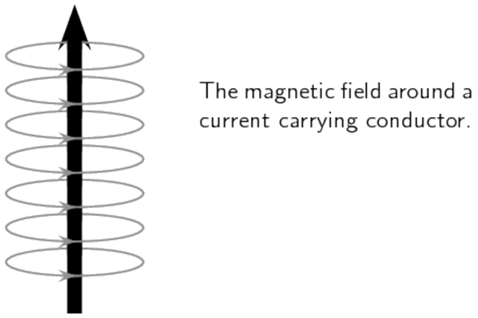


Figure 54: *Magnetic field around a current carrying conductor*

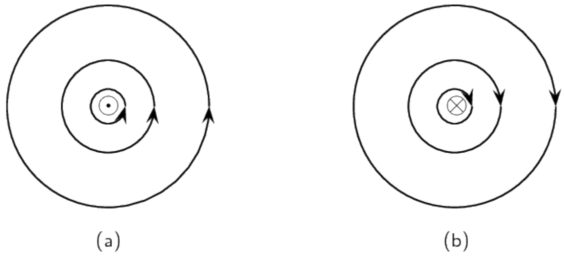


Figure 55: *Magnetic field around a conductor when you look at the conductor from one end. (a) Current flows out of the page and the magnetic field is counter-clockwise. (b) Current flows into the page and the magnetic field is clockwise.*

2. **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.

3. **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.

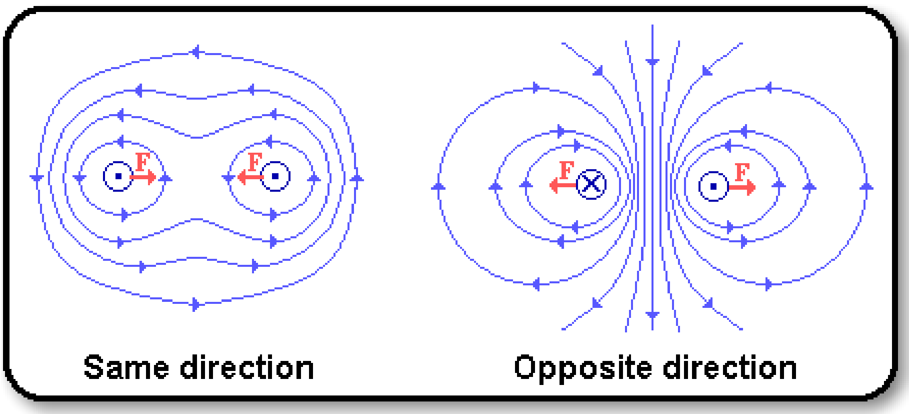


Figure 56: *Magnetic field around parallel conductors with the same and opposite direction*

4. **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.

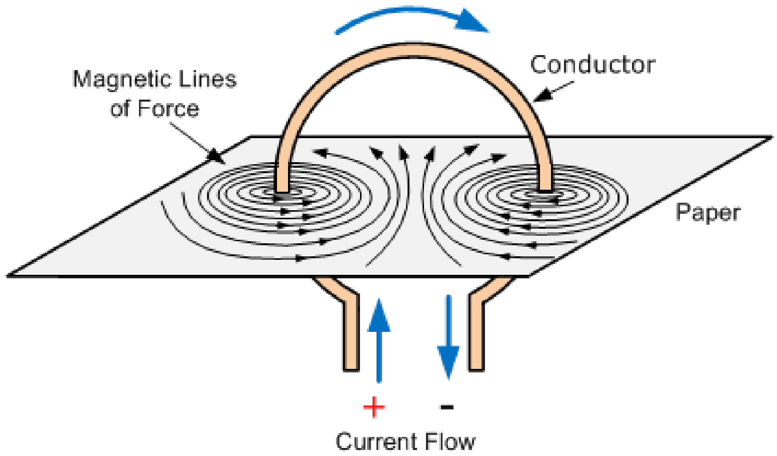


Figure 57: *Magnetic field due to a current through a circular loop*

5. **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. For example, solenoids are used in various devices, such as electromagnetic locks, solenoid valves, and MRI machines, where a strong, controlled magnetic field is needed.

A current-carrying conductor placed in a magnetic field experiences a force perpendicular to the current's direction and the magnetic field. This force can be calculated using the formula

$F = BILsin(\theta)$

where B is the magnetic field strength, I is the current, L is the length of the conductor inside the field, and θ is the angle between the current and the magnetic field.

The current can be increased by increasing the e.m.f. of the power supply, using a thicker wire of the same length, or using a shorter wire. The strength of the magnetic field can be increased by using more powerful magnets, using two pairs of magnets with like poles side by side, or placing the magnets closer together. Additionally, the longer the wire in the magnetic field, the larger the force on the wire.

For example, the force on a straight conductor carrying a current of 5A is calculated in a magnetic field of strength of 0.2T. The length of the conductor is 0.1m long and makes an angle of 90 degrees with the magnetic field.

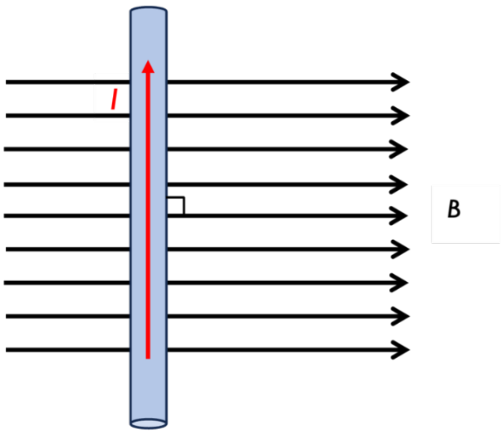


Figure 58: *Current-carrying conductor through a magnetic field at 90o*

$F = BILsin(\theta)$

$F = 0.2 \times 5 \times 0.1 \times sin(90)$

$sin(90) = 1$

$F = 0.2 \times 5 \times 0.1$

$F = 0.1N$

The force on the conductor is 0.1N.

We can also discover the direction of this force using Fleming's Left Hand Rule. According to the rule, if you hold your left hand with the thumb, first finger, and second finger mutually perpendicular, the thumb represents the direction of the force (motion), the first finger represents the magnetic field, and the second finger represents the current.

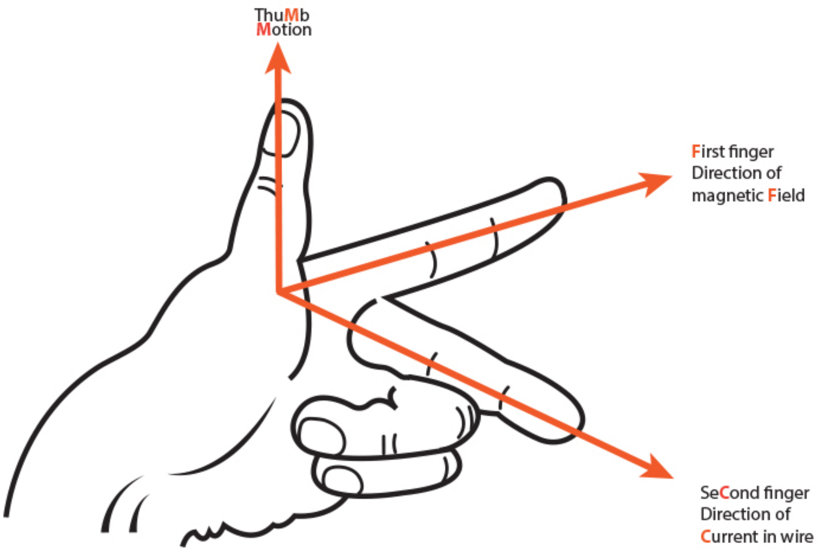


Figure 59: *Fleming's Left Hand Rule mnemonic*

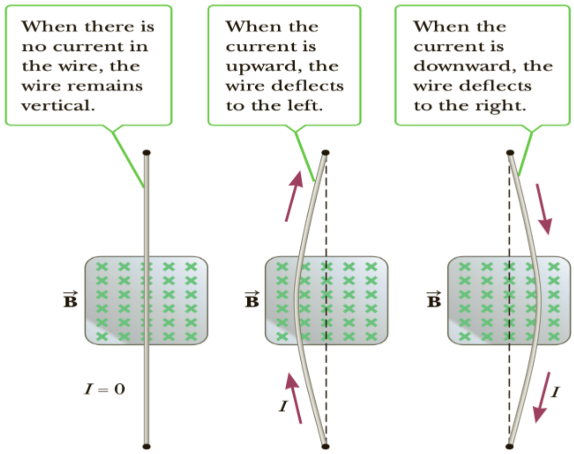


Figure 60: *A segment of a flexible vertical wire partially stretched between the poles of a magnet, with the field (green crosses) directed into the page*

Everyday applications of these principles are numerous. Electric motors, which convert electrical energy into mechanical energy, rely on the force of a current-carrying conductor in a magnetic field. Motors are essential components in household appliances, industrial machines, and electric vehicles. Generators, which work on the principle of electromagnetic induction, are used to produce electricity in power plants and portable generators. Magnetic levitation (maglev) trains use magnetic forces to lift and propel the train, reducing friction and allowing for high-speed transportation. In the medical field, Magnetic Resonance Imaging (MRI) utilises magnetic fields to produce detailed images of the inside of the human body.

Figure 61: *Video of how a maglev train works*

LEARNING TASKS

1. Observe and describe a laboratory experiment of the magnetic field around a straight current-carrying conductor.
2. Conduct an experiment to compare magnetic fields around parallel conductors with currents in the same and opposite directions.
3. Utilise a computer simulation to visualise and analyse the magnetic field patterns around a narrow circular coil.
4. Calculate the magnetic force on a current-carrying conductor in various configurations using $F = BILsin(\theta)$.

PEDAGOGICAL EXEMPLARS

1. Talk for Learning

a. Introduce the concept of magnetic fields around a straight conductor using everyday objects like wires and batteries to create a simple circuit. Demonstrate the magnetic field created by the current using a compass.

b. Explain Fleming's Left-Hand Rule by holding your left hand with the thumb, first finger, and second finger mutually perpendicular. Explain that the thumb represents the direction of the force (motion) – M in the thumb for motion, the first finger represents the magnetic field – F in the finger for the field, and the second finger represents the current – C in the second for the current.

i. Ensure that learners are told that a magnetic field points from north to south and that the current in a conductor points from the positive to the negative terminal of a battery. Show them how directions 'into the page' or 'out of the page' are represented with crosses and dots respectively.

ii. Let learners work in pairs to solve simple problems from diagram of magnetic fields and current carrying wires drawn/projected onto the whiteboard; give them a short time to figure out the missing information (direction of motion, direction of magnetic field or direction of current) and then ask the class to simultaneously point in the correct direction.

c. Introduce the formula $F = BILsin(\theta)$ for calculating the force on a current-carrying conductor.

i. Discuss the factors affecting the magnitude of the magnetic force on a current-carrying conductor (current, magnetic field strength, length of conductor, and angle between the conductor and the magnetic field). Ask learners to think-pair-share how the current or magnetic field strength could be varied in practice.

2. Experiential Learning

a. Demonstrate the experimental setup of two parallel wires which can carry currents in the same or in opposite directions, using available materials like copper wires and batteries. Ensure the setup is safe and feasible. Use this with iron filings or paper clips to help learners visualise the magnetic fields surrounding the wires.

i. Let learners bend their wires into different shapes and observe the resulting field patterns (e.g., single loop of wire, solenoid, rectangular loop of wire). Show learners accurate diagrams of these fields once they have investigated them themselves.

b. Explain Fleming's Left Hand Rule and let learners experiment with the equipment available to very this. They should use a single, straight wire placed between the poles of a horse-shoe magnet.

c. Using videos, or interactive virtual laboratories, or printed screenshots or diagrams, learners experiment with varying currents, magnetic field strength, and conductor length to observe changes in the magnetic force. They record their observations and discuss how these factors influence the force.

   i. Demonstrate the simulation and basic controls, ensuring all learners understand how to use the software. If technology is limited, use printed screenshots or diagrams to explain the simulation.

   ii. Learners explore the simulation in small groups, analysing different parameters (e.g., number of turns, current strength) and applying Fleming's Left-Hand Rule to predict the direction of forces in the simulation.

3. Problem-Based/Collaborative Learning

a. Provide worksheets with different configurations to learners in mixed-ability groups; learners discuss their observations for different conductor configurations (straight, parallel with same-direction currents, parallel with opposite-direction currents, circular coil, solenoid). Encourage them to draw their observations on paper or cardboard and use hand gestures to apply Fleming's Left-Hand Rule. Groups present their findings to the class, focusing on differences and similarities in magnetic field patterns and how Fleming's Left-Hand Rule applies to each configuration.

b. Introduce the formula $F = BILsin(\theta)$ for calculating the force on a current-carrying conductor. Provide learners with practice problems that vary the current, magnetic field strength, length of the conductor, and angle to reinforce their calculation skills. Review the solutions as a class, discussing common mistakes and ensuring understanding.

c. Advanced groups design an experiment within the simulation to test specific hypotheses (e.g., the effect of coil radius on magnetic field strength) and present their comprehensive reports, including data analysis and theoretical implications.

KEY ASSESSMENTS

Level 1: What is the shape of the magnetic field inside and outside a solenoid?

Level 2: If the angle between the conductor and the magnetic field is changed to 30 degrees, how does this affect the force on the conductor? Calculate the percentage change in the magnitude of the force.

Level 3: Analyse the differences in magnetic field patterns around parallel conductors with currents in the same and opposite directions and explain the underlying principles.

Hint

The recommended mode of assessment for week 17 is ***dramatisation****. Use the level 3 question as a sample question and the Teacher Assessment Manual and Toolkit page 80 for more information on how to use dramatisation.*

WEEK 18

Learning Indicators

1. *Explain the forces acting between parallel conductors carrying current in a magnetic field*
2. *Explain the torque on a rectangular current-carrying coil in a magnetic field*
3. *Describe and analyse the structure and working principle of the motor and moving coil galvanometer*
4. *Describe the electromagnetic switches and applications*

FOCAL AREA 1: MAGNETIC FIELD AROUND A CURRENT-CARRYING CONDUCTOR

Understanding the magnetic field around current-carrying conductors is crucial for the design and operation of many devices.

1. **Electric motors**: Convert electrical energy into mechanical energy, which is used in various appliances such as electric fans, washing machines, and industrial machines.
2. **Moving coil galvanometers**: Measure small electric currents with high sensitivity, essential for scientific instruments.
3. **Electromagnetic switches:** Control electrical circuits, widely used in relays, circuit breakers, and other control devices in household appliances and power systems.
4. **Power distribution:** Parallel conductors carrying current in power lines and electrical grids.

A rectangular coil carrying current in a magnetic field experiences forces in opposite directions on either side of the coil (due to the opposite directions of the currents on these sides). This therefore produces a torque that tends to rotate the coil. This torque is the basis for operating devices like electric motors and galvanometers. The torque (t)

$\tau = nBIAsin(\theta)$

n is the number of turns in the coil,

B is the magnetic field strength,

I is the current in the coil,

A is the area of the coil,

θ is the angle between the plane of the coil and the magnetic field.

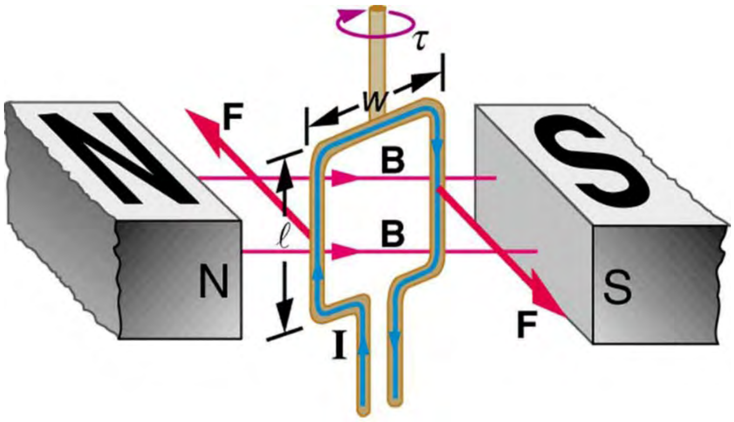


Figure 62: *Torque on a current loop*

For example, Calculate the torque if a rectangular coil with 10 turns, carrying a current of 2 A, is placed in a magnetic field of 0.3 T, with an area of 0.5 m² and an angle of 60 degrees between the coil and the magnetic field.

$\tau = nBIASin(\theta)$

$\tau = 10 \times 0.3 \times 2 \times 0.5 \times Sin(60)$

$Sin\ (60) = \frac{\sqrt{3}}{2}$

$\tau = 10 \times 0.3 \times 2 \times 0.5 \times \frac{\sqrt{3}}{2}$

$\tau = 2.598Nm$

Therefore, the torque on the coil is 2.598Nm.

A moving coil galvanometer is a device used to measure small electric currents. It consists of a rectangular coil of wire that rotates in a magnetic field. When current passes through the coil, it experiences a torque that causes it to rotate. The rotation is proportional to the current, and a needle attached to the coil provides a reading on a calibrated scale.

Figure 63: *DC moving coil galvanometer*

Figure 64: *Video on how to build a moving coil galvanometer with locally available materials*

LEARNING TASKS

1. Demonstrate the repulsive and attractive forces between parallel current-carrying conductors in a magnetic field using simulation or laboratory setup to learners.
2. Construct a basic electric motor and discuss its operation.
3. Draw and discuss the principle of a moving coil galvanometer and the factors that affect the current sensitivity of the galvanometer.

PEDAGOGICAL EXEMPLARS

1. Talk for Learning

a. Explain the concept of torque on a rectangular coil in a magnetic field, explaining how this principle is used in electric motors. Use a small rectangular coil and a magnet to demonstrate how the coil experiences torque when current flows through it. Discuss the structure of a split-ring commutator and challenge more able learners to explain to their peers why they think this is a crucial feature of a DC motor.

b. Discuss the structure and working principle of electric motors and moving coil galvanometers. Show diagrams of an electric motor and a moving coil galvanometer. Explain how the torque on the coil makes the motor spin or moves the needle in the galvanometer.

- Ask learners to think-pair-share how a galvanometer could be made more sensitive to small currents.

2. Experiential Learning

a. Guide learners in constructing a basic electric motor using wire coils, magnets, and batteries. Give learners materials and show them how to wind the coil, attach it to the battery, and place the magnets. Explain how the magnetic field and the current-carrying coil affect motion. Discuss the operation and key components of the motor, including the split ring commutator.

b. Learners draw and discuss the principle of a moving coil galvanometer. Use a small coil and a magnet to demonstrate the operation of a galvanometer. Have learners draw the device and label its parts. Provide materials for learners to build a basic model and observe how it works.

c. Perform experiments to observe the factors affecting the sensitivity of a moving coil galvanometer. Set up experiments where learners can change the number of turns in the coil, the magnets' strength, or the coil's size. Have them measure and record how these changes affect the sensitivity of the galvanometer (the angle to which the coil deflects).

d. In the absence of practical equipment, use computer simulations to investigate the behaviour of moving coil galvanometers as described above.

