MINISTRY OF EDUCATION

PHYSICS

For Senior High Schools

TEACHER MANUAL



YEAR THREE

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

PHYSICS

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

PHYSICS

For Senior High Schools

Teacher Manual

Year Three

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

PHYSICS TEACHER MANUAL

Enquiries and comments on this manual should be addressed to:

The Director-General
National Council for Curriculum and Assessment (NaCCA)
Ministry of Education
P.O. Box CT PMB 77
Cantonments Accra

Telephone: 0302909071, 0302909862

Email: info@nacca.gov.gh

website: www.nacca.gov.gh

©2026 Ministry of Education

This publication is not for sale. All rights reserved. No part of this publication may be reproduced without prior written permission from the Ministry of Education, Ghana.

Contents

INTRODUCTION VII

ACKNOWLEDGEMENTS IX

SECTION 1: MOMENTS AND GRAVITATION 1

STRAND: MECHANICS AND MATTER 1

Sub-Strand: Basic Physics 1

WEEK 1 4

FOCAL AREA: MOMENTS AND EQUILIBRIUM 4

WEEK 2 13

FOCAL AREA: GRAVITATIONAL FIELDS AND SATELLITE MOTION 13

MARKING SCHEMES FOR THE KEY ASSESSMENTS 22

SECTION 2: THERMAL EXPANSION AND ITS APPLICATIONS 27

STRAND: ENERGY 27

Sub-Strand: Heat Energy 27

WEEK 3 29

FOCAL AREA: THERMAL EXPANSION AND ITS APPLICATIONS 29

MARKING SCHEMES FOR THE KEY ASSESSMENTS 39

SECTION 3: ELECTRIC CIRCUITS, RESISTANCE, AND KIRCHHOFF'S LAWS 41

STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS 41

Sub-Strand: Direct Current 41

WEEK 4 44

FOCAL AREA 1: ELECTRIC CIRCUITS AND OHM'S LAW 44

WEEK 5 50

FOCAL AREA: RESISTORS, VARIABLE RESISTORS, AND THEIR APPLICATIONS IN CIRCUITS 50

WEEK 6 59

FOCAL AREA: KIRCHHOFF'S LAWS AND GALVANOMETERS IN ELECTRICAL NETWORKS 59

MARKING SCHEMES FOR THE KEY ASSESSMENNTS 67

SECTION 4: X-RAYS AND NUCLEAR ENERGY 70

STRAND: ATOMIC AND NUCLEAR PHYSICS 70

Sub-Strand: Atomic Physics 70

Sub-Strand: Nuclear Physics 70

WEEK 7 73

FOCAL AREA: X-RAYS: NATURE, PRODUCTION, PROPERTIES, AND APPLICATIONS 73

WEEK 8 80
FOCAL AREA: NUCLEAR REACTIONS AND ENERGY GENERATION 80
MARKING SCHEMES FOR THE KEY ASSESSMENTS 89
SECTION 5: ASTRONOMY AND COSMOLOGY 93
STRAND: MECHANICS AND MATTER 93
Sub-Strand: Basic Physics 93
WEEK 9 95
FOCAL AREA: THE UNIVERSE: ORIGIN, STRUCTURE, AND CULTURAL PERSPECTIVES 95
WEEK 10 102
FOCAL AREA: EXPLORING GALAXIES AND CELESTIAL PHENOMENA: SCIENTIFIC AND CULTURAL PERSPECTIVES 102
MARKING SCHEMES FOR THE KEY ASSESSMENTS 110
SECTION 6: ALTERNATING CURRENT 114
STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS 114
Sub-Strand: Alternating Current 114
WEEK 11 116
FOCAL AREA: FUNDAMENTALS OF ALTERNATING CURRENT (AC) 116
WEEK 12 122
FOCAL AREA: AC CIRCUITS WITH RESISTORS, INDUCTORS, AND CAPACITORS 122
MARKING SCHEMES FOR THE KEY ASSESSMENTS 170
SECTION 7: BEHAVIOUR OF LIGHT IN LENSES AND LASER SYSTEMS 175
STRAND: ENERGY 175
Sub-Strand: Wave 175
WEEK 13 178
FOCAL AREA: LENSES 178
WEEK 14 189
FOCAL AREA: LASERS 189
MARKING SCHEMES FOR THE KEY ASSESSMENTS 199
SECTION 8: PRINCIPLES AND APPLICATIONS OF ELECTROMAGNETIC INDUCTION 204
STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS 204
Sub-Strand: Electromagnetic Induction & Applications 204
WEEK 15 207
FOCAL AREA: ELECTROMAGNETIC INDUCTION AND ITS LAWS 207
WEEK 16 214