3. **Problem-based / Collaborative Learning**

   a. Using practice questions of problems with a varying number of turns, magnetic field strength, current, area of the coil and the angle to calculate the torque on a rectangular current-carrying coil in a magnetic field. Provide learners with practice problems that vary the number of turns, magnetic field strength, current, area of the coil, and angle to reinforce their calculation skills. Review the solutions as a class, discussing any common mistakes and ensuring understanding.

KEY ASSESSMENTS

Level 1: Define the term 'magnetic field.'

Level 2: Explain the difference in forces between parallel conductors carrying current in the same direction versus opposite directions.

Level 3: Figure 65 shows a rectangular loop of current-carrying wire between the poles of a magnet. The sides of the loop parallel to line d_1 are parallel to the magnetic field, and the sides of the loop parallel to line d_2 are perpendicular to the magnetic field. The current in the loop is 350 mA, and the magnetic field strength is 0.12 T. The length of d_1 = 0.025m and the length of d_2 = 0.015m. Calculate the torque acting on the coil.

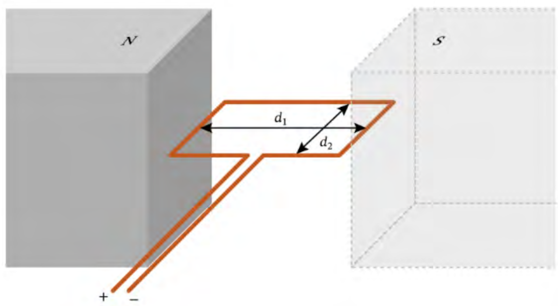


Figure 65: *Calculating the torque on a coil*

Level 4: Evaluate the applications of torque on current-carrying coils in various industries. Discuss how understanding these principles can lead to innovations in technology and engineering.

FOCAL AREA 2: ELECTROMAGNETIC SWITCHES AND THEIR APPLICATIONS

The concept of electromagnetic switches emerged in the early 19th century, paralleling the development of electromagnetism. Michael Faraday's work on electromagnetic induction in the 1830s laid the groundwork for practical applications of electromagnetism in switching devices. The invention of the telegraph by Samuel Morse in 1837 and the subsequent development of relays and solenoids revolutionised communication and control systems. These devices have since evolved into critical components in various industries, from automotive to telecommunications and household appliances.

Figure 66: *An electromagnetic switch*

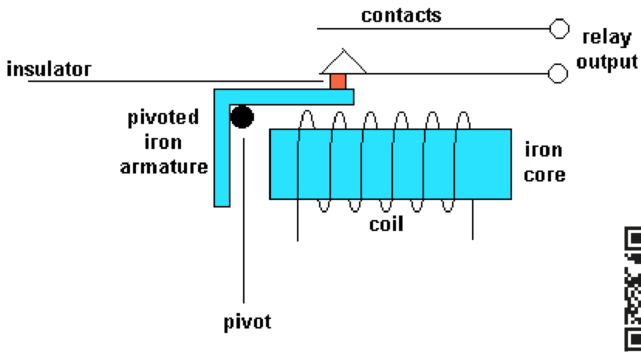


Figure 67: *Electric relay*
Electromagnetic Relays Tutorial & Circuits – Electromagnetic Relay – Electronics Components Tutorial – Hobby Projects

Electromagnetic switches, such as relays and solenoids, use the principle of electromagnetism to open or close electrical circuits. When current flows through the coil of the switch (see diagram above), it generates a magnetic field that moves a lever or armature, thereby opening or closing the circuit (see diagram above – the pivoted armature pushes the contacts of the relay output together). Applications include controlling high-power devices with low-power signals; this means that humans can switch on a low-current, low-risk circuit which can in turn switch on a high current, more dangerous circuit. This is seen in automotive starters, industrial machinery, and household appliances.

Figure 68: *Video on how relays work*

Applications of electromagnetic switches include

1. **Automotive industry:** Electromagnetic switches are used in car starters, fuel injectors, and control systems.
2. **Industrial machinery:** Relays and solenoids control machinery operations, providing automation and safety features.
3. **Household appliances:** Devices such as washing machines, dishwashers, and microwaves use electromagnetic switches to control functions and ensure safe operation.
4. **Telecommunications:** Relays are essential in switching circuits in telecommunication networks, enabling efficient and reliable signal routing.

LEARNING TASKS

1. Identify and describe the components of an electromagnetic switch.
2. Draw and explain the working principle of a relay.
3. Illustrate the application of solenoids in real-world devices.
4. Analyse the advantages and limitations of electromagnetic switches.

PEDAGOGICAL EXEMPLARS

1. **Inquiry-based and Teacher-led Learning**
   - **a.** Describe electromagnetic switches and their applications, providing examples such as relays and circuit breakers in local electrical systems. Use diagrams or physical examples of electromagnetic switches like relays and circuit breakers. Explain how these devices use electromagnetism to open or close circuits.
     - i. Think-pair-share or use targeted questioning to facilitate a discussion on the potential advantages or applications of an electromagnetic switch/relay.
   - **b.** Learners must design a relay or solenoid for a specific application. Each group must be mixed ability.
   - **c.** Have each group present their designs and research methodology, explaining how they applied the principles to solve the problem and how they collaborated and applied their theoretical knowledge. They should also state the safety precautions necessary with their switch.
2. **Experiential Learning**
   - **a.** Provide learners with basic components of electromagnetic switches or pictures or diagrams of them. Remind learners of precautionary measures to observe

when dealing with electronics concerning wearing of protective equipment and being alert.

b. Demonstrate the construction and working principles of electromagnetic switches using locally available materials. Discuss their everyday applications, such as household appliances and power systems. Show how to build a simple electromagnetic switch using a coil, a battery, and a piece of iron. Explain how the switch operates and where similar switches are used in everyday life, like in doorbells or remote controls.

    i. Challenge learners, in small groups, to construct an electromagnet and to then investigate either how its strength varies with current or how its strength varies with number of turns. Note that the strength could be measured by counting the number of paperclips it can hold, or similar.

    ii. More able learners should support less able learners in performing their experiment and recording their results accurately. They should also be encouraged to critically analyse the experimental technique and discuss how their hypothesis could be measure more accurately, perhaps using different equipment.

3. **Collaborative Learning:** Assign learners to mixed-ability groups. Provide each group with a list of questions to facilitate a group discussion such as "What are the main parts of a relay and how do they work?" and "Can you think of any devices that use solenoids?". Ensure a range of questions such that less confident learners will be able to contribute to the most accessible ones.

4. **Inquiry-based Learning**

    a. Organise a debate for learners in a scenario involving designing and testing an electromagnetic switch.

    b. Learners must design a relay or solenoid for a specific application. Each group must be mixed-ability.

    c. Have each group present their designs and research methodology, explaining how they applied the principles to solve the problem and how they collaborated and applied their theoretical knowledge. They should also state the safety precautions necessary with their switch.

KEY ASSESSMENT

Level 1: What is the primary function of an electromagnetic switch?

Level 2: Name a household appliance and describe how electromagnetic switches are used in it.

Level 3: Analyse the advantages and limitations of using electromagnetic switches in applications such as automotive starters and industrial machinery.

Level 4: Discuss the potential future advancements in electromagnetic switch technology. Explore how these advancements could impact fields such as robotics and automation.

Hint

The recommended mode of assessment for week 18 is ***mid-semester examination****. Refer to Appendix F for a Table of specification to guide you to set the questions.*

WEEK 19

Learning Indicators

1. *Calculate the force on a charged particle in a magnetic field*
2. *Explain the force on a moving charged particle in an electric field*
3. *Describe the force on a moving charged particle in a crossed field (Lorentz force)*

FOCAL AREA 1: FORCE ON A CHARGED PARTICLE

Studying the forces acting on charged particles in electric and magnetic fields is fundamental in electromagnetism and has numerous practical applications. During World War II, the principles of electromagnetism were crucial in developing technologies like the mass spectrometer. Mass spectrometers were used to separate the radioactive uranium isotope U-235 from the more common uranium isotope U-238, playing a significant role in the development of nuclear weapons.

A stationary charged particle does not interact with a static magnetic field. However, when a charged particle moves through a magnetic field, it experiences a magnetic force. This force reaches its maximum value when the particle's velocity is perpendicular to the magnetic field lines, decreases at other angles, and becomes zero when the particle moves parallel to the field lines. The magnetic force (F) on a moving charged particle is given by the formula:

$F = qvBsin(\theta)$

Where:

q is the charge of the particle,

v is the velocity of the particle,

B is the magnetic field strength,

θ is the angle between the velocity and the magnetic field.

The Left Hand Rule can once again be used to determine the direction of the force. Note that the 'current' acts in the direction that a positive charge is moving. If the charge is negative, then the current points in the opposite direction to its motion.

Example

A proton moves at 4.38 x 10^5 m/s along the x-axis. It enters a region in which there is a magnetic field of magnitude 2.0 T, directed at an angle of 60.0° with the x-axis and lying in the xy-plane. (a) Find the initial magnitude and direction of the magnetic force on the proton. (b) Calculate the proton's initial acceleration.

Magnetic force on a charged particle

$F = qvBsin(\theta)$

$F = (1.60 \times 10^{-19}) \times (4.38 \times 10^{5}) \times 2.0 \times sin(60)$

$F = 9.69 \times 10^{-14} N$

The Left Hand Rule gives the direction of the magnetic force. If the proton moves along the x-axis and the magnetic field is in the xy-plane at an angle of 60∘ with the x-axis, the force will be perpendicular to both the velocity and the magnetic field, therefore act in the z-direction.

Acceleration of the proton: $\mathrm{a} = \frac{\mathrm{F}}{\mathrm{m}}$

Where:

a is the acceleration,

F is the magnetic force,

m is the mass of the proton (m=1.67 × 10^{-27} kg).

Using the force determined earlier,

$F = ma$

$a = \frac{F}{m}$

$a = \frac{9.69 \times 10^{-14} N}{1.67 \times 10^{-27} kg}$

$\mathrm{a} = 5.80 \times 10^{13} m/s^2$

When a charged particle moves through an electric field, it experiences an electric force (F) given by:

$F = qE$

Where:

q is the charge of the particle,

E is the electric field strength.

Now, when a particle with charge q moves with velocity v perpendicular to an electric field E and a magnetic field B. The electric force acts in the direction of the electric field (qE), while the magnetic force acts perpendicular to both the velocity and the magnetic field (qv × B). The resultant force is the vector sum of these two forces, which affects the particle's trajectory. The Lorentz Force principle is utilised in devices like velocity selectors and mass spectrometers to control and measure particle velocities and trajectories.

The velocity selector practically applies the Lorentz force in a crossed electric and magnetic field. It is a device used in mass spectrometers and particle accelerators to filter particles based on their velocities. In a velocity selector, charged particles pass through a region with perpendicular electric and magnetic fields. The electric field (E) exerts a force on the charged particles in one direction, while the magnetic field (B) exerts a force perpendicularly (and in the opposite direction to the electric force). For particles to pass through the velocity selector without being deflected, the electric and magnetic forces must balance each other.

Figure 70: *Video on Lorentz Force*

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator at CERN (the European Organization for Nuclear Research), Meyrin, Geneva, Switzerland. It accelerates protons and heavy ions to near the speed of light and then collides them to study fundamental particles and forces. In the LHC, charged particles are accelerated and controlled using electric and magnetic fields. The Lorentz force, which is the force experienced by a charged particle moving through electric and magnetic fields, is a key principle in the operation of the LHC.

Figure 71: *An aerial view of CERN's Large Hadron Collider (LHC) circumference of 27km*

Mass spectrometry is a powerful tool with many applications, including the detection of drugs in athletes' blood or urine, helping fight against doping in sports. It works by passing the ions which make up the chemicals through a velocity selector, and then into a separate magnetic field which moves each ion into a path of a different radius depending on its specific charge. The ions are then detected at different distances along a screen and these distances are used to identify the nature of the ion. Scientists often combine mass spectrometry with chromatography, a technique that separates different substances in a sample. The sample is first separated using chromatography and then analysed by a mass spectrometer. The National Sports Authority of Ghana has a National Anti-Doping

Committee that ensures that Ghanaian athletes do not use any substance banned when participating in local and international sporting activities.

Cyclotrons are used in medical applications to produce high-energy particles for cancer treatment. In a cyclotron, charged particles (such as protons) are accelerated in a circular path by a perpendicular magnetic field and an alternating electric field. As the particles gain energy, their velocity increases and spirals outward to higher energy levels. These high-energy particles can then be directed towards a target to destroy cancer cells precisely.

Figure 72: *Video of the use of cyclotrons in Medical Physics for treatment of cancer*

LEARNING TASKS

1. Calculate the force on a charged particle in a magnetic field using $F = qvBsin(\theta)$.
2. Calculate the force on a moving charged particle in an electric field using $F = qE$.
3. Describe the Lorentz force in a crossed electric and magnetic field.
4. Analyse the applications of magnetic and electric fields in real-world scenarios.

PEDAGOGICAL EXEMPLARS

1. **Teacher-led Learning**
   - **a.** Introduce learners to the formulae for electric and magnetic forces on charged particles.
   - **b.** Conduct a short multiple-choice quiz whereby learners are given diagrams of particles in either magnetic or electric fields and have to select the correct direction in which the particle will move.
2. **Experiential Learning**
   - **a.** Using a cathode ray tube (CRT), or a simulation (e.g., JavaLab), demonstrate the deflection of electron beams in an electric and in a magnetic field. Learners will observe that a stationary charged particle does not interact with the magnetic field, but a moving charged particle does. They will note how the direction and magnitude of deflection change with different magnetic field strengths and orientations, as well as with different voltages. Ensure learners handle the CRT

with care. Do not look directly into the CRT or point it at others. Follow all safety instructions and use protective eyewear.

3. **Problem-based Learning**
   a. Learners should calculate the electric and magnetic forces on charged particles individually, in pairs or in mixed-ability groups with $F = qvBsin(\theta)$ and $F = qE$.
      i. Problems should be differentiated to begin with simple examples of electric or magnetic fields and should increase in difficulty until learners are faces with crossed fields in a variety of applications.
      ii. Learners should be expected to give the magnitude and the direction of the electric force, magnetic force and/or resultant force.

4. **Collaborative Learning**
   a. In mixed-ability groups, learners present research topics related to the applications of forces on charged particles in the form of essays or posters.
      i. Assign roles and encourage the use of varied resources (note that learners should be provided with a list of appropriate resources and given some ideas for topics that they may choose to research, e.g. mass spectrometry or cyclotrons). Learners should be mindful of the source of their information and **properly** cite any information used. Learners with less computer user experience should be assisted or grouped with learners with more computer user experience.
      ii. **Groups** should collaborate and provide a detailed presentation or report with explanations, formulas, diagrams, and real-world applications. Provide less able learners with templates to record findings and structure responses.
      iii. Engage in discussions on the practical implications of the topics. Target specific learners, which may include girls in the class, with example questions to encourage their participation in the discussion.

KEY ASSESSMENT

Level 1: Give the unit for magnetic field strength and the unit for electric field strength.

Level 2: A proton moves with a velocity of 2.00×10^6 m/s at an angle of 30° to a magnetic field of 0.50 T. Calculate the magnetic force acting on the proton. (Charge of proton $q=1.60 \times 10^{-19}$ C)

Level 3: If a proton moves through a region with both electric and magnetic fields, how does the Lorentz force affect its path compared to a region with only a magnetic field?

Level 4: Investigate how varying the strengths of the electric and magnetic fields in a crossed field setup affects the motion of a charged particle. Present your findings with calculations and potential applications.

Hint

*The recommended mode of assessment for week 19 is **research**. Use the level 4 question as a sample question and the Teacher Assessment Manual and Toolkit page 84 for more information on how to use research.*

Section 6 Review

This section reviewed three primary themes: Magnetic Field Around a Current-Carrying Conductor Electromagnetic Switches and their Applications, and the Interaction of Electric and Magnetic Fields. The first theme covered the forces between parallel conductors carrying current, the torque on rectangular coils, and the principles of electric motors, moving coil galvanometers. The second theme discussed electromagnetic switches and their uses, for example in relay circuits. The third theme explored how electric and magnetic fields affect charged particles, focusing on crossed fields and the Lorentz force. Practical applications such as mass spectrometers and cyclotrons were highlighted. By the end of this section, learners should understand the key concepts, be able to perform relevant calculations, and demonstrate practical skills through experiments and simulations. Differentiation ensured all learners grasped the concepts, with additional support for those who needed it and more challenging tasks for advanced learners. This comprehensive review ensured learners were well-prepared to apply these principles in various contexts.

APPENDIX F: MID SEMESTER EXAMINATION

Structure

20 Multiple Choice Questions

Duration : 30 minutes

Table of Specification

WEEK	Learning Indicator	DoK Level				Total
		1	2	3	4	
13	Determine the time taken by the projectile to reach the maximum height and the magnitude of the maximum height.	1	1	1		**3**
14	Identify some effects and applications of friction.	1	2	1		**4**
15	Explain circular motion and give some examples of circular motion.	1	1	1		**3**
16	Calculate maximum and minimum tension in a string.	1	2	1		**4**
17	Discuss the factors that affect the magnitude of the magnetic force on a current-carrying conductor in a magnetic field.	2	2	2		**6**
Total		**6**	**8**	**6**		**20**

SECTION 7: WAVES

Strand: Energy

Sub-Strand: Waves

Learning Outcomes

1. *Deduce the wave equation from the features of a periodic wave signal*
2. *Using the property of reflection of sound, and the phenomenon of resonance, give an account of how the speed of sound can be determined.*

Content Standards

1. Demonstrate knowledge and understanding of the wave equation.
2. Demonstrate knowledge and understanding of sound waves.

INTRODUCTION AND SECTION SUMMARY

The section begins with an explanation of waves, and their properties which include reflection, refraction, diffraction, interference, and polarisation. Each of these properties defines how waves propagate through different mediums and how they affect their surroundings.

The weeks covered by the section are:

Week 20: Wave motion

Waves are classified into several categories: longitudinal, transverse, electromagnetic, mechanical, progressive, and stationary. Longitudinal waves and transverse ways have different mechanisms of propagation. Electromagnetic waves, which do not require a medium, are contrasted with mechanical waves that do. Additionally, the section distinguishes between progressive waves, which move through a medium, and stationary waves, which result from the superposition of two waves traveling in opposite directions.

The section then focuses on determining key parameters from a wave's sinusoidal signal, including amplitude, velocity, frequency, period, and wavelength. Understanding these parameters allows for the deduction of the wave equation, a mathematical representation of the wave's properties and behaviour. Given the amplitude, velocity, frequency, period, and wavelength, the wave equation can be formulated, providing a foundational tool for analysing wave phenomena.

Week 21: Sound waves

Sound production, nature, and transmission are also explored, elucidating how sound waves are generated and propagate through different mediums. Sound waves are classified into infrasonic (below human hearing range), audio sonic (within human hearing range), and ultrasonic (above human hearing range).

The phenomenon of echoes is explained, demonstrating how reflected sound waves can be used to determine the depth of rivers and other bodies of water.

Finally, the concept of resonance is discussed, particularly its application in determining the speed of sound in air.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Teaching waves and sound effectively involves a multifaceted approach that includes clear explanations, visual aids, practical experiments, videos, interactive simulations, and collaborative problem-solving activities. Begin by explaining what waves are and illustrating different types and their properties using diagrams, animations, and real-life videos. Classify waves into categories such as longitudinal, transverse, electromagnetic, mechanical, progressive, and stationary, using real-life examples and interactive simulations. Teach key wave parameters like amplitude, velocity, frequency, period, and wavelength through graphical representations, hands-on activities, and simulations. Guide learners in deducing the wave equation from given parameters through step-by-step problem-solving and group work, using simulations for immediate feedback.

Explain the production, nature, and transmission of sound waves with demonstrations and simulations. Classify sound into infrasonic, audio sonic, and ultrasonic categories with examples and applications, using audio equipment and simulations to enhance understanding.

Demonstrate how echoes occur and apply this to measure the depth of bodies of water, using practical examples and interactive simulations. Introduce resonance and its use in determining the speed of sound with experiments and videos, guiding learners through related calculations. Integrating these strategies ensures comprehensive understanding and practical application of wave and sound concepts, making abstract ideas tangible and engaging for learners.

ASSESSMENT SUMMARY

Effective assessment strategies for understanding waves and sound involve a comprehensive and varied approach, combining theoretical explanations, practical applications, and analytical problem-solving. Use conceptual questions that assess their understanding of waves, including their definitions and fundamental properties. Identification tasks should be provided where learners describe different types of waves and highlight their specific properties, using diagrams and real-world examples to facilitate understanding.

Classification tasks, such as asking learners to categorise waves into longitudinal, transverse, electromagnetic, mechanical, progressive, and stationary, can be assessed through multiple-choice questions, matching exercises, or short-answer questions that require explanations for each classification. Problem-solving exercises should be given where learners determine key parameters from sinusoidal wave signals, such as amplitude, velocity, frequency, period, and wavelength, through graphical analysis and mathematical calculations. Analytical tasks should require learners to deduce the wave equation given specific parameters, demonstrating their understanding of the interrelation of these parameters.

Short-answer and essay questions can assess learners' understanding of how sound is produced, its nature, and how it is transmitted through different media. Classification tasks should also be used to categorise sound into infrasonic, audio sonic, and ultrasonic, assessed through multiple-choice questions, matching exercises, or short-answer questions with real-life examples. Understanding echoes and their applications can be evaluated through short-answer questions and practical problems where learners determine the depth of rivers using echo calculations. Applying the concept of resonance to determine the speed of sound can be assessed through laboratory experiments where learners take precise measurements and perform calculations, as well as problem-solving exercises applying theoretical knowledge of resonance.

WEEK 20

Learning Indicators

1. *Identify different types of waves and their properties*
2. *Classify waves as longitudinal, transverse, electromagnetic, mechanical, progressive and stationary*
3. *Determine the amplitude, velocity, frequency, period, wavelength from a wave sinusoidal signal*
4. *Given the amplitude, velocity, frequency, period, wavelength of a wave, deduce the wave equation*

FOCAL AREA 1: WAVE MOTION

Think about when you drop a pebble into a pond. Ripples spread out in circles from the point where the pebble hits the water. These ripples are waves.

Consider sound, when someone speaks, their vocal cords create vibrations that travel through the air and reach our ears as sound waves.

A wave is a disturbance that transfers energy from one point to another without particles in the medium travelling between the two points. For instance, when you speak, the air particles vibrate back and forth, but they don't travel with the sound wave to your friend's ears. Waves are created by disturbances. In the case of water waves, the disturbance is the pebble hitting the water. For sound waves, it's the vocal cords vibrating.

Figure 73: *Water ripples*

Properties of waves

When a wave travels through a medium and encounters a different medium or a barrier, several interactions can occur, including reflection, transmission, and absorption.

1. Reflection

Reflection involves the wave bouncing back into the original medium. Reflection occurs without a change in a wave's velocity, frequency or amplitude.

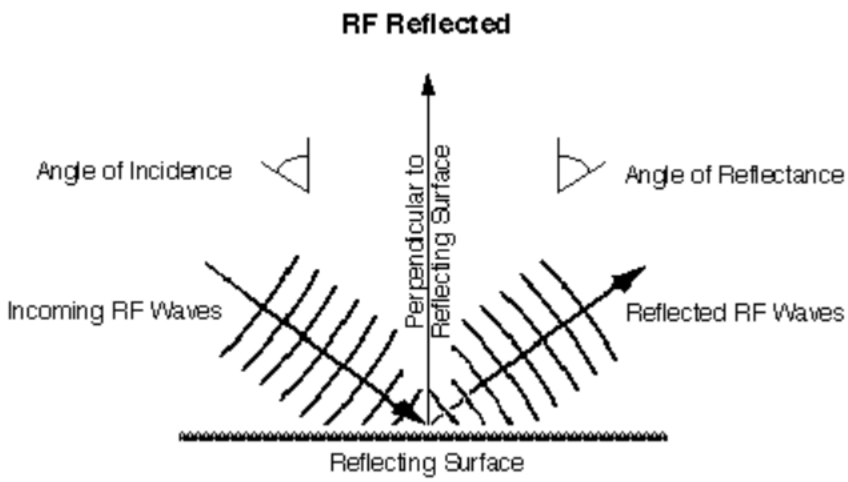


Figure 74: *Diagram representing reflection of wave*

Source: Figure from NASA's Jet Propulsion Laboratory's publication: Basics of Space Flight Learner's Workbook. http://www-b.jpl.nasa.gov/basics/

Examples

When sound waves hit a large, hard surface, such as a wall or a cliff, they reflect toward the source, this is why we hear echoes.

- Light waves reflect off smooth, shiny surfaces like mirrors.
- When water waves hit the edge of a pond or a swimming pool, they reflect.

2. Refraction

When a wave encounters a boundary between two different media, part of the wave is reflected into the original medium, and part is transmitted into the new medium. The transmitted wave changes speed, which causes a change in its direction. This bending of the wave is known as refraction.

Examples

When sound waves travel from air into water, they speed up because sound travels faster in water. This causes the sound waves to change direction.

- As water waves move from deeper to shallower regions, they slow down and bend towards the normal.

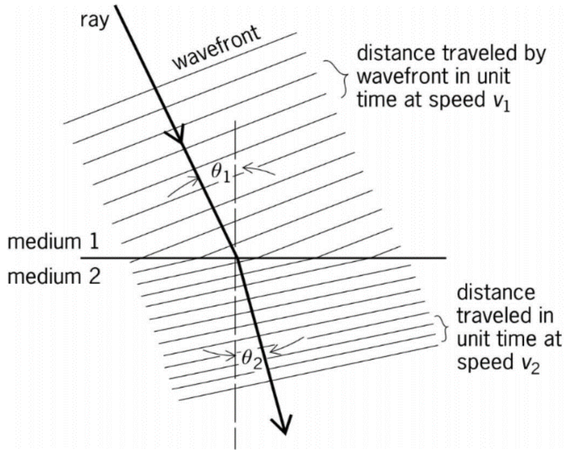


Figure 75: *Diagram representing refraction of wave*

3. Diffraction

When a wave encounters an obstacle or passes through a gap, the wavefront bends around the edges of the obstacle or spreads out after passing through the gap. The amount of diffraction increases with increasing wavelength and with decreasing size of the obstacle or opening.

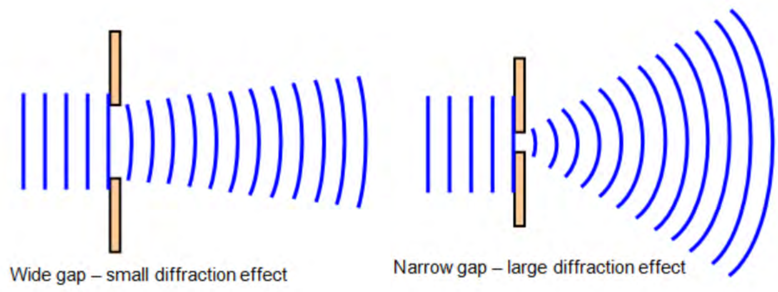


Figure 76: *Diagram representing diffraction*

4. Interference

Interference of waves occurs when two or more waves overlap and combine to form a new wave pattern. This can happen with any type of waves, including sound, light, and water waves. The principle of superposition states that when two waves meet, the resultant displacement at any point is the sum of the displacements of the individual waves at that point.

Types of interference

1. Constructive Interference: Occurs when the crests (or troughs) of two waves align, resulting in a wave with a larger amplitude.

   Example: When two speakers emit sound waves in phase, the sound waves combine to produce a louder sound.

2. Destructive Interference: Occurs when the crest of one wave aligns with the trough of another, resulting in a wave with a smaller (or zero) amplitude.

   Example: Noise-cancelling headphones use destructive interference to cancel out unwanted ambient sounds.

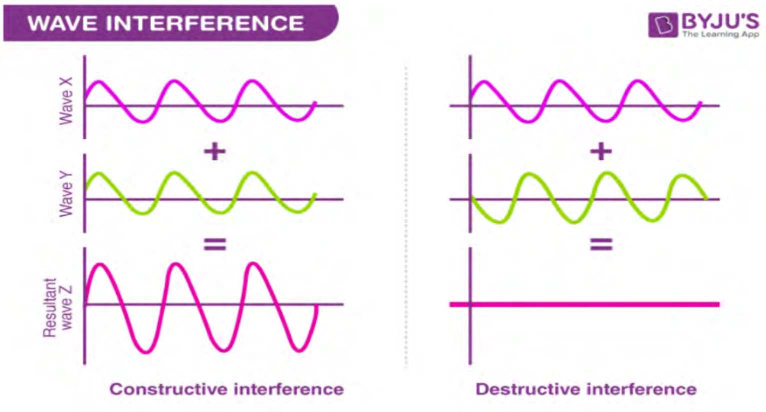


Figure 77: *Constructive and destructive interference*

Conditions for perfect constructive and destructive interference

1. The two sources must be coherent (they must have a constant phase difference as well as the same frequency).
2. The waves that are interfering must have the same amplitude.
3. The distance between the sources must be of the order of the wavelengths of the waves.

5. Polarisation

Polarisation of a wave refers to the orientation of the oscillations in the wave, particularly in transverse waves, such as electromagnetic waves. It describes the direction in which the electric field vector oscillates in an electromagnetic wave.

For example, in light waves (which are electromagnetic waves), polarisation can determine the direction of the electric field vector. If the electric field oscillates in a single plane, the wave is said to be linearly polarised. Polarisation can affect how the wave interacts with materials and filters, such as polarising lenses in sunglasses or photographic filters.

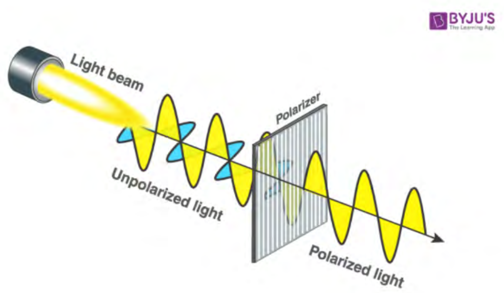


Figure 78: *Diagram representing polarisation of wave*

Classification of Waves

Based on Ability to Transmit

1. **Mechanical wave**: is a wave which requires a material medium for its transmission. E.g., sound waves, water waves, tidal waves, waves in a string etc.
2. **Electromagnetic wave**: is a wave which does not require a material medium for its transmission. E.g., radio waves, light waves and X-rays etc.

Based on Propagation of Energy

1. **Progressive wave:** A progressive wave, also known as a traveling wave, is a type of wave that moves or propagates through a medium transferring energy from one location to another. In progressive waves, the wave energy is transferred through the medium without the actual transportation of matter.
2. **Stationary wave:** A stationary wave, also known as a standing wave, is a wave pattern that results from the superposition of two waves of the same frequency and amplitude traveling in opposite directions. Unlike progressive waves, stationary waves do not transfer energy from one location to another. Instead, they exhibit regions of maximum and minimum amplitude called nodes and antinodes, respectively.

Based on Direction of Waves

1. **Transverse wave**: is a wave in which the direction of travel of the wave is perpendicular to the direction of oscillation of the medium or field e.g. water waves, waves on a plucked string, light waves, radio waves. The region of maximum upward displacement is called a crest. The region of maximum downward displacement is called a trough.
2. **Longitudinal wave**: is a wave in which the oscillations occur in the same direction as the direction of travel of the waves e.g. sound waves in air. The vibrating particles behave like a spiral spring that has a series of compressed regions and spaced-out regions travelling along it called compressions and rarefaction.

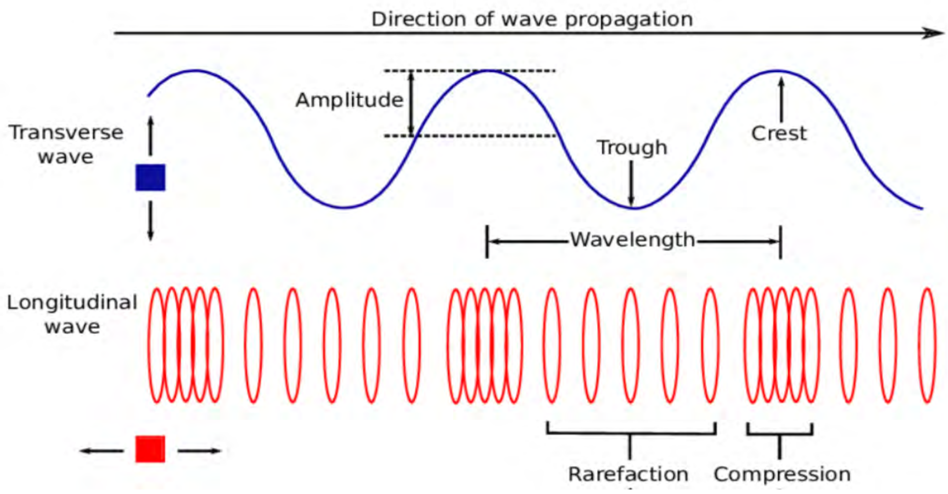


Figure 79: *Transverse and Longitudinal wave*

LEARNING TASKS

1. Describe different types of waves.
2. Classify waves based on a variety of factors.
3. Describe the properties and behaviours of waves.

PEDAGOGICAL EXEMPLARS

1. **Talk for Learning / Collaborative Learning**
   - **a.** Explain the concept of waves as disturbances that transfer energy through a medium or space.
   - **b.** Ask learners to recall any prior knowledge of waves; give them some key words to prompt their discussions and ask them to produce a concept map of these in small groups.
   - **c.** Create a visual aid or diagram that demonstrates the properties of waves, such as reflection, refraction, diffraction, polarisation and interference, and use it to explain how waves interact with different mediums and obstacles.
   - **d.** Give learners two lists: one with the definitions of the terms transverse, longitudinal, progressive, stationary, mechanical and electromagnetic and the other a list of different types of wave. Ask the learners to discuss in pairs or in small groups and to classify the waves into different types.
2. **Experiential Learning**
   - **a.** Arrange learners in a large circle or line. Have learners raise and lower their arms in sequence to create a "transverse wave" that travels around the group.
     - i. Ask learners to comment on how the motion of the 'particles' (people) compares to the motion or 'propagation' of the wave. Praise the use of

accurate key words such as ‘vibrate’, ‘oscillate’, ‘perpendicular’, ‘energy’ etc.

ii. Repeat the demonstration, this time asking learners to gently bump into one another in a ‘side-to-side’ motion (modelling a longitudinal wave). This time, praise the use of the term ‘parallel’.

b. Use water waves in a ripple tank to illustrate the peaks and troughs of a transverse wave, as well as the phenomena of reflection, refraction, diffraction, and interference.

Figure 80: *video on using the ripple tank to investigate the properties of wave*

c. Shine a laser pointer through

i. a diffraction grating to project interference patterns on a screen,

ii. at different angles onto a mirror to demonstrate reflection and

iii. at different angles through a glass prism to illustrate refraction.

d. Using long rope or string, stretch the rope or string between two fixed points. Have one learner quickly move one end of the rope up and down to create transverse waves.

e. Using a slinky spring on a flat surface, stretch the slinky across a flat surface, have one learner hold one end stationary while another learner quickly pushes and pulls the other end to create longitudinal waves. To demonstrate transverse waves, move one end of the slinky up and down or side-to-side while the other end is held stationary.

f. Demonstrate stationary waves using a vibrating guitar string.

g. After each demonstration, lead a discussion on the observed characteristics and properties of each type of wave. Encourage learners to classify the waves based on their observations and understanding.

h. On a whiteboard, create a classification chart with columns for longitudinal, transverse, electromagnetic, mechanical, progressive, and stationary waves. Have learners categorize each demonstrated wave type accordingly based on their properties.

i. Have learners access an online wave simulation tool. Instruct learners to explore different types of waves (longitudinal, transverse, electromagnetic, mechanical). Ask them to identify and classify each type of wave based on their characteristics and behaviours in the simulation.

KEY ASSESSMENT

Level 1

1. Define a wave.
2. State two differences between mechanical waves and electromagnetic waves and give two examples each.

Level 2: Given a wave on a string, determine whether it is transverse or longitudinal and explain your reasoning.

Level 3: Describe the formation of stationary waves on a string and the conditions required for their formation.

FOCAL AREA 2: WAVE MOTION

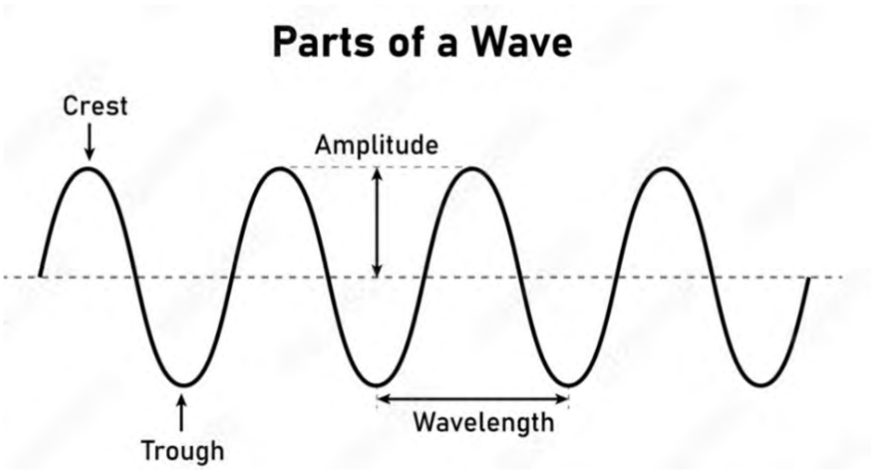


Figure 81: *Parts of a transverse wave*

1. **Amplitude (a):** is the maximum displacement of a particle from its equilibrium (rest) position. SI unit is the metre.
2. **Displacement (s)**: is the instantaneous distance moved by the wave particle from the position of rest. SI unit is the metre.
3. **Wavelength (λ):** is the distance between two successive crest or troughs OR the distance between two successive points that are in phase. SI unit is the metre.
4. **Frequency (f):** is the number of complete cycles which the wave completes in one second OR is the number of waves passing a point per unit time. SI unit is Hertz(Hz)
5. **Period (T):** is the time required for a wave to complete one full cycle. SI unit is seconds.