FOCAL AREA: PRINCIPLES AND APPLICATIONS OF INDUCTANCE AND ELECTROMAGNETIC INDUCTION 214
WEEK 17 224
FOCAL AREA: ELECTROMAGNETIC INDUCTION-EDDY CURRENTS AND TRANSFORMER OPERATION 224
MARKING SCHEMES FOR THE KEY ASSESSMENTS 234
SECTION 9: SIMPLE HARMONIC MOTION AND COLLISIONS 244
STRAND: MECHANICS AND MATTER 244
Sub-Strand: Kinematics 244
Sub-Strand: Dynamics 244
WEEK 18 247
FOCAL AREA: SIMPLE HARMONIC MOTION: PRINCIPLES, EQUATIONS, AND APPLICATIONS 247
WEEK 19 277
FOCAL AREA: ENERGY TRANSFORMATION IN SIMPLE HARMONIC MOTION 277
WEEK 20 282
FOCAL AREA: MOMENTUM, IMPULSE, AND COLLISIONS 282
MARKING SCHEMES FOR THE KEY ASSESSMENTS 290
SECTION 10: FUNCTIONAL ELECTRONIC CIRCUITS FOR RECTIFICATION, AMPLIFICATION, DETECTION, AND BATTERY CHARGING 300
STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS 300
Sub-Strand: Applications of Electronics 300
WEEK 21 303
FOCAL AREA: RECTIFIERS AND SMOOTHER/FILTER CIRCUITS 303
WEEK 22 309
FOCAL AREA: AMPLIFIERS 309
WEEK 23 314
FOCAL AREA: DARKNESS DETECTOR 314
WEEK 24 319
FOCAL AREA: BATTERY CHARGER 319
MARKING SCHEMES FOR THE KEY ASSESSMENTS 326
REFERENCES 340

Introduction for the Year Three Teacher Manual

The National Council for Curriculum and Assessment (NaCCA) has developed the third and final set of curriculum materials to support the implementation of the new Senior High School curriculum.

This Year Three Teacher Manual for covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively support learners in their final year of Senior High School. All the necessary information for the Student Assessment Portal has been included in the Year Three Teacher Manual to simplify the development of weekly learning plans, meaning that teachers have a single reference document.

The Year Three Teacher Manual has two main objectives:

- To support learners to consolidate and deepen their understanding of the content, pedagogy, and assessment across all three years of the new Senior High School curriculum in preparation for the West Africa Senior Secondary Certificate Examination (WASSCE).
- To equip teachers with the tools and resources needed to deliver revision-focused, assessment-led lessons that build on the knowledge learners have acquired from Year One to Year Three.

In this third year, teachers will be supporting learners to prepare for the WASSCE. Each section of the Teacher Manual is therefore structured around the highest Depth of Knowledge (DoK) levels, allowing learners to build progressively on knowledge acquired from Year One to Year Three. For each week, learning tasks and pedagogy are built around the assessment, ensuring that classroom activities directly prepare learners for the demands of the examination. Two sets of sample examination papers are also provided; one administered by Week 12 as a first semester practice examination, and one by Week 20 as a mock examination, to gauge learners' competencies and identify areas requiring remediation.

To further support teachers in delivering Year Three, NaCCA, working with the Ghana Education Service, has developed a subject specific App for each subject.

The Year Three PLC sessions have been revised in response to findings from the 2025 annual evaluation survey. The survey confirmed that teachers have made strong progress in lesson planning, use of varied instructional methods, ICT integration and modes of assessment. To address the identified gap in explaining concepts clearly using examples familiar to learners, each PLC session now includes a dedicated Content Exploration segment. This ten-minute segment brings the subject group together to work through one challenging problem or concept from the week's Teacher Manual content, not to plan how to teach it, but to ensure that every teacher in the group fully understands it.