6. **Velocity (v/c):** is the distance which the wave travels in one second. SI unit is metres per second.

$f = \frac{1}{T}$

$velocity = \frac{displacement\ (\lambda)}{time\ (T)}$

$v = \frac{\lambda}{T}$

$v = \lambda f$ …………………….. wave equation

Finding the displacement of a particle at any given time

The displacement equation of the particle is given as:

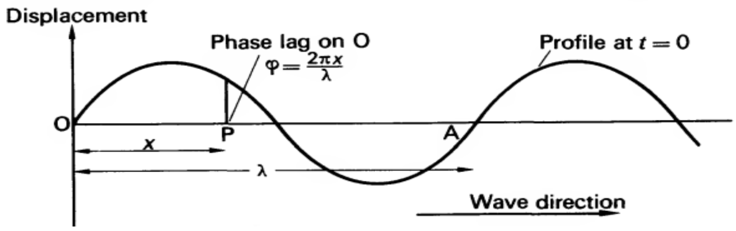
$y = a\sin\theta$

where θ is the phase of the cycle through with the particle has oscillated (e.g. a particle at the beginning of an oscillation, in the rest position, has a phase angle of zero. A particle a quarter of the way through a cycle has a phase angle of 90 degrees or $\frac{\pi}{2}$ radians).

$= a\ sin\ \omega t$

where ω is the angular frequency; the angle per second through which the particle oscillates, and t is the time that has passed.

Extension work for the most able learners: Progressive wave equation



Suppose the wave moves from left to right, or in the positive x- direction

The displacement equation of the particle at O is given as

$y = a\ sin\ \omega t$

The displacement equation of another particle P which lags on O is

$y = a\ sin\ (\omega t - \phi)$

where ϕ is the phase angle between the two vibrations. The negative sign means that P lags on O

$\phi = \frac{2\pi x}{\lambda}$

$y = a\ sin\left(\omega t - \frac{2\pi x}{\lambda}\right)$

$y = a \sin(\omega t - kx)$

where $k = \frac{2\pi}{\lambda}$, is called wave number

$v = \frac{\lambda}{T} \approx T = \frac{\lambda}{v}$

and $\omega = \frac{2\pi}{T}$

$\omega = \frac{2\pi v}{\lambda}$

substituting ϕ and ω into $y = a \sin(\omega t - \phi)$

$y = a \sin\left(\frac{2\pi vt}{\lambda} \mp \frac{2\pi x}{\lambda}\right)$ OR

$y = a \sin\left(2\pi ft \mp \frac{2\pi x}{\lambda}\right)$

This equation is called progressive wave equation.

v is the velocity of the wave

x is the distance of the particle from the origin

a is the amplitude of vibration

f is the frequency of the vibrating particle

LEARNING TASKS

1. Define key wave parameters: amplitude, velocity, frequency, period, and wavelength
2. Measure key wave parameters: amplitude, displacement, period, and wavelength from a given sinusoidal signal.
3. Solve numerical problems to determine the displacement, amplitude, angular frequency, velocity and frequency from given wave data or graphical representations.

PEDAGOGICAL EXEMPLARS

1. Talk for Learning

a. Use visual aids, videos and interactive simulations to introduce learners to the terms which define a wave such as amplitude, frequency, time period, wavelength etc. Ensure that you address the differences between a displacement-distance graph and a displacement-time graph in terms of the 'stories' that they tell and the quantities that can be found by analysing them.

i. Follow this introduction with a short quiz requiring learners to identify the term demonstrated in an image projected onto the board (e.g. an arrow from the equilibrium position vertically upwards to a peak – learners should identify 'amplitude')

   b. Let learners employ the definition of speed/velocity to establish the relationship between the speed, wavelength and frequency or the period.

   c. Introduce learners to the equation for the displacement of a particle at any given time and guide them through a worked example using this equation.

   d. Introduce more able learners to the progressive wave equation and guide learners to deduce amplitude, wavelength, frequency, velocity from a progressive wave equation

2. **Experiential Learning**

   a. Display a sine wave graph and label its key components: amplitude, wavelength, crest, trough, and equilibrium position. Define each parameter:

   b. Distribute graph paper, rulers, and markers to learners. Instruct learners to draw their own sine waves with specified amplitudes and wavelengths.

   c. Introduce an online sine wave generator tool or app and allow learners to input different parameters (amplitude, wavelength, frequency) and observe the resulting changes in the wave.

   d. Have learners access an online wave simulation tool. Explore different wave settings and generate sinusoidal waves. Measure amplitude, frequency, wavelength, and period using the simulation's tools. Record the measurements for various wave settings. Calculate wave velocity using the recorded frequency and wavelength. Given the measured amplitude, velocity, frequency, period, and wavelength, have learners deduce the wave equation.

3. **Problem-Based Learning**

   a. Distribute worksheets with problems that require learners to measure and calculate amplitude, displacement, wave speed, wavelength, period and frequency from graphical representations of waves. Include real-world examples, such as calculating the speed of sound in different conditions or analysing light waves of different colours. Include differentiated problems.

   b. Distribute worksheets requiring learners to use the equation for the instantaneous displacement of a particle to find the displacement, the amplitude, the angular frequency, or the time that has passed.

   c. Distribute worksheets to the most able learners with problems that require learners to deduce key parameters from given wave equation.

KEY ASSESSMENT

Level 1: Define the term wavelength.

Level 2: Given an amplitude of 2 metres and an angular frequency of 10 radians per second, write the wave equation.

Level 3

1. Explain the difference between the frequency and the angular frequency of a wave.
2. Discuss the formation of stationary waves on a string and the conditions required for their formation

> ***Hint***
>
> *The recommended mode of assessment for week 20 is* ***essay****. Use the level 3 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 74 for more information on how to use essay as an assessment tool.*

WEEK 21

Learning Indicators

1. *Explain the production, nature and transmission of sound*
2. *Classify sound into infrasonic, audio sonic, and ultrasonic*
3. *Explain how an echo comes about and apply the phenomenon in the determination of depth of rivers*
4. *Apply the concept of resonance in the determination of speed of sound in air*

FOCAL AREA 1: SOUND WAVE

Production, Nature and Transmission of Sound

Sound production begins with an object vibrating. This can be anything from a vocal cord, a guitar string, or a loudspeaker diaphragm. When an object vibrates, it moves back and forth rapidly. The vibrating object pushes air molecules together (compression) and then pulls them apart (rarefaction). This creates alternating high and low-pressure regions in the air. These compressions and rarefactions travel through the medium as longitudinal waves, where the direction of particle displacement is parallel to the direction of wave propagation. Sound waves require a medium to travel, which can be a gas (air), liquid (water), or solid (metal). The speed at which sound waves travel depends on the medium. Sound travels faster in solids than in liquids, and faster in liquids than in gases due to differences in molecular density and elasticity.

Examples

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.

Voice Production: In humans, the vocal cords vibrate as air passes through them, producing sound waves that form speech and singing.

Speakers: In a loudspeaker, an electrical signal causes a diaphragm to vibrate, creating sound waves that propagate through the air.

Classification of Sound Based on Frequency

1. **Infrasonic (Infrasound)** - Frequency range: Below 20 Hz

   These are sound waves with frequencies lower than the audible range for humans. Infrasound 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** - Frequency range: 20 Hz to 20,000 Hz (20 kHz)

   This is the range of sound frequencies that can be heard by the average human ear. It includes most of the sounds we encounter in daily life, such as speech, music, and environmental noises.

3. **Ultrasonic (Ultrasound)** - Frequency range: Above 20,000 Hz (20 kHz)

   These are sound waves with frequencies higher than the audible range for humans. 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.

Echoes

An echo is a phenomenon where a sound wave reflects off a surface and is heard again after a delay. This delay occurs because sound takes time to travel to the reflecting surface and back to the listener.

When a sound wave encounters a surface, it can be reflected, absorbed, or transmitted. An echo occurs when a significant portion of the sound wave is reflected back towards the source.

The time it takes for the echo to be heard depends on both the speed of the sound through the medium and the distance between the source of the sound and the reflecting surface. The further the distance, the longer the time delay. The formula for calculating this time delay is:

$$Time\ delay = \frac{2 \times distance}{speed\ of\ sound}$$

where the speed of sound is approximately 343 meters per second (m/s) in air at room temperature.

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.

Applications and Examples

Echoes are often heard in large open spaces, such as canyons, valleys, and empty buildings. They are also used in various applications, such as sonar (for detecting objects underwater), echolocation (used by animals like bats and dolphins for navigation), and medical ultrasonography (imaging the inside of the body) and also can be used to determine the depth of rivers.

Resonance

Resonance is a phenomenon which occurs whenever a body is set in oscillation at its own natural frequency because of impulses received from another body vibrating with the same frequency.

Example: If a sounding tuning fork is held over a column of air particles trapped inside a tube, the air particles can be made to resonate if their natural frequency matches the frequency of the tuning fork.

Resonance has diverse applications

1. Musical Instruments: Enhances sound in string and wind instruments.
2. Tuning Circuits: Used in radios and TVs to isolate specific frequencies.
3. Mechanical systems: Important in bridge and building design to avoid failures.
4. Medical imaging: MRI and ultrasound devices rely on resonance.
5. Communication systems: Antennas use resonance for effective signal transmission.
6. Acoustic design: Optimizes sound quality in concert halls and auditoriums.
7. Timekeeping: Quartz crystals in watches provide precise timing.
8. Laser technology: Optical resonators amplify light in lasers.
9. Energy Systems: Enables wireless power transfer via resonant inductive coupling.
10. Seismology: Analyses building and Earth's resonance during earthquakes.
11. Everyday Objects: Examples include resonating wine glasses.
12. Determining the speed of sound in air.

Experiment to Determine the Speed of Sound in Air using a Resonance Tube

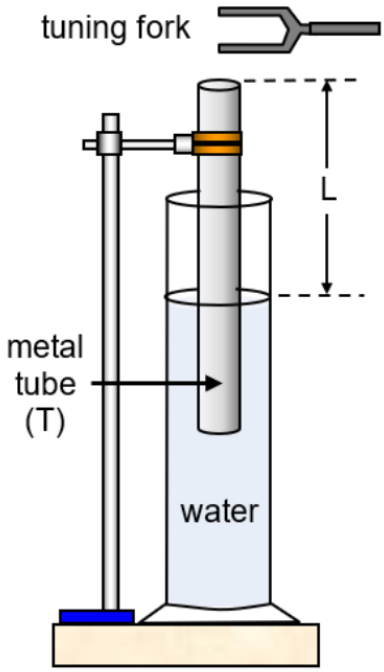


Figure 82: *Resonance tube with tuning fork*

1. Place the resonance tube in a vertical position with the open end facing upward.
2. Fill the container with water and submerge the closed end of the tube in the water. Adjust the water level so that the air column's length inside the tube can be varied by raising or lowering the tube.
3. Strike the tuning fork gently with a rubber mallet to produce a sound of a known frequency.
4. Hold the vibrating tuning fork near the open end of the resonance tube.
5. Slowly raise or lower the tube in the water to change the length of the air column until you hear the loudest sound (resonance). This occurs when the air column resonates with the frequency of the tuning fork.
6. Once resonance is achieved, measure the length of the air column from the water surface to the open end of the tube. This length corresponds to a quarter wavelength ($\lambda/4$) of the sound wave in the first resonance condition (fundamental frequency).
7. Record the frequency of the tuning fork (f) and the measured length of the air column (L).

   The speed of sound in air (v) can be calculated using the formula

   $v = \lambda f$

Since the first resonance length corresponds to λ/4, the wavelength (λ) can be found using:

$\lambda = 4l$

Therefore, the speed of sound in air is: $v = f \times 4l$

8. Repeat the experiment with different tuning forks of known frequencies to verify the consistency of your results.

LEARNING TASKS

1. Describe the process by which sound is produced by vibrating objects.
2. Identify the mediums through which sound can travel and compare their properties.
3. Define infrasonic, audio sonic, and ultrasonic sounds and state their frequency ranges.
4. Explain how an echo is formed when sound waves reflect off surfaces.

PEDAGOGICAL EXEMPLARS

1. **Talk for learning**
   - **a.** Explain sound as a longitudinal wave and demonstrate using a slinky by compressing and expanding it.
   - **b.** Facilitate a class-wide discussion comparing the speed of sound in solids, liquids, and gases. Discuss why the speed of sound varies across different states of matter.
   - **c.** Watch a video of a blind person using echolocation to 'see'.
     - i. Ask the learners to discuss how this works, and to feedback other applications of echolocation that they may know of.
     - ii. Ask the learners which other animals use echolocation, and whether we can hear these sounds. Link this to ultrasound, audio-sound and infrasound, giving the learners the definitions of each.
   - **d.** Explain the concept of resonance and use videos or equipment to demonstrate this.
2. **Enquiry-based learning/ Experiential Learning**
   - **a.** Ask learners to place their hands gently on their necks, specifically over their throat (oesophagus area). This helps them feel the vibrations when they produce sound. Have learners hum or produce a simple sound (like "ah" or "oo") while

feeling the vibrations with their hands. Encourage them to change pitch or volume to notice the differences in vibration intensity.

b. After a few minutes, let them have a discussion about what they felt. Ask questions like:

i. What did you notice about the vibrations when you changed the sound?

ii. How do you think this relates to how we produce different sounds when speaking or singing?

c. Strike a tuning fork with a rubber mallet and let learners observe the vibrations.

d. Use different materials (e.g., air, water, metal) to transmit sound. Have learners listen to the sound transmitted through each medium (e.g., placing a tuning fork in water vs. air).

e. Use a frequency generator to produce a sound frequence. Demonstrate sounds in different frequency ranges by slowly lowering and raising the frequency.

i. Have learners categorise sounds they hear from the generator based on their frequency ranges.

ii. Ask learners to raise their hand when they can hear the sound and to keep it raised until they can no longer hear it. Discuss factors which may affect peoples' ability to hear sounds of particularly high or low frequencies.

f. Create an echo by clapping hands or using a whistle near a wall or large open space. Have learners listen for the reflected sound. Use the formula to calculate the distance, using an average speed of sound in air (343m/s).

g. Set up and perform an experiment to determine to speed of sound in air using resonance tube. Let them watch a video if the items are not available.

Figure 83: *Video on experiment to determine to speed of sound in air using resonance tube*

3. Collaborative Learning

a. Learners using some local musical instruments such as drums, percussions, flute, horns and stringed instruments describe how sound is produced. Learners then discuss the longitudinal nature of sound.

b. Instruments should cut across the various ethnic groups. Opportunity for all to participate - be mindful of gender biased groupings and encourage peer teaching where applicable. Learners with some form of physical challenges should be assisted in the performance of the experiments.

c. Divide learners into small groups, assigning each group one state of matter: solid, liquid, or gas. Let each group research on the speed of sound in their assigned state of matter, factors affecting the speed of sound in that state and examples of materials in which the speed of sound can be measured.

KEY ASSESSMENT

Level 1

1. How is sound produced?
2. What is the range of frequencies for audio sonic sound?

Level 2

1. Why does sound travel faster in solids than in gases?
2. Calculate the depth of a valley if an echo is heard rebounding from its base 2 seconds after the sound is produced. (Speed of sound in air = 343 m/s).

Level 3

1. Using the concept of resonance, explain how to determine the speed of sound in air with a resonance tube experiment.
2. Describe the process of sound production and transmission and compare the speed of sound in solids liquids and gases.

Hint

*The recommended mode of assessment for week 21 is **role play**. Use the level 3 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 80 for more information on how to use role play to assess learners.*

Section 7 Review

Over the past two weeks, the study has delved into the fascinating world of waves and sound, uncovering fundamental principles and applications. The exploration began by examining the concept of waves, identifying different types and their properties, such as reflection, refraction, diffraction, interference, and polarisation. Waves were classified into categories: longitudinal, transverse, electromagnetic, mechanical, progressive, and stationary. Practical sessions focused on determining key wave parameters from sinusoidal signals, including amplitude, velocity, frequency, period, and wavelength, and learners deduced the wave equation from these parameters.

In the following week, the focus shifted to sound, a mechanical wave produced by vibrating sources. The production, nature, and transmission of sound were explored, emphasising how sound waves propagate through various media. Sound was classified into infrasonic, audible, and ultrasonic based on frequency. The formation of echoes was examined and applied to determine the depth of rivers. Finally, the concept of resonance was used to determine the speed of sound in air. These two weeks provided a comprehensive understanding of waves and sound, equipping learners with the ability to analyse wave behaviour and sound properties, laying the groundwork for more advanced studies in physics

SECTION 8: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Strand: Electric Fields, Magnetic Fields and Electronics

Sub-Strand: Digital Electronics

Learning Outcomes

1. *Distinguishing between digital and analogue signals and how digital systems work.*
2. *Distinguish between the working operations of analogue and digital systems as well as design and build a decision-making circuit.*
3. *Describe integrated circuits and design and build simple integrated circuits.*

Content Standards

1. Demonstrate and understanding of the basics of digital electronics
2. Demonstrate the understanding of logic gates and describe their output in a digital system.
3. Demonstrate knowledge and understanding of simple integrated circuits and be able to identify and construct them.

Hint

*Remind learners of the **end of semester examination** in week 24. Refer to **Appendix G** at the end of this section for Table of specification that will guide you to set the questions.*

INTRODUCTION AND SECTION SUMMARY

In this section, learners will explore key concepts in electronics and digital systems, including analogue and digital signals, basic logic gates, combinational logic circuits, Arduino microcontrollers, and integrated circuits. They will learn to distinguish between signal types, understand and apply logic gates, design and construct circuits, and explore the design and fabrication of ICs. The section integrates practical projects and historical context to enhance understanding. Differentiated instruction ensures that all learners engage with the content at their level, preparing them for advanced studies in electronics and digital systems.

The weeks covered by this section are:

Week 22: *Analogue and Digital Signals*

Learners will identify, describe, and analyse analogue and digital signals using various tools and techniques, such as oscilloscopes and digital simulation software. The binary number system and its application in digital systems will also be covered. This knowledge is essential for understanding advanced topics in electronics and digital communication systems. Learners will distinguish between analogue and digital signals, explain their graphical representations, and convert between these signals.

Week 23: *Logic*

This week introduces learners to the fundamental concepts of logic gates, including AND, OR, NOT, NAND, and NOR gates. Learners will use Boolean notation to write expressions, convert truth tables into Boolean expressions, and construct simple logic circuits. Historical context and technological advancements related to logic gates will also be explored. Learners will describe and explain the functions of basic logic and universal gates, construct truth tables, and design simple logic circuits. Additionally, learners will explore combinational logic circuits, their applications, and the fundamentals of microcontrollers, specifically Arduino. They will focus on designing and constructing various combinational logic circuits and applying Arduino microcontrollers to solve basic community challenges.

Week 24: *Integrated Circuits*

This week focuses on the design and fabrication of integrated circuits (ICs). Learners will identify different types of ICs, understand the design process, and fabricate simple ICs. The historical development and significance of ICs in modern electronics will be explored. Learners will describe the design and fabrication process of ICs and create simple integrated circuits.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Teachers will employ a variety of teaching methods to engage learners and ensure they understand key concepts in electronics and digital systems. The pedagogical approaches include experiential learning, collaborative learning, inquiry-based learning, and project-based learning.

Begin with visual representations and hands-on activities using oscilloscopes to differentiate between analogue and digital signals. Use digital simulation tools for practical understanding of binary number systems. Group activities will analyse signal types and convert between analogue and digital signals, ensuring differentiated instruction to provide scaffolding for learners who need it and challenging tasks for advanced learners.

Introduce basic logic gates and their symbols, followed by constructing truth tables and converting them into Boolean expressions. Use real-world examples to explore the historical context and technological advancements. Design and construct combinational logic circuits using Arduino microcontrollers to solve basic community challenges. Encourage learners to engage in practical projects that integrate theoretical knowledge with hands-on application.

Identify different types of ICs and understand the design process. Use educational kits and design software for practical design and fabrication of simple ICs. Group learners to work on designing and fabricating ICs, with additional resources and support for those who need it and more complex projects for advanced learners.

ASSESSMENT SUMMARY

Assessments will be diverse, including practical tasks, quizzes, projects, and written exams to evaluate learners' understanding and application of concepts in electronics and digital systems.

Quizzes and class discussions will assess understanding of analogue and digital signals, graphical representations, and conversions. Practical exams and projects will evaluate learners' ability to distinguish signal types, perform conversions, and apply binary systems.

Quizzes and peer reviews will assess knowledge of logic gates, truth tables, and Boolean expressions. Practical projects and written exams will evaluate learners' proficiency in designing and constructing logic circuits and applying Boolean algebra.

Class discussions and written assessments on the design process and historical significance of ICs will ensure learners' comprehension. Hands-on projects where learners design and fabricate simple ICs will be used, with performance recorded to ensure comprehensive evaluation of their skills in IC identification, design, and fabrication processes.

Overall, these assessments will ensure learners have a thorough understanding of the topics covered and can apply their knowledge practically.

WEEK 22

Learning Indicators

1. *Describe analogue and digital signals*
2. *Distinguish between pull-up and pull-down resistors*
3. *Describe and use the 7-segment display module*

FOCAL AREA 1: ANALOGUE AND DIGITAL SIGNALS

Analogue signals are characterised by their continuous, smoothly varying nature. Analogue signals represent numerical values of physical quantities as a continuous range of values between two extremes. For example, a visit to the hospital will require measuring your temperature as part of the triaging process. The thermometer to be used would have to operate from 0 to 100 °C, and your recorded temperature may be recorded as 37°C, 36.96°C, 36.958°C, or even 36.9579°C, depending on the accuracy of the measuring instrument.

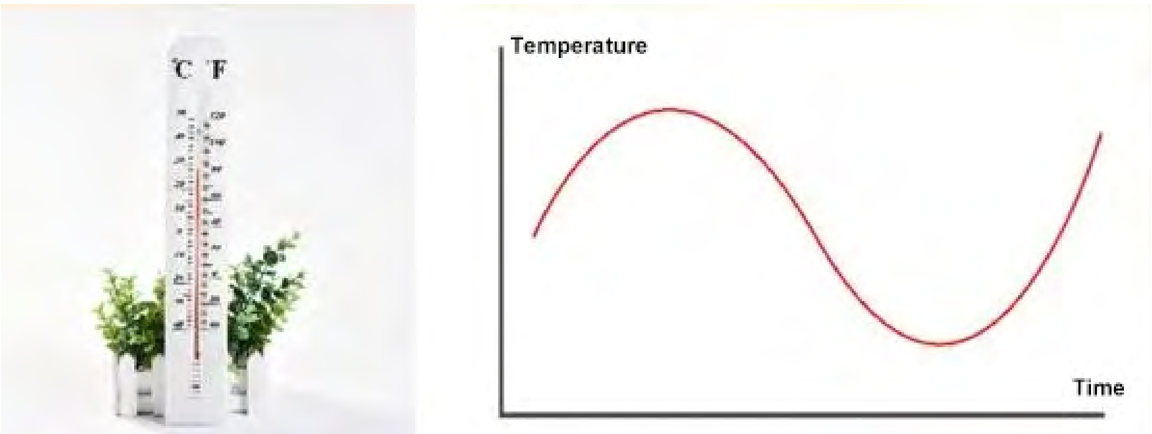


Figure 84: *The continuous curve of temperature to time*

Similarly, the voltage across a component in an electronic circuit could be measured as 6.5 V, 6.49 V, 6.487 V, or 6.4869 V. The key idea is that analogue values can take infinite possible values within the given range, providing a continuous output.

Unlike analogue signals, which have a smooth curve, digital signals convey information through steps or levels, allowing for precise representation and data transmission. They are discrete and comprised of specific, distinct values, typically represented in binary code (0s and 1s). For instance, the oven's temperature may be represented in whole degrees like 64°C, 65°C, 66°C, etc. In contrast to analogue displays, digital displays produce a discrete output, representing values in specific steps rather than a continuous range.

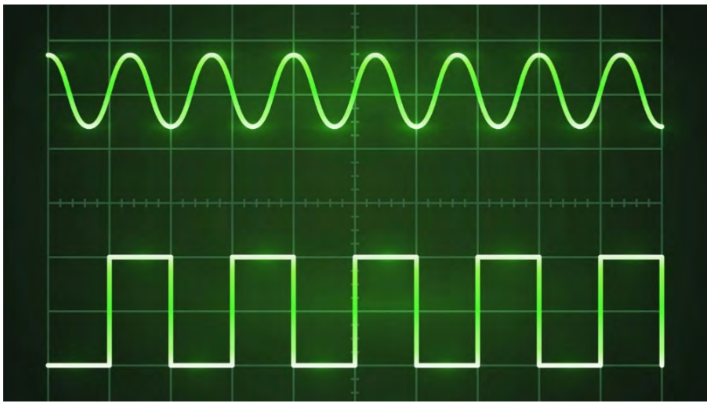


Figure 85: *Analogue (above) and digital (below) signals*

After the analogue-to-digital conversion process, each change/step in the signal has a corresponding specific value. No matter how many times it is copied or transmitted, signal loss can be greatly avoided if it corresponds to the original value. However, you must also be able to see that digital signals are "distorted" during the recording process. Like the image below, it is always different from the original image.

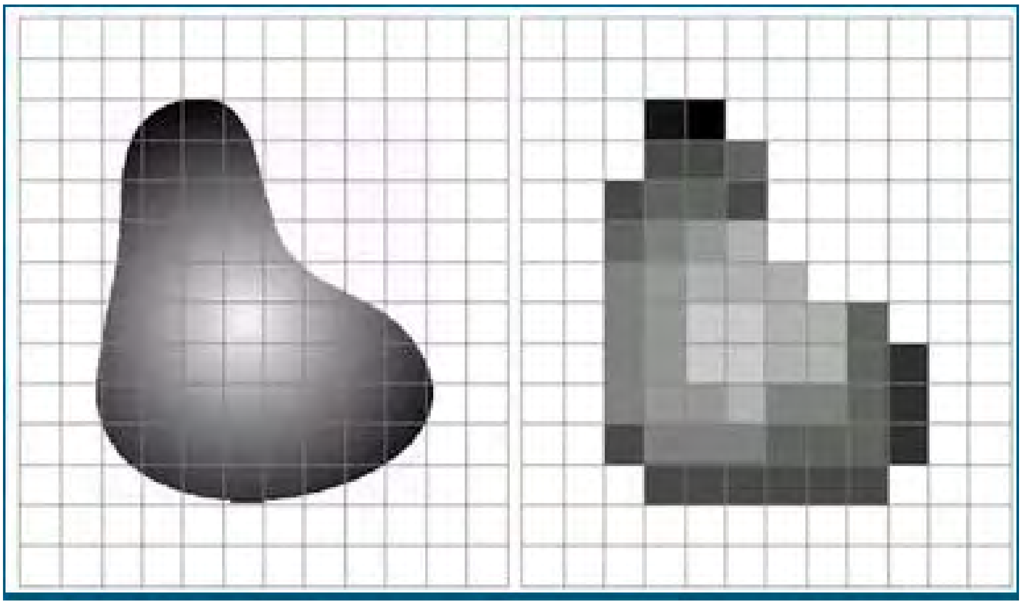


Figure 86: *Comparison between an analogue signal (left) and its digital copy (right)*

For example, when we listen to music, we will sometimes feel an obvious "digital flavour", which is also a manifestation of "distortion".

Converting from Analogue to Digital Signals and Vice Versa

To convert from analogue to digital signals or the reverse, follow this format:

1. **Analogue to digital conversion:** The process begins with sampling, which takes measurements of the analogue signal at regular intervals. The rate at which the samples are taken is called the sampling rate. Each sampled value is then rounded to the nearest value within a range of digital steps – quantisation. The number of bits

per sample determines the number of steps. The quantised values are then encoded into binary numbers, which digital systems can process and store.

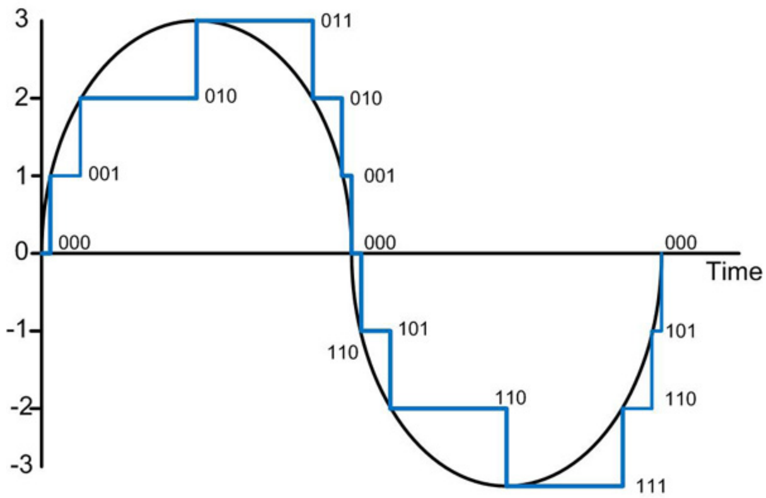


Figure 89: *An analogue and digital representation of a sine wave. Note that the digital samples are not evenly spaced in time, but the step or magnitude is equally divided.*

2. **Digital to analogue conversion:** The binary numbers are decoded into discrete levels. Interpolation converts these discrete levels into a continuous signal, approximating the original analogue signal.

	Advantages	Disadvantages
Analogue	Continuous, accurate, natural representation.	Prone to noise distortion, difficult to process, limited storage.
Digital	Noise-resistant, easy to process, high storage capacity.	Discrete representation, requires conversion, higher bandwidth needed.

Analogue signals are not useless or obsolete. The data collected in actual applications are all analogue signals, from sensors to signals to processes. Analogue signals are the basis of digital signals, and digital signals are the quantification of analogue signals. There is no distinction between superior and inferior, just different ways of expression.

Binary Number Systems and Conversion

We will begin our discussion on various number systems by briefly describing the parameters that are common to all number systems. Understanding these parameters and their relevance to number systems is fundamental to understanding how various systems operate. Different characteristics that define a number system include the number of independent digits used in the number system, the place values of the different digits constituting the number, and the maximum numbers that can be written with the given number of digits.

Among these characteristic parameters, the most fundamental is the number of independent digits or symbols used in the number system. It is known as the radix or base of the number system. The decimal number system with which we are all so familiar can have a radix of 10 as it has 10 independent digits, i.e., 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Similarly, the binary number system with only two independent digits, 0 and 1, is a radix-2 number system.

In the decimal number system, all higher numbers after '9' are represented in terms of these 10 digits. Writing higher-order numbers after '9' involves writing the second digit (i.e., '1') first, followed by the other digits, one by one, to obtain the next 10 numbers from '10' to '19'. The next 10 numbers, from '20' to '29', are obtained by writing the third digit (i.e., '2') first, followed by digits '0' to '9', one by one. The process continues until we have exhausted all possible two-digit combinations and reached '99'. Then, we begin with three-digit combinations. The first three-digit number consists of the lowest two-digit number followed by '0' (i.e., 100), and the process goes on endlessly.

The 'place values' of different digits in a mixed decimal number, starting from the decimal point, are 10^0, 10^1, 10^2 and so on.

The binary number system is a radix-2 number system with '0' and '1' as the two independent digits. All larger binary numbers are represented in terms of '0' and '1'. Starting from the binary point, the place values of different digits in a mixed binary number are 2^0, 2^1, 2^2 and so on.

The procedure for writing higher-order binary numbers after '1' is similar to the one explained in the case of the decimal number system. For example, the first 16 numbers in the binary number system would be 0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, and 1111. The next number after 1111 is 10000, the lowest binary number with five digits. This also proves the earlier point that a maximum of only 16 ($= 2^4$) numbers could be written with four digits.

Example:

The number 27 would be given as:

Place values	$2^4 = 16$	$2^3 = 8$	$2^2 = 4$	$2^1 = 2$	$2^0 = 1$
Binary code	1	1	0	1	1

$16 + 8 + 2 + 1 = 27.$

LEARNING TASKS

1. Describe and explain analogue and digital graphical displays using an oscilloscope.
2. Compare the advantages and disadvantages of analogue and digital signals.

3. Explain how signals can be converted from analogue to digital and vice versa.
4. Describe how the binary number system works and perform conversions between decimal and binary.

PEDAGOGICAL EXEMPLARS

1. **Experiential Learning**
   - **a.** Using an oscilloscope or signal generator or video (scan the QR Code below for a video), show learners real-time analogue signals (like sound waves) and their digital counterparts. Learners observe and sketch the waveforms and describe the key differences in what they see.
     - i. Instruct learners to follow safety procedures when using electronic equipment and avoid touching live circuits.

Figure 91: *YouTube video on analogue and digital signals*

   - **b.** Discuss with learners how analogue signals have a continuous range while digital signals consist of discrete steps. Ask learners to think-pair-share how these two different types of signal may have their own advantages and disadvantages. For groups that are struggling, give them some prompts such as 'storage' 'noise' and 'bandwidth'.
   - **c.** Record a sound using a microphone, play it back, and show its waveform in an audio editing software.
     - i. Explain how the sound is an analogue signal with continuous variations.
     - ii. Demonstrate how the sound can be digitised into a digital format (like MP3) and show the digital representation (binary data) in the software.
   - **d.** Teach learners the basics of binary numbers (0s and 1s). Give them a set of decimal numbers and have them convert these numbers into binary. Discuss how digital signals use these binary values to represent information in devices like computers and digital clocks.
   - **e.** Discuss sampling rate and bit depth in the digital conversion process; show the learners a worked example of this, linking the number of steps available during sampling to the binary conversion process.
   - **f.** Use visual aids and provide vocabulary lists to help learners understand technical terms.

2. Collaborative and Problem-based Learning

a. In small groups, create a detailed poster presentation on the conversion processes (analogue to digital and vice versa), including diagrams and examples. The groups should be provided with appropriate research resources and examples to support their work.

b. Ask learners to sketch analogue signal onto some graph paper (include an x-axis labelled from 0-10 seconds and a y-axis from 0 to 5V) and to swap it with their friend. They should then convert their friend's signal into a digital one using a sampling rate of 1 Hz and 3-bit coding.

   i. Provide a worked example of what this should look like for less able learners to refer to.

c. Provide a worksheet with a set of problems requiring them to convert from binary to decimal and vice versa.

d. Teach learners how to use their calculators to do these conversions.

e. Discuss how digital signals use these binary values to represent information in devices like computers and digital clocks. Provide worked examples for learners who need more support. Allow confident learners to create examples for others to use.

3. Enquiry-Based Learning

a. Use a digital simulation tool to show how analogue signals can be sampled and quantised into digital signals. Allow learners to adjust parameters like sampling rate and bit depth to see how these affect the quality of the digital signal. Follow all safety guidelines when using software tools.

b. Discuss real-world applications like how Ghana migrated from analogue to digital terrestrial TV. Learners should share experiences watching television content from any of these devices and describe how the analogue television will be able to receive digital TV content.

Figure 93: *Analogue and Digital Televisions*

c. Using gamification, let learners learn about how to convert decimal numbers to binary and the reverse. Scan the QR code below for a game on converting binary to decimal and reverse.

Figure 94: *Game on converting binary to decimal and reverse.*

KEY ASSESSMENT

Level 1: What digits are used in the binary number system?

Level 2: Why might digital signals be preferred over analogue signals in certain applications?

Level 3: The sound card's job is to act as a highly sensitive and accurate voltmeter, recording the voltage every set period. These measurements are passed to the computer software to save the recorded voltages. Given a scenario where a high-quality digital recording is needed, decide on the appropriate sampling rate and bit depth. Explain your choices.

Level 4: Investigate the historical development of the binary number system and its impact on modern computing. Present your findings with supporting evidence

FOCAL AREA 2: PULL-UP AND PULL-DOWN RESISTORS

Digital logic gates are the fundamental building blocks of any digital circuit. We can construct complex combinational circuits by using combinations of basic gates such as AND, OR, and NOT. These circuits operate with two logic states: high (1) and low (0). Different voltage levels represent these states, typically 0V for low (logic 0) and a higher voltage like +5V for high (logic 1).

Modern digital logic gates, integrated circuits (ICs), and microcontrollers contain multiple inputs (pins) and outputs, all of which need to be correctly set to high or low logic levels for the circuit to function as expected. If the inputs are not within the specified range for high or low states, the circuit might misinterpret the signals, leading to unpredictable behaviour.

When an input pin is left unconnected, it is in a floating or high-impedance state, which means it is not pulled to a definite logic level. This floating state can cause the input to pick up noise, leading to erratic or unpredictable digital circuit operation. For example, an unconnected input on a microcontroller can randomly be interpreted as either high or low, causing the microcontroller to behave unexpectedly. This is where pull-up and pull-down resistors come into play.

Consider a digital circuit with two switches, “a” and “b,” representing inputs to a generic logic gate. When the switch “a” is closed (ON), input “A” is connected to ground (0V), representing logic level “0” (LOW). Similarly, when switch “b” is closed (ON), input “B” is also connected to the ground, representing logic level “0” (LOW).