The PLC sessions in Year Three also place particular emphasis on connecting the week's content to equivalent topics taught in Years One and Two. Teachers are encouraged to note the recap weeks signposted throughout the Teacher Manual and to use the App to explore how content across all three years links together.

As in previous years, teachers are expected to integrate National Values, Gender Equality and Social Inclusion (GESI), Social and Emotional Learning (SEL), and 21st-century skills into their learning activities, assessment tasks, and rubrics and mark schemes. The subject-specific App will support teachers in doing this throughout the year.

Ghana Education Service acknowledges the dedication of the teachers who have implemented the new curriculum across Years One and Two and recognises that Year Three represents both the culmination of that effort and a critical moment for learners. The Year Three Teacher Manual and its accompanying resources have been developed to ensure that every learner, regardless of background, ability, or school context, is fully prepared to demonstrate what they know and can do in the WASSCE and to progress confidently to further studies, the world of work, and adult life.

Acknowledgements

Special thanks to Professor Samuel Ofori Bekoe, Director-General of the National Council for Curriculum and Assessment (NaCCA) and all who contributed to the successful writing of the Teacher Manuals for the new Senior High School (SHS) curriculum.

The writing team was made up of the following members:

National Council for Curriculum and Assessment (NaCCA)	
Name of Staff	**Designation**
Reginald Quartey	Ag. Director, Curriculum Development Directorate
Anita Cordei Collison	Ag. Director, Standards, Assessment and Quality Assurance Directorate
Dr. Mercy Nyamekye	Ag. Director, Research, Planning, Monitoring, and Evaluation
Joana Adua Vanderpuije	Ag. Director, Instructional Resources Directorate
Rebecca Abu Gariba	Ag. Director, Corporate Affairs
Nii Boye Tagoe	Senior Curriculum Development Officer
Juliet Owusu-Ansah	Principal Curriculum Development Officer
Samuel Owusu Ansah	Principal Curriculum Development Officer
Godwin Mawunyo Kofi Senanu	Assistant Curriculum Development Officer
Stephen Acquah	Principal Curriculum Development Officer
Thomas Kumah Osei	Principal Curriculum Development Officer
Ayuuba Sullivan	Principal Curriculum Development Officer
Dr.Jephtar Adu-Mensah	Principal Standards, Assessment and Quality Assurance Officer (SAQA)
Richard Teye	Principal Standards, Assessment and Quality Assurance Officer (SAQA)
Nancy Asieduwaa Gyapong	Assistant Standards, Assessment and Quality Assurance Officer (SAQA)
Bridget Aku Anku	Principal, Standards, Assessment and Quality Assurance Officer (SAQA)
Francis Agbalenyo	Principal Research, Planning, Monitoring and Evaluation Officer
Joseph Barwuah	Senior Instructional Resource Officer
Samuel Amankwa Ogyampo	Senior Corporate Affairs Officer
Seth Nii Nartey	Corporate Affairs Officer