However, when switch “a” is open (OFF), the voltage applied to input “A” is undefined and may float between 0V and +5V (Vcc). This floating state can cause the digital input at “A” to remain at logic level “0” (LOW) when it should be at logic level “1” (HIGH), leading to false triggering of the logic gate

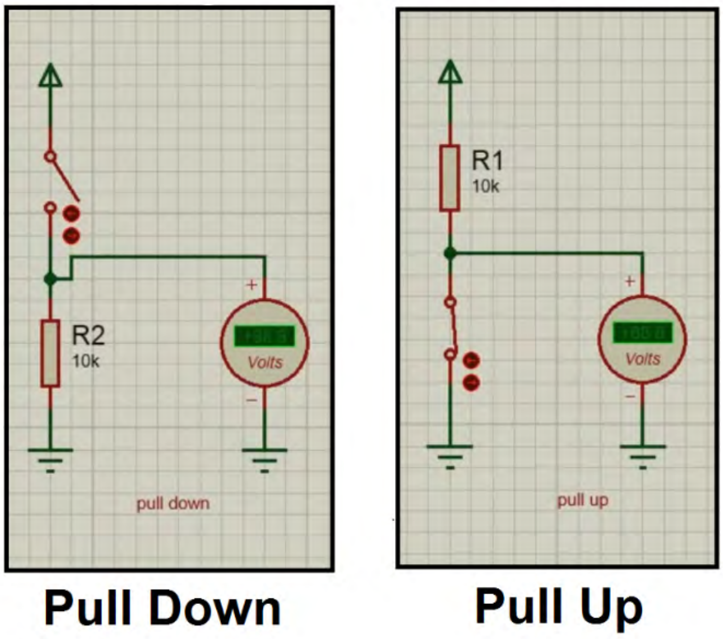


Figure 95: *Circuit diagrams of pull-down and pull-up resistors in use*

Pull-up resistors are used to prevent this. When switch “a” is open (OFF), the input is effectively connected to the +5V supply rail via the pull-up resistor, ensuring a high logic state. When switch “a” is closed (ON), the input is shorted to ground, creating a low logic state. This setup ensures that the input always has a default state, either “1” or “0,” preventing floating inputs and ensuring proper logic gate operation.

Similarly, pull-down resistors can be used when the default state needs to be low. For instance, if a button connects the input to a high voltage when pressed, a pull-down resistor ensures the input reads low when the button is not pressed, preventing floating inputs and false readings.

The QR code links to a YouTube video that further explains pull-up and pull-down resistors.

Figure 96: *YouTube video pull-up and pull-down resistors*

Applications of Pull-Up and Pull-Down Resistors

Pull Up	Pull Down
Buttons and switches: Make sure a computer knows when a button is pressed or released.	Inputs that are active when low: Make sure a computer know when something is turned off.
Computer communications: Keep communication lines stable.	Creating a reference voltage: Help the computer to measure other voltages.

Why use Pull-Up and Pull-Down Resistors?

Floating inputs can cause digital circuits to behave unpredictably. Pull-up and pull-down resistors ensure that inputs are always at a defined logic level, either high or low, preventing erratic behaviour. Digital circuits require correct logic levels for proper operation. Pull-up and pull-down resistors help maintain these levels, ensuring the circuit operates reliably.

LEARNING TASKS

1. Differentiate between pull-up and pull-down resistors.
2. Identify applications of pull-up and pull-down resistors.
3. Explain the importance of preventing floating inputs in digital circuits.
4. Construct and test simple circuits using pull-up and pull-down resistors.

PEDAGOGICAL EXEMPLARS

1. **Experiential Learning:**
   - **a.** Set up circuits with pull-up and pull-down resistors connected to the digital input pins of a microcontroller. Observe the behaviour of the input pins when the resistors are connected and disconnected. Ensure proper handling of components and adherence to safety protocols. Avoid short circuits while following the following steps:
     - i. Connect a pull-up resistor between the input pin and the +5V supply.

ii. Connect a pull-down resistor between the input pin and ground.

iii. Observe and record the voltage at the input pin when the switches are open and closed.

b. Discuss with learners how pull-up resistors pull the input to a high state and pull-down resistors pull the input to a low state. Provide worked examples and templates for learners needing additional support.

c. Provide learners with breadboards, resistors, and microcontrollers. Have them construct circuits with pull-up and pull-down resistors, then measure and record the voltage levels at different points in the circuits. Emphasise safety and proper handling of electrical components.

2. Collaborative Learning

a. Divide learners into small groups to research real-world applications of pull-up and pull-down resistors in digital circuits. Provide resources for research. Emphasise the proper use of internet resources and correct citation.

b. Each group creates a presentation on their findings, including diagrams and examples. Groups present their findings to the class. Assign roles within groups to ensure participation and provide questions to support discussion.

c. Provide a case study involving a circuit design problem where pull-up and pull-down resistors are required. Have groups analyse the problem and propose solutions.

i. Discuss the importance of avoiding floating inputs and how pull-up and pull-down resistors help achieve this. Use visual aids and vocabulary lists to assist learners.

ii. Discuss the solutions and the reasoning behind choosing pull-up or pull-down resistors. Provide templates for groups to record their thinking.

3. Enquiry-Based Learning

a. Show a video that explains the basic principles of pull-up and pull-down resistors with animations and diagrams illustrating their purpose, placement, and effect on digital circuits, and include real-world examples and simple circuit diagrams for better relatability.

b. Use simulation software to model circuits with pull-up and pull-down resistors. Allow learners to modify the circuits and observe the effects on the input pins. Guide learners to follow all safety guidelines when using software tools.

c. Discuss how changes in resistor values affect the behaviour of the circuit. Allow learners to explore different configurations and parameters.

KEY ASSESSMENT

Level 1: Name one application of a pull-down resistor.

Level 2: Describe the difference between a pull-up and a pull-down resistor.

Level 3: Compare the effects of using pull-up versus pull-down resistors in a microcontroller circuit. How does each configuration affect the input pin's behaviour?

Level 4: Investigate how the values of pull-up and pull-down resistors are chosen in different applications. Present your findings with a focus on design considerations and trade-offs

FOCAL AREA 3: 7-SEGMENT DISPLAY MODULE

A 7-segment display module is an electronic display device used for displaying decimal numerals and some alphabetic characters. It consists of seven LEDs (Light Emitting Diodes) arranged in a rectangular fashion, as well as an additional LED for a decimal point if needed. Each of the seven segments can be illuminated individually to form the numbers 0 through 9 and some letters, making it a simple and effective way to display numerical information in electronic devices.

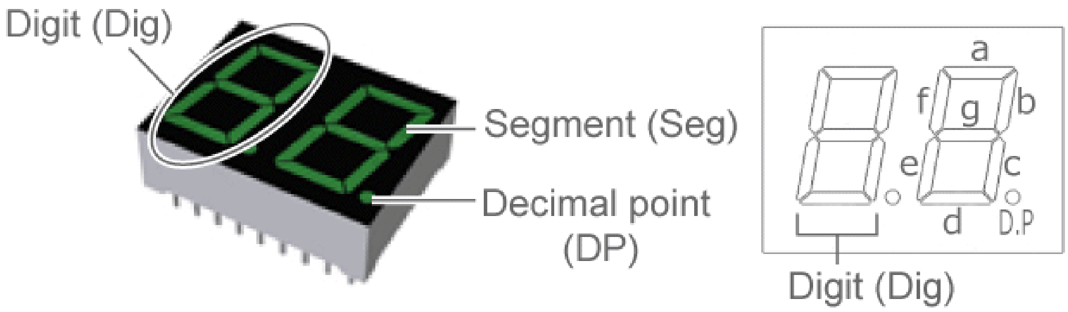


Figure 97: *Parts of the 7-segment display LED parts*

Structure and Function

The seven segments are labelled 'a' through 'g' and arranged to form a figure-eight pattern. An eighth segment, commonly called 'DP' (Decimal Point), is used to display decimal points.

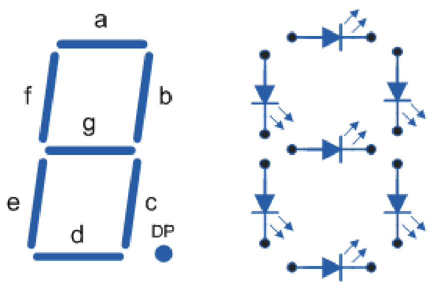


Figure 98: *7-Segment display decoder format*

There are two types of 7-segment LED digital display.

1. **Common Cathode (CC):** In this type, all the cathodes (negative terminals) of the LEDs are connected together and to the ground. To light up a segment, a positive voltage is applied to its anode (positive terminal).
2. **Common Anode (CA):** In this type, all the anodes (positive terminals) of the LEDs are connected together and to a positive voltage supply. To light up a segment, the cathode (negative terminal) of the segment is connected to the ground.

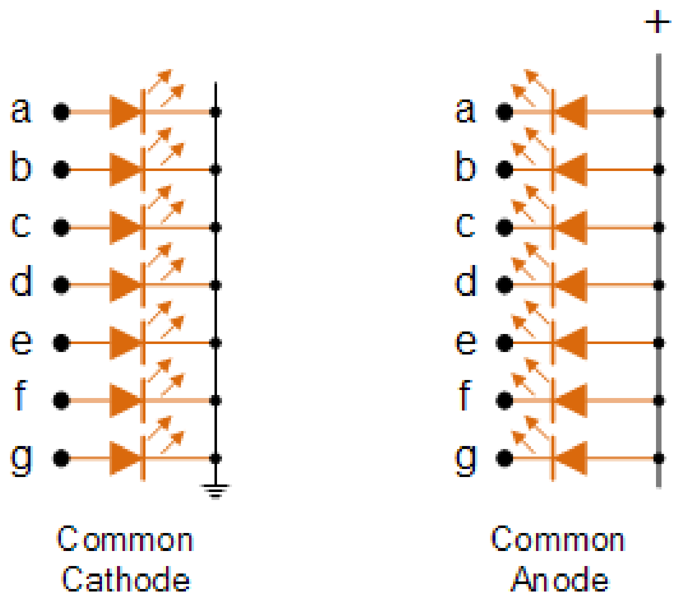


Figure 99: *Common cathode and common anode format*

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.

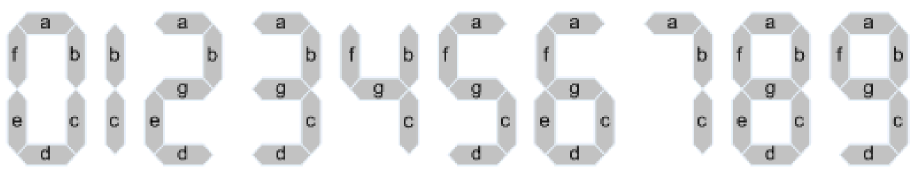


Figure 100: *7-Segment display elements for all numbers*

Some common applications include

1. Digital Clocks
2. Calculators
3. Meters
4. Counters
5. Household Appliances: Microwave ovens, washing machines, and other appliances to display settings and timers.

LEARNING TASKS

1. Identify the components and structure of a 7-segment display module.
2. Explain the difference between common cathode and common anode 7-segment displays.
3. Connect a 7-segment display module to a microcontroller and program it to display numbers.
4. Describe real-world applications of 7-segment display modules.

PEDAGOGICAL EXEMPLARS

1. **Teacher-led Learning:** Explain the structure of a 7-segment display module and the difference between Common Anode and Common Cathode devices.
2. **Experiential Learning**
   a. Provide learners with 7-segment displays, microcontrollers, and breadboards. Guide them in connecting the displays to the microcontrollers following these steps:
      i. Identify the type of 7-segment display (common anode or common cathode).
      ii. Connect the common pin (anode or cathode) to the appropriate voltage supply.
      iii. Connect each segment to the microcontroller output pins through current-limiting resistors.
      iv. Discuss the different combinations of segments required to display each numeral from 0 to 9.

Figure 101: *Video tutorial on setting up the 7-segment display with a microcontroller*

a. For more able learners, provide a set of problems requiring the display of specific sequences of numbers or letters. Learners write programs to display different sequences, such as counting up from 0 to 9 or displaying "HELLO", test and debug the programs. Demonstrate the working displays to the class.

b. In the absence of equipment, divide learners into mixed-ability groups and assign them to create a multi-digit display using 7-segment modules on a virtual interactive platform following these steps:

i. Design a circuit to control multiple 7-segment displays using multiplexing.

ii. Write a program to control the displays, ensuring they can show multi-digit numbers.

iii. Build and test the circuit, making sure the numbers are displayed correctly. Emphasise the importance of correct wiring and coding to prevent component damage.

Figure 102: *Tutorial on simulation*

iv. Each group presents their project and explains how they implemented multiplexing.

3. **Collaborative Learning:** Provide a case study of a real-world application of 7-segment displays, such as a digital clock or a calculator. In small groups of mixed ability, learners should analyse the design and implementation of the 7-segment display in these applications and should comment on the limitations of the 7-segment display.

4. **Enquiry-Based Learning**

a. Have learners research and compare 7-segment displays with other display technologies, such as LCDs and OLEDs. Ensure learners cite reliable sources and understand the practical implications of each technology.

b. Discuss the situations in which 7-segment displays are more suitable than other technologies.

KEY ASSESSMENT

Level 1: What is a 7-segment display module?

Level 2: How is the number '8' displayed on a 7-segment display?

Level 3: How would you troubleshoot the issue if one segment of a 7-segment display is not working?

Level 4

1. Investigate the latest advancements in display technologies. How do 7-segment displays compare to newer technologies like OLEDs and e-ink? Present your findings with a focus on future trends and applications.
2. Investigate the historical development of the binary number system and its impact on modern computing. Present your findings with supporting evidence.

Hint

*The recommended mode of assessment for week 22 is **group essay**. Use the level 4 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 74 for more information on how to use essay to assess learners.*

WEEK 23

Learning Indicators

1. *Describe the characteristics of basic logic and universal gates*
2. *Describe and explain sum of product in Boolean notation*
3. *Describe combinational logic applications and microcontrollers*

FOCAL AREA 1: BASIC LOGIC AND UNIVERSAL GATES

In digital systems, binary variables can have either of two states: logic '0' or logic '1'. These states are represented by two different voltage or current levels. If the more positive voltage or current level represents a logic '1' and the less positive level represents a logic '0', the logic system is referred to as a positive logic system. Conversely, if the more positive level represents a logic '0' and the less positive level represents a logic '1', the system is known as a negative logic system.

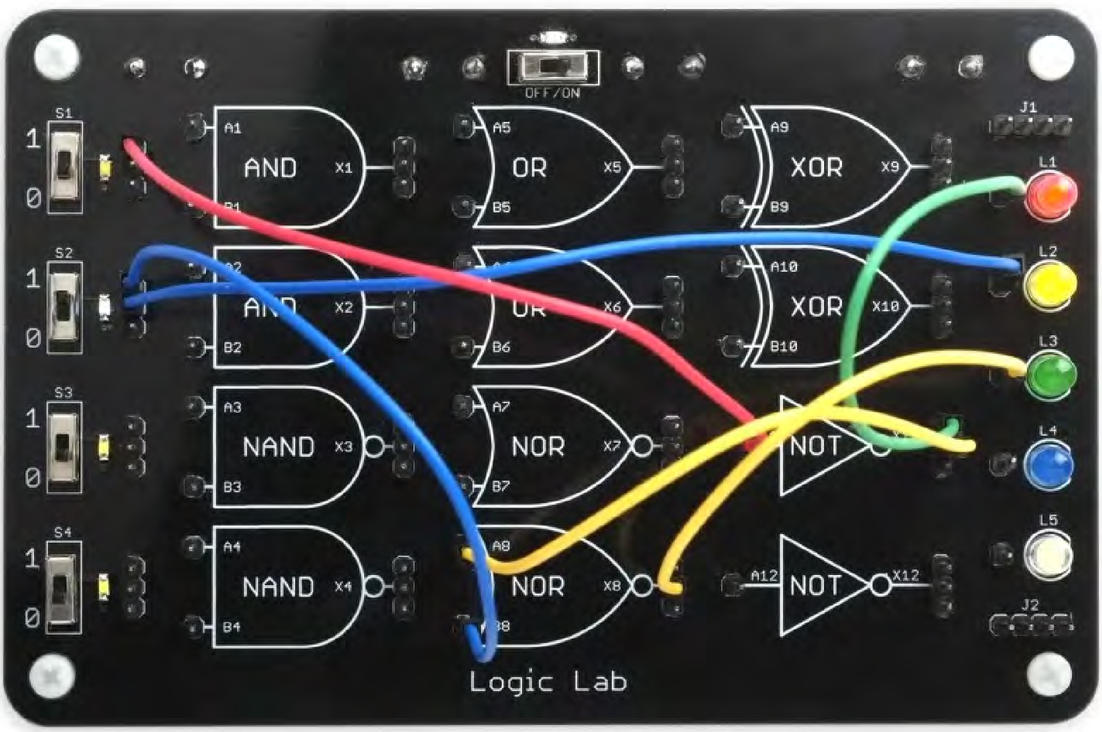


Figure 103: *A microcontroller with logic gates*

Truth Tables and Logic Gates

Logic gates are the most basic building blocks of any digital system, including computers. Each basic logic gate is an electronic circuit that performs a specific logical operation on one or more binary inputs to produce a single binary output.

The three fundamental logic gates are the OR gate, the AND gate, and the NOT gate. Boolean algebra helps in simplifying complex logic circuits, making them easier to design and understand. This simplification reduces the number of gates and components needed, which can save space and cost.

Functions of each gate

AND Gate: Outputs '1' only if all inputs are '1'. Otherwise, the output is '0'.

OR Gate: Outputs '1' if at least one input is '1'. If all inputs are '0', the output is '0'.

NOT Gate: Inverts the input signal. If the input is '1', the output is '0', and vice versa.

NAND Gate: Inverts the output of an AND gate. It outputs '0' only if all inputs are '1'; otherwise, it outputs '1'.

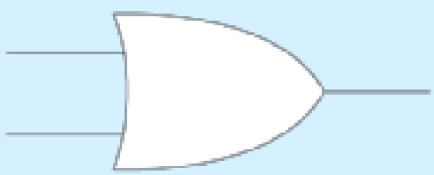
NOR Gate: Inverts the output of an OR gate. It outputs '0' if at least one input is '1'; otherwise, it outputs '1'.

Truth tables are essential tools in digital electronics for describing the function of individual and combinations of multiple logic gates. They list all possible combinations of input binary variables and the corresponding outputs of a logic system. The logic system output can be determined from the logic expression, often referred to as the Boolean expression, that relates the output with the system's inputs.

Input 1	Input 2	Output
0	0	0
0	1	0
1	0	0
1	1	1

Figure 104: *A diagram of an AND logic gate and its truth table*

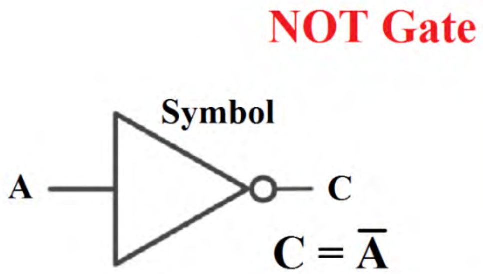
In Figure 104 the truth table shows the four possible input combinations (00, 01, 10 and 11) The output is governed by the rules for the AND logic gate which states it outputs 1 if both inputs are 1 otherwise the output is 0.



Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	1

Figure 105: *A diagram of the OR logic gate and its truth table*

The OR logic gate rule states if at least one input is 1 then the output is 1, if both inputs are 0 then the output is 0. Reading the truth table in the diagram shows this rule has been followed.



Truth Table

INPUT	OUTPUT
A	NOT A
0	1
1	0

Figure 106: *A diagram of the NOT logic gate and its truth table*

The rule followed by the NOT gate is simply to invert the input. There can only be one input, the output is either 0 or 1, depending on the input. This rule is clear from the truth table.

With three binary inputs, the number of possible input combinations increases to eight: 000, 001, 010, 011, 100, 101, 110, and 111. A truth table would have four columns and eight rows, including the output. The principle can be generalised: if a logic circuit has n binary inputs, its truth table will have 2^n possible input combinations or 2^n rows.

George Boole first introduced the concept of logic gates in the mid-19th century. Boole's work laid the foundation for the field of Boolean algebra, which is the mathematical basis for digital logic and computer science. In his groundbreaking 1937 thesis, Claude Shannon applied Boolean algebra to electrical circuits, demonstrating how logical operations could be performed using switches and relays. This work was pivotal in the development of digital circuits and computers.

Several Nobel Prize winners have significantly contributed to digital electronics and logic gates. John Bardeen, Walter Brattain, and William Shockley were awarded the Nobel Prize in Physics in 1956 for discovering the transistor, a crucial component in modern digital circuits and logic gates. Jack Kilby received the Nobel Prize in Physics in 2000 for inventing the integrated circuit, which contains multiple logic gates on a single chip, revolutionising electronics and computing.

Significant technological advancements have stemmed from the development of logic gates and digital circuits. The invention of integrated circuits (ICs) allowed for the miniaturisation and mass production of electronic components, leading to modern computers, smartphones, and other digital devices. The development of microprocessors, essentially complex ICs containing millions of logic gates, has enabled the advancement of computing technology, making it more powerful and efficient. Emerging technologies like quantum computing are building upon the principles of digital logic, exploring new ways to perform computations using quantum bits (qubits) that can represent multiple states simultaneously.

LEARNING TASKS

1. Describe truth tables and demonstrate the output of digital circuits based on input combinations.
2. Explain the functions of NOT, AND, and OR draw their symbols, and construct truth tables for each.
3. Research the following logic gates: NAND, NOR, XOR and XNOR. Construct their truth tables.
4. Design a circuit which includes an AND logic gate and a NOT logic gate which, given a high input, lights up an LED to show that the next patient in a hospital waiting room may visit the nurse. Circuit could be built using a breadboard and wires, LED, 2 logic gates, current limiting resistors, 5v power source, switch.

PEDAGOGICAL EXEMPLARS

1. **Experiential Learning**
   - **a.** Provide learners with breadboards, logic gate ICs, and other necessary components to build basic digital circuits. Guide learners in connecting the components according to the provided circuit diagrams. Assist learners with challenges. This tutorial video may be used to assist.

     Figure 107: *Tutorial video on creating a logic gate circuit on a breadboard.*

   - **b.** Instruct them to create circuits for NOT, AND, OR, NAND, and NOR gates by applying different input combinations and observing the outputs.
   - **c.** Have them observe the various combinations and record the outputs to create and confirm the truth tables. Ensure proper handling of electronic components and adherence to safety protocols to avoid damage where they will handle electronic components.

2. **Collaborative Learning**
   a. Divide learners into mixed-ability groups and assign each group a specific logic gate (e.g., NOT, AND, OR, NAND, NOR) to research the functions and applications of the logic gates.
      i. Learners identify a community need that can be addressed with a digital circuit (e.g., an automatic lighting system) and design and build a circuit using their assigned logic gates to meet the need.
      ii. Provide resources for research and encourage collaboration. Have each group create a presentation on their findings.
      iii. Emphasise the importance of citing reliable sources, properly handling components, and adhering to safety protocols.
3. **Inquiry-Based Learning**
   a. Introduce learners to the simulation tool. Have learners create circuits that use single and multiple logic gates (e.g., a NAND gate followed by a NOT gate).
   b. Learners observe and analyse the behaviour of the combined circuit.
   c. Learners discuss the implications of combining different logic gates and how they can be used to create more complex circuits. Follow guidelines for using the simulation tool to ensure accurate results.

KEY ASSESSMENT

Level 1: Draw the symbol for a NOT gate

Level 2: Explain the function of an OR gate with an example.

Level 3: Analyse the differences in the outputs of an AND gate and a NOR gate for all possible input combinations.

Level 4: Discuss the role of universal gates (NAND and NOR) in digital circuit design. Provide examples of how they can be used to implement other logic gates.

FOCAL AREA 2: BOOLEAN NOTATION

Boolean algebra is a mathematical framework that deals with binary variables, which can take on only two values: 0 and 1. These values hold logical significance rather than numerical meaning.

The operators in Boolean algebra are given special symbols

AND is given a dot (·)

OR is given a plus (+)

NOT is given an apostrophe (‘)

In a NOT logic gate an input reversed is often shown with a bar over it, so A' or $\overline{A}$ is the reverse of A. If A is 1 then A' is 0)

The Boolean expression for an AND gate is X = A · B

The Boolean expression for an OR gate is X = A + B

The Boolean expression for a NOT gate is X = A' (or $\overline{A}$)

The diagram below shows the symbols and expressions for four of the basic logic gates

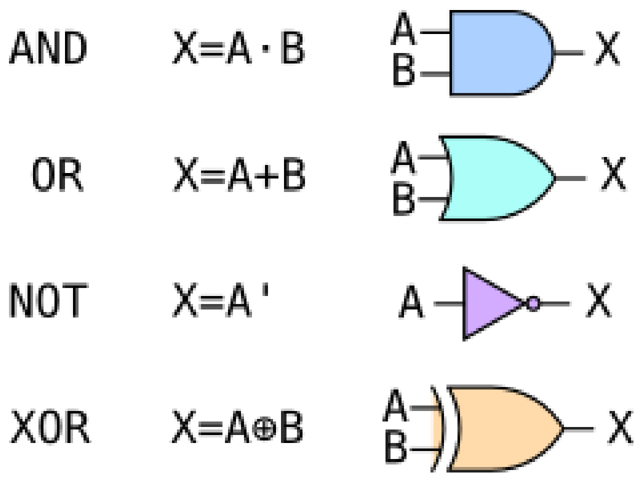


Figure 108: *Boolean expressions for basic logic gates*

Note:

XOR (⊕) is a gate which gives an output of 1 only if the inputs are different.

The following shows the truth tables for the four gates in Figure 108 given two inputs A and B.

Table 3: *Boolean truth table for AND, OR, NOT and XOR*

Input A	Input B	A· B (AND)	A + B (OR)	A' (NOT)	A ⊕ B (XOR)
0	0	0	0	1	0
0	1	0	1	1	1
1	0	0	1	0	1
1	1	1	1	0	0

Understanding and utilising Boolean expressions is crucial for designing and analysing digital electronic systems. In circuits with multiple logic gates a Boolean expression can be derived from the truth table. Given all the possible combinations of inputs in a truth table a Boolean expression that represents the circuit can be derived using the Sum of Products (SOP) method.

The following example shows how this is done:

Consider a truth table for a function (or output) F (A,B)

Input A	Input B	Output F
0	0	0
0	1	1
1	0	1
1	1	0

Convert this to SOP following these steps:

Identify rows with output 1 – rows 2 and 3

Write the product for these rows – Row 2 is $\overline{A} \cdot B$ and Row 3 is $A \cdot \overline{B}$

Combine the product terms using the OR operator ((+)): $F = (\overline{A} \cdot B) + (A \cdot \overline{B})$

The sum of these products (SOP) is $F = \overline{(A} \cdot B) + (A \cdot \overline{B)}$

This expression represents the logical function described by the truth table. In terms of electronics it is the specific configuration of logic gates that perform the desired operation to produce the output F.

More complicated Boolean expressions derived from truth tables representing combinational digital circuits can be simplified using a set of laws and theorems, including

the Identity Law, Null Law, Idempotent Law the Complement Law and Distributive Law. Applying these laws and theorems helps simplify the design of electronic circuits reducing the need for electronic components and therefore bringing down costs.

The Boolean expression $A \cdot B' + A \cdot B$ can be simplified to A by applying the distributive law and complement law.

When multiple logic gates are put together they form **combinational circuits.**

Consider the following combinational circuit:

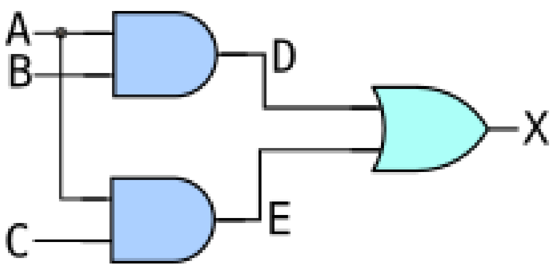


Figure 109: *Combinational circuit logic gates*

The truth table for the combinational circuit in figure 109 is shown in the table below, figure 110.

The three inputs have eight possible combinations.

From figure 109:

A and B are ANDed to produce D

A and C are ANDed to produce E

D and E are ORed to produce X

This produces the following truth table:

Table 4: *Boolean truth table for combination circuit*

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

Following the same procedure outlined above to find the sum of products the Boolean algebraic expression is $X = A{\cdot}B + A{\cdot}C$ and this corresponds precisely to the circuit diagram in figure 109.

Boolean algebra is fundamental to digital electronics and computer science. It is used to design and analyse digital circuits, simplify logic expressions, and ensure the efficient operation of digital systems. Some key applications include digital circuit design, computer algorithms, and data processing.

LEARNING TASKS

1. Write Boolean expressions for NOT, AND, OR, NAND, and NOR gates.
2. Convert truth tables (up to three inputs) using the Sum of Products method to derive a Boolean expression for a logic circuit.

PEDAGOGICAL EXEMPLARS

1. **Teacher-led Learning:** Explain the concept of truth tables and their importance in digital logic design and demonstrate how to construct a truth table for a single input (e.g., NOT gate) and multiple inputs (e.g., AND, OR gates).

2. Problem-based Learning

a. Provide learners with truth table templates and logic gate symbols and guide them through at least one worked example of constructing truth tables for NOT, AND, OR, NAND, and NOR gates.

b. Provide learners with a truth table for a three-input logic function, guide them through at least one worked example of identifying rows with output 1 and writing the corresponding product terms and combining the product terms to form the SOP expression.

c. Provide learners with different truth tables and have them convert these tables to SOP expressions independently. Provide additional support and worked examples for learners who need help and encourage confident learners to assist their peers.

3. Collaborative Learning

a. Divide learners into small groups and assign roles: leader, scribe, task manager, and presenter. Ensure groups are of mixed abilities to promote peer learning.

   i. Groups design simple digital circuits that could be used for practical applications in their community. *Example:* Design a digital lock system that opens when a specific combination of inputs is applied. Guide learners in writing the Boolean expression and constructing the corresponding digital circuit.

   ii. Groups present their findings and circuit designs to the class. Facilitate a class discussion on the different designs and their applications. Provide templates and guiding questions to support group discussions.

b. Check-in with each group to ensure participation and understanding. Ensure proper handling of components and adherence to safety protocols.

3. Enquiry-Based Learning

a. Introduce learners to a digital simulation tool. Demonstrate how to use the tool to create and analyse logic circuits.

b. Have learners create circuits that combine multiple logic gates (e.g., a NAND gate followed by a NOT gate). Learners observe and analyse the behaviour of the combined circuit and discuss the implications of combining different logic gates and how they can be used to create more complex circuits.

   i. Provide step-by-step guides and additional resources for learners who need help with coding and circuit design. Encourage peer support and collaboration. Follow guidelines for using the simulation tool to ensure accurate results.

KEY ASSESSMENT

Level 1: What is the Boolean expression for a NOT gate?

Level 2: Given the inputs A=1 and B=0, what is the output of a NAND gate?

Level 3: Compare the Boolean expressions for NAND and AND gates. How do their truth tables differ?

Level 4: Investigate the applications of Boolean algebra in modern computing. How do Boolean expressions facilitate the design and operation of computer processors? Present your findings with supporting arguments.

FOCAL AREA 3: LOGIC APPLICATIONS AND MICROCONTROLLER

Combinational logic circuits are fundamental components in digital electronics. They consist of logic gates arranged to produce specific outputs based on given inputs without relying on previous states or memory elements. These circuits are essential for performing arithmetic operations, data processing, and control functions in digital systems. Combinational logic circuits combine multiple logic gates to achieve a desired logical function.

Some common types of combinational logic circuits

Adders

1. ***Half Adder***: A half adder is a simple combinational circuit that adds two single-bit binary numbers, producing a sum and a carry. It consists of an XOR gate for the sum and an AND gate for the carry.
2. ***Full Adder***: A full adder adds three binary numbers (including a carry from a previous addition) and produces a sum and a carry. It uses two half-adders and an OR gate.

Multiplexers

A multiplexer (MUX) selects one of several input signals and forwards the selected input to a single output line. It is often used in communication systems to manage multiple data streams.

Decoders

A decoder converts binary information from ‘n’ input lines to a maximum of 2^n unique output lines. It is used in applications such as data demultiplexing and memory address decoding.

Encoder

An encoder performs the reverse operation of a decoder. It converts 2^n input lines to ‹n› output lines, providing a binary code corresponding to the active input.

These combinational circuits are crucial in constructing more complex digital systems, such as arithmetic logic units (ALUs), data path circuits, and control units.

Microcontrollers

Microcontrollers are compact integrated circuits designed to govern a specific operation in an embedded system. They include a processor, memory, and input/output (I/O) peripherals on a single chip. Arduino is a popular open-source platform based on easy-to-use hardware and software, making it ideal for creating interactive projects.

Figure 110: *Video on microcontrollers*

The features and characteristics of Arduino

1. Microcontroller**:** Arduino boards typically use Atmel AVR microcontrollers, such as the ATmega328. These microcontrollers include a CPU, flash memory, SRAM, and EEPROM.
2. Digital and Analog I/O Pins**:** Arduino boards have multiple digital and analogue I/O pins used to connect sensors, actuators, and other devices. Digital pins can be configured as input or output, while analogue pins can read variable voltage levels.
3. USB Interface**:** Arduino boards have a USB interface for programming and communication with a computer. The USB port also powers the board when connected to a computer.
4. Power Supply: Arduino can be powered through a USB connection or an external power supply. The board has an onboard voltage regulator to ensure a stable power supply.
5. Development Environment**:** The Arduino Integrated Development Environment (IDE) is a user-friendly platform for writing, compiling, and uploading code to the Arduino board. The IDE supports the C++ programming language with simplified functions for ease of use.

These can be applied in solving some challenges in the community, such as:

1. Automatic Street Lighting System: Design a system to automatically turn streetlights on at dusk and off at dawn using an Arduino and a light-dependent resistor (LDR).

2. Smart Irrigation System: Create an irrigation system that automatically waters plants based on soil moisture levels.
3. Home Security System**:** Develop a security system that detects motion and sounds an alarm.

LEARNING TASKS

1. Describe and explain the function of a given combinational logic circuit.
2. Describe an Arduino's features and characteristics and apply them to solve basic community challenges.

PEDAGOGICAL EXEMPLARS

1. **Teacher-led Learning**
   - **a.** Explain the function and importance of combinational logic circuits.
   - **b.** Explain the features and characteristics of Arduino microcontrollers.
   - **c.** Learners watch a video on the story of William Kamwamba and how he used physics to solve his community's challenges. Guide them through the theory of setting up and programming simple projects, such as automatic street lighting or smart irrigation systems. Provide learners with step-by-step guides for more complex projects. For example, develop a home security system using a PIR sensor and buzzer or create a temperature monitoring system using a temperature sensor and LCD.

Figure 111: *Video on William Kamkwamba and how he solved his community's challenges using physics*

2. **Experiential Learning**
   - **a.** Provide learners with breadboards, logic gate ICs, and other necessary components and guide them through building and testing circuits like half adders, full adders, and multiplexers. For example, construct a half adder circuit using XOR and AND gates or build a 4-to-1 multiplexer circuit.

b. Demonstrate how to set up an Arduino board and use the Arduino IDE. Provide learners with Arduino boards, sensors, actuators, and other necessary components.

c. Provide additional support and worked examples for learners who need help and encourage confident learners to assist their peers. Ensure proper handling of electronic components and adherence to safety protocols to avoid damage. Learners must follow guidelines for using Arduino components to ensure accurate results.

d. In the absence of practical equipment, introduce learners to a digital simulation tool. Demonstrate how to use the tool to create and analyse logic circuits.

i. Have learners create circuits that combine multiple logic gates (e.g., a full adder using two half adders and an OR gate) and observe and analyse the behaviour of the combined circuit.

ii. Introduce learners to basic coding concepts using a platform like Arduino or a digital logic simulator. They also write simple code to implement the Boolean expressions and test their circuits; for example, they write code to implement a smart irrigation system using Arduino.

iii. Provide step-by-step guides and additional resources for learners who need help with coding and circuit design. Encourage peer support and collaboration. Follow guidelines for using the simulation tool and Arduino components to ensure accurate results.

3. Collaborative Learning

a. Divide learners into small groups and assign roles: leader, scribe, task manager, and presenter. Ensure groups are of mixed abilities to promote peer learning.

b. Assign each group a specific combinational logic circuit to research (e.g., adders, multiplexers, decoders). Provide resources for research and encourage collaboration.

c. Groups design simple digital circuits and Arduino-based projects that could be used for practical applications in their community. For example: Design an automatic street lighting system using Arduino.

d. Guide learners in writing the Boolean expression for their circuit. If the equipment is available, learners could construct the corresponding digital circuit, and programme the Arduino.

e. Groups present their findings and project designs to the class. Facilitate a class discussion on the different designs and their applications. Provide templates and guiding questions to support group discussions. Check-in with each group to ensure participation and understanding.

KEY ASSESSMENT

Level 1: List two types of I/O pins on an Arduino board.

Level 2: Explain how a 4-to-1 multiplexer selects its output based on the input signals and selection lines.

Level 3: Analyse the advantages of using Arduino in community projects compared to traditional electronic circuits.

Level 4

1. Discuss the role of combinational logic circuits in modern computing. Provide examples of how these circuits are used in computer processors and other digital device.
2. You have a circuit that requires multiple transistors, resistors, and capacitors. Explain how using an integrated circuit could simplify your design.

Hint

*The recommended mode of assessment for week 23 is **homework**. Use the level 4 question 2 as a sample question and the Teacher Assessment Manual and Toolkit page 46 for more information on how to go about the homework.*

WEEK 24

Learning Indicators

1. *Describe simple integrated circuits*
2. *Design and describe the fabrication of a simple integrated circuit*

FOCAL AREA 1: SIMPLE INTEGRATED CIRCUIT

Integrated circuits (ICs) are fundamental components in modern electronics, combining numerous transistors, resistors, capacitors, and other components into a single chip to perform complex functions. The development of ICs has revolutionised electronics by enabling the miniaturisation of circuits, reducing power consumption, and increasing reliability and performance. ICs are used in various applications, including computers, smartphones, home appliances, and industrial equipment.

Figure 112: *Video on introduction to ICs*

In this theme, we will explore the process of designing and fabricating a simple integrated circuit. The aim is to provide teachers with the knowledge and tools to help learners identify simple ICs using charts, describe the design and fabrication process, and design and fabricate a simple IC. By understanding these processes, learners will gain insight into the intricacies of modern electronics and develop highly relevant skills in today's technology-driven world.

Integrated circuits come in various types and packages, each designed for specific applications. Common types include digital ICs (such as logic gates and microcontrollers), analogue ICs (such as operational amplifiers and voltage regulators), and mixed-signal ICs (combining both digital and analogue functions).

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.

Designing and Fabricating a Simple IC

Designing and fabricating a simple IC can be achieved through educational kits and software tools that simulate the IC design process. Learners can use these tools to design a basic digital or analogue circuit, such as a simple logic gate or amplifier. However, in the absence of this software, some IC could be replicated using breadboards and components.

Steps to Replicate an IC on a breadboard

1. **Understand the IC's Function:** Obtain the datasheet for the IC to understand its pin configuration, internal circuitry, and functionality.
2. **Gather Components:** Collect all the necessary discrete components (resistors, capacitors, transistors, etc.) that replicate the internal circuitry of the IC.
3. **Create a Schematic:** Draw a schematic diagram of the IC's internal circuit. This will help plan the layout on the breadboard (often on the datasheet)
4. **Assemble the Circuit:** Place the components on the breadboard according to the schematic. Use jumper wires to make the necessary connections.
5. **Power the Circuit:** Connect the power supply to the breadboard, ensuring the correct voltage levels as specified in the IC's datasheet.
6. **Test the Circuit:** Verify the output of the breadboard circuit against the expected output of the IC to ensure it functions correctly. This could be achieved by using a multimeter to compare the output of the IC on the breadboard to the IC.

LEARNING TASKS

1. Identify simple integrated circuits using charts.
2. Describe the process of design and fabrication of integrated circuits.
3. Design and fabricate a simple IC.

PEDAGOGICAL EXEMPLARS

1. **Teacher-led Learning**
   a. Explain the different types of ICs and their applications using charts and diagrams. Demonstrate how to identify ICs based on their markings and packaging.

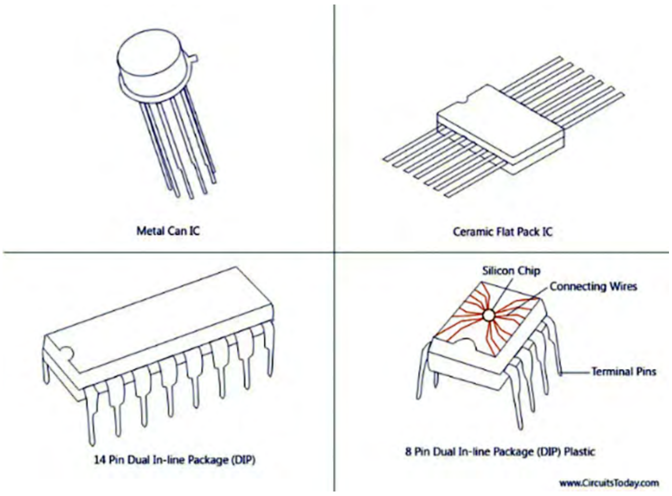


Figure 113: *Types of ICs*

- **a.** Provide learners with various ICs and charts. Guide them through the process of identifying each IC and understanding its function.
- **b.** Introduce learners to IC design software. Guide them through designing a simple IC, such as a logic gate or amplifier, and simulating its operation.

2. Experiential Learning

- **a.** Provide kits for constructing and testing their IC designs on a breadboard or prototyping platform. Assist learners in assembling and testing their circuits.
- **b.** Provide additional resources and one-on-one assistance for learners who need help with identification, design, or fabrication. Ensure learners handle electronic components carefully and follow safety protocols.

2. Collaborative Learning

- **a.** Divide learners into small groups and assign roles: leader, scribe, task manager, and presenter. Ensure groups are of mixed abilities to promote peer learning.
- **b.** Assign each group a specific aspect of IC design and fabrication to research (e.g., circuit design, layout design, fabrication techniques). Provide resources for research and encourage collaboration. Each group creates a presentation on their findings.
- **c.** Groups design simple ICs that could be used for practical applications in their community. Example: Design a simple logic gate or amplifier IC. Guide learners in writing the design specifications, creating the schematic and layout, and simulating the IC.
- **d.** Groups present their findings and IC designs to the class. Facilitate a class discussion on the different designs and their applications.

e. Provide templates and guiding questions to support group discussions. Check in with each group to ensure participation and understanding. Ensure proper handling of components and adherence to safety protocols.

3. Enquiry-Based Learning

a. Introduce learners to IC design software and tools. Demonstrate how to use the tools to create and simulate IC designs.

Figure 114: *Simulation laboratory for electronics*

b. Have learners research different IC fabrication techniques (e.g., photolithography, doping, etching). Discuss the advantages and limitations of each technique.

c. Learners write simple code to implement their IC designs and simulate the operation using design software. Example: Write code to design a simple logic gate or amplifier IC.

Figure 115: *Video on programming ICs with Arduino*

d. Provide step-by-step guides and additional resources for learners who need help with coding and IC design. Encourage peer support and collaboration. Follow guidelines for using the design software and tools to ensure accurate results.

KEY ASSESSMENT

Level 1: List two common applications of integrated circuits.

Level 2: You have a circuit that requires multiple transistors, resistors, and capacitors. Explain how using an integrated circuit could simplify your design.

Level 3: Analyse the role of integrated circuits in the development of modern computing devices.

Level 4: Explore the environmental impact of electronic waste (e-waste) and propose solutions to mitigate these effects.

Hint

The recommended mode of assessment for week 24 is ***end of semester examination****.*
Refer to ***Appendix G*** *for a table of specification to guide you to set the questions.*

Section 8 Review

This section covered essential concepts in electronics and digital systems, including analogue and digital signals, logic gates, combinational logic circuits, Arduino microcontrollers, and integrated circuits. Learners distinguished and converted signal types, applied binary systems, and explored logic gate functions and truth tables. They designed and constructed simple digital circuits and engaged in practical projects using Arduino to solve real-world problems. The study of integrated circuits included identification, design, and fabrication activities, with historical context provided for deeper understanding. Differentiated instructioªn allowed all learners to engage with the content at their level, while advanced learners tackled more complex tasks. Overall, learners gained a comprehensive understanding of these fundamental topics, preparing them for more advanced studies in electronics and digital systems.

APPENDIX G: END OF SEMESTER EXAMINATION

Structure

SECTION A – 40 Multiple Choice Questions – 45 mins (40 marks)

SECTION B -1hr 15mins (60 Marks)

Part 1 – 6 Questions; Answer All [Simple DoK Level 1 and 2 questions for 15 marks]

Part 2 – 4 Questions; Answer 3 [DoK Level 2 and 3 questions for 45 marks]

Table of Specification

Week	Learning Indicator	Type of Question	DoK Level				Total
			1	2	3	4	
13	Resolve vectors into their components.	MCQ	2	2	-	-	**4**
		Essay	-	1	-	-	**1**
14	State principle of flotation.	MCQ	1	-	-	-	**1**
		Essay	-	-	1	-	**1**
15	Distinguish elastic deformation from plastic deformation.	MCQ	1	1	1	-	**3**
		Essay	-	1	-	-	**1**
16	Calculate the energy stored in an elastic material.	MCQ	1	1	2	-	**4**
		Essay	-	-	1	-	**1**
17	Calculate the specific heat capacities of substances.	MCQ	2	3	2	-	**7**
		Essay	-	-	-	-	**-**
18	Explain latent heat of fusion and vaporisation and specific latent heat of fusion and vaporisation.	MCQ	2	1	1	-	**4**
		Essay	1	-	-	-	**1**
19	State Coulomb's law of electrostatics and calculate electrostatic force acting on the charges.	MCQ	1	1	1	-	**3**
		Essay	1	-	-	-	**1**
20	Define and calculate potential difference.	MCQ	-	2	-	-	**2**
		Essay	-	-	1	-	**1**

Week	Learning Indicator	Type of Question	DoK Level				Total
			1	2	3	4	
21	Determine the effective capacitance of a number of capacitors arranged in series and in parallel.	MCQ	1	1	1	-	**3**
		Essay	-	1	-	-	**1**
22	Determine the effective capacitance of a number of capacitors arranged in series and in parallel.	MCQ	-	2	1	-	**3**
		Essay	-	-	1	-	**-**
23	State the laws of photoelectric effect.	MCQ	1	1	-	-	**2**
		Essay	-	1	-	-	**1**
24	Calculate the half-life of a radioactive sample.	MCQ	1	1	2	-	**4**
		Essay	-	-	-	-	-
Total			**15**	**20**	**15**	-	**48**

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LINKS OF IMAGES

No.	Name of Image	Reference (link)
1	Figure 6: Experiment to measure the density of an irregular solid	*https://www.sciencephoto.com/media/981020/view/measuring-the-density-of-an-object-illustration*
2	*Figure 7: Aerial view of Lake Bosomtwe*	*https://www.researchgate.net/profile/John-King-29/publication/229720686/figure/fig4/AS:668748935602189@1536453579693/An-aerial-photograph-of-Lake-Bosumtwi-from-the-southeast-taken-in-September-2004.png*
3	Figure 11: Comparison of objects and the buoyant force acting on them	*https://t4.ftcdn.net/jpg/05/00/63/21/240_F_500632168_o80Lcpszfe3qCdbmDsIXWhFtbUOpRqzy.jpg*
4	Figure 2 : Components of the vector F applied on the football	https://senecalearning.com/en-GB/revision-notes/a-level/physics/aqa/4-1-2-vector-problems
5	Figure 4: Parallelogram Method of resolving vectors	*https://qph.cf2.quoracdn.net/main-qimg-7366d8ec4fa3d82a5ea60e5e9b8edd6c-lq*
6	Figure 14: Types of stress that produce deformation of the Earth's crust	*Fig 13 : Jones, N.W., and C.E. Jones. Laboratory Manual for Physical Geology. McGraw Hill, 2003.* https://books.google.com.gh/books?id=vJruAAAAMAAJ
7	Figure 16: The Adomi Bridge at Atimpoku, Eastern Region of Ghana.	*https://www.shutterstock.com/image-photo/adomi-bridge-atimpoku-ghana-january-23-1961684620*
8	Figure 18: A material's Young's modulus is equal to the slope of its stress-strain curve in the elastic region	https://efficientengineer.com/wp-content/uploads/stress-strain-youngs-modulus2.jpg

No.	Name of Image	Reference (link)
9	Figure 19: Determination of the specific heat capacity of a solid by method of mixtures	QUANTITY OF HEAT - Form 3 Physics Notes | Easyelimu
10	Figure 22 : determination of the specific latent heat of fusion of ice by method of mixtures.	What is Calorimetry? - revisionug.com
11	Figure 25: Lines of force associated with a positively charged sphere in isolation.	https://byjus.com/physics/electric-field-lines/
12	Figure 26: Lines of force associated with a negatively charged sphere in isolation	https://byjus.com/physics/electric-field-lines/
13	Figure 27: Lines of force associated with two like point charges of equal amplitude	https://byjus.com/physics/electric-field-lines/
14	Figure 28: Lines of force associated with two unlike point charges of equal amplitude	https://byjus.com/physics/electric-field-lines/
15	Figure 30: A drawing of Coulomb's torsion balance, which he used to measure the electrical force between charged spheres	Coulomb (martinezwritings.com)
16	Figure 31: Parallel conducting plates	https://openstax.org/books/college-physics-2e/pages/19-2-electric-potential-in-a-uniform-electric-field
17	Figure 32: Capacitor	Electrolytic Capacitor Use and Design | Advanced PCB Design Blog | Cadence
18	Figure 35: Capacitors in series	What is grouping of Capacitors? (thebigger.com)

No.	Name of Image	Reference (link)
19	Figure 36: Capacitors in parallel	What is grouping of Capacitors? (thebigger.com)
20	Figure 39: Instead of a photographic film, a digital camera uses a CCD to capture images	https://www.keyence.com/Images/cooled-ccd_feature_thum_2100262.jpg
21	*Figure 41: The diagrammatic representation of the projectile motion of a projectile*	What is Projectile Motion? Definition, Concepts, and Formulas (atlearner.com)
22	*Figure 43: Friction*	Types of Friction - GeeksforGeeks
23	*Figure 44: Static and Sliding Friction*	Different type of friction – വ്യത്യസ്ത തരം ഘർഷണം – Endz
24	*Figure 46: Images of some examples of circular motion*	Circular Motion: Definition, Formula, and Examples (geeksforgeeks.org)
25	*Figure 47: Schematic diagram of circular motion*	Angular Displacement - Definition, Units, Examples and FAQs (byjus.com)
26	*Figure 48: Banked road curve*	Category:Banked road curves - Wikimedia Commons
27	*Figure 49: Image of car negotiating a turn*	Banking Of Roads And Angle Of Banking Definition And Derivation (byjus.com)
28	*Figure 50: Tubular Centrifuge*	Separators: High Speed Tubular Centrifuge - GN Separation Equipment Manufacturer
29	*Figure 51: Schematic diagram of centrifuge*	Centrifuge - Bottle, Separation, Rotor | Britannica
30	*Figure 53: Large Capacity Amusement Park Swing Rides*	Amusement Park Swing Rides for Sale - Beston Rides (bestonamusementparkrides.com)
31	*Figure 54: Magnetic field around a current carrying conductor*	

No.	Name of Image	Reference (link)
32	*Figure 55: Magnetic field around a conductor when you look at the conductor from one end. (a) Current flows out of the page and the magnetic field is counter-clockwise. (b) Current flows into the page and the magnetic field is clockwise.*	https://www.siyavula.com/read/za/physical-sciences/grade-11/electromagnetism/images/4e218d38478f644a067aa9a72092eda1.png
33	*Figure 56: Magnetic field around parallel conductors with the same and opposite direction*	https://www.physics.louisville.edu/cldavis/phys111/notes/mag_2wires.gif
34	*Figure 57: Magnetic field due to a current through a circular loop*	https://search-static.byjusweb.com/question-images/toppr_ext/questions/198800_180239_ans.gif
35	*Figure 59: Fleming's Left Hand Rule mnemonic*	https://www.tutoroot.com/blog/wp-content/uploads/2022/08/flemings-right-and-left-hand-rule-2.d4511ce.jpg
36	*Figure 62: Torque on a current loop*	https://openbooks.lib.msu.edu/app/uploads/sites/11/2019/07/Figure_23_08_01a.jpg
37	*Figure 63: DC moving coil galvanometer*	https://www.eiscolabs.com/cdn/shop/products/PH1084D_1184x1280.jpg?v=1571438818
38	*Figure 65: Calculating the torque on a coil*	https://images.nagwa.com/figures/explainers/519142828465/7.svg
39	*Figure 66: An electromagnetic switch*	https://www.topmaq.co.nz/content/prod-ucts/10a-electromagnetic-switch-kjd6-el-mi3100-elmi3100a.jpg?crop=1:1&auto=web-p&optimize=high&width=896
40	*Figure 71: An aerial view of CERN's Large Hadron Collider circumference of 27km*	https://imageio.forbes.com/specials-images/imageserve/577c1291d7c6ee6a37c42063/An-aerial-view-of-CERN--with-the-Large-Hadron-Collider-s-circumference-outlined-/960x0.jpg?format=jpg&width=1440
41	Figure 73: Water ripples	Ripples in the Water.. I went for a walk the other day as it… | by Taylor J. Bottles | Medium

No.	Name of Image	Reference (link)
42	Figure 74: Diagram representing reflection of wave	*http://www-b.jpl.nasa.gov/basics/*
43	Figure 75: Diagram representing refraction of wave	Refraction of waves I Article about Refraction of waves by The Free Dictionary
44	Figure 76: Diagram representing diffraction	schoolphysics ::Welcome::
45	Figure 77: Constructive and destructive interference	Constructive Interference - Wave Interference, Types, Explanation, and FAQs (byjus.com)
46	Figure 78: Diagram representing polarisation of wave	Polarization of Light - Definition, Types, Methods, & Applications (byjus.com)
47	Figure 79: Transverse and Longitudinal wave	1: Longitudinal and transverse waves. I Download Scientific Diagram (researchgate.net)
48	Figure 81: Parts of a transverse wave	Parts of a transverse wave in physics. The basic properties of waves. Crest, trough, amplitude and wavelength. Vector illustration isolated on white background. Stock Vector I Adobe Stock
49	Figure 82: Resonance tube with tuning fork	schoolphysics ::Welcome::
50	Figure 84: The continuous curve of temperature to time	https://ueeshop.ly200-cdn.com/u_file/UPAH/UPAH886/2402/photo/c525913d20.jpg
51	Figure 85: Analogue (above) and digital (below) signals	https://www.redsharknews.com/hubfs/Analogue_vs_Digital.jpg
52	Figure 86: Comparison between an analogue signal (left) and its digital copy (right)	https://ueeshop.ly200-cdn.com/u_file/UPAH/UPAH886/2402/photo/417d2fdb8b.jpg

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53	Figure 89: An analogue and digital representation of a sine wave. Note that the digital samples are not evenly spaced in time, but the step or magnitude is equally divided.	https://screaminfx.com/images/tech-images/what-is-analog-verse-digital-explanation.jpg
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57	Figure 95: Circuit diagrams of pull-down and pull-up resistors in use	https://circuits-diy.com/wp-content/uploads/2019/09/pull-up-pull-down-resistor.png
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60	Figure 99: Common cathode and common anode format	https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/combination-comb40.gif
61	Figure 100: 7-Segment display elements for all numbers	https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/combination-comb18.gif
62	Figure 103: A microcontroller with logic gates	https://hackaday.com/wp-content/uploads/2023/08/logic-main.jpg?w=800

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63	Figure 104: A diagram of an AND logic gate and its truth table	https://cdn.ttgtmedia.com/rms/onlineimages/diagram1-f.png
64	Figure 105: A diagram of the OR logic gate and its truth table	https://cdn.ttgtmedia.com/rms/onlineimages/diagram2-f.png
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66	Figure 108: Boolean notation	https://liucs.net/cs101f16/bool-gates.png
67	Figure 109: Combinational circuit logic gates	https://liucs.net/cs101f16/circuit-ab-or-ac.png
68	Figure 114: Types of ICs	https://www.circuitstoday.com/wp-content/uploads/2009/09/IC-Types.jpg