S/N	Name	Name of Institution	Subject
1	Bernard Adobaw	West African Examinations Council	Accounting
2	Emmanuel Kodwo Arthur	Institttue of Charted Accountants, Ghana	
3	Benedicta Ama Yekua Etuaful	Ogyeedom SHTS	Additional Mathematics
4	Innocent Nunana Duncan	KNUST SHS	
5	Benedicta Carbilba Foli	Pope Johns SHS & Minor Seminary, Koforidua	Agricultural Science
6	David Esela Zigah	Achimota School	
7	Prof. Jakpasu Victor Kofi Afun	Kwame Nkrumah University of Science and Technology	
8	Eric Morgan Asante	St. Peter's Boys SHS	Agriculture
9	Prof. Frederick Adzitey	University for Development Studies, Tamale	
10	Akuffo Twumhene Frederick	Koforidua SHTS	Applied Technology
11	Emmanuel Korletey	Benso SHTS	
12	Firmin Anewuoh	Presbyterian College of Education, Akropong	
13	Isaac Buckman	Armed Forces SHTS	
14	Kunkyuuri Philip	Kumasi Senior High Technical School	
15	Lavoe Daniel Kwaku	Sokode SHTS	
16	Philip Turkson	St Joseph's SHTS, Bekwai	
17	Dr. Sherry Kwabla Amedorme	Univ. of Skills Training and Entrepreneurial Development	
18	Walter Banuenumah	Univ. of Skills Training and Entrepreneurial Development	
19	Wisdom Dzidzienyo Adzraku	Univ. of Skills Training and Entrepreneurial Development	
20	Abass Umar Mohammed	University of Ghana, Legon	Arabic
21	Mohammed Mahey Ibrahim	Tijjaniya Senior High School, Kumasi	
22	Dr. Ebenezer Acquah	University of Education, Winneba	Art and Design Studio and Foundation
23	Dr. Mantey Jectey-Nyarko	Kwame Nkrumah University of Science and Technology	
24	Kwame Opoku-Bonsu	Kwame Nkrumah University of Science and Technology	
25	Seyram kojo Adipah	GES- Ga East	

26	David Kofi Oppong	Kwame Nkrumah University of Science and Technology	Aviation and Aerospace
27	Obed Frimpong	Zipline International	
28	Jo Ann Naa Dei Neequaye	Nyakrom SHTS	Biology
29	Paul Beeton Damoah	Prempeh College, Kumasi	
30	Dr. Daniel Akwei Addo	Kwame Nkrumah University of Science and Technology	Biomedical Science
31	Dr. Mrs. Dorothy Araba Yakoba Agyapong	Kwame Nkrumah University of Science and Technology	
32	Avole Baba Ansbert	Bolga SHS	Business Management
33	Emmanuel Caesar Ayamba	Bolgatanga Technical University	
34	Faustina Graham	GES HQ	
35	Bismark Kwame Tunu	Opoku Ware School, Kumasi	Chemistry
36	Patrick Nsobila Awumbire	Bolgatanga S.H.S.	
37	Francis Normanyo	Mt Mary College of Education	Christian Religious Studies & Islamic Religious Studies
38	Francis Opoku	Valley View University	
39	Haruna Zagoon-Sayeed	University of Ghana	
40	Kabiru Soumana	GES HQ	
41	Richardson Addai-Mununkum	University of Education, Winneba	
42	Seth Tweneboah	University of Education, Winneba	
43	Jusinta Kwakyewaa (Rev.Sr.)	St Francis SHTS, Akim Oda	Clothing and Textiles
44	Rahimatu Yakubu	Potsin T.I Ahmadiyya SHS	
45	Dordoe Raphael Senyo	Ziavi SHTS	Computing and ICT
46	Gaddafi Abdul-salaam	Kwame Nkrumah University of Science and Technology	
47	Kwasi Abankwa Anokye	Ghana Education Service	
48	Gabriel Boafo	Kwabeng Anglican Senior High Technical School	Design and Communication Technology
49	Mensah Henry Angmor	Anglican Senior High School, Kumasi	
50	Phyllis Mensah	University of Skills Training and Entrepreneurial Development (	
51	Charlotte Kpogli	Ho Technical University	Economics
52	Salitsi Freeman Etornam	Anlo SHS, Anloga	
53	Daniel Kwesi Agbogbo	Kwabeng Anglican Senior High Tech School	Engineering
54	Dr Valentina Osei-Himah	Atebubu College of Education	

55	Benjamin Orrison Akrono	Islamic Girls' SHS	English Language
56	Esther Okaitsoe Armah	Mangoase SHS	
57	Kukua Andoh Robertson	Breman Asikuma SHS	
58	Perfect Quarshie	Mawuko Girls SHS, Ho	
59	Ama Achiaa - Afriyie	St. Louis SHS, Kumasi	Food and Nutrition
60	Lily-Versta Nyarko	Mancell Girls SHTS, Kumasi	
61	Osmanu Ibrahim	Mount Mary College of Education, Somanya	French
62	Mawufemor Kwame Agorgli	Akim Asafo SHS	
63	Comfort Korkor Sam	University for Development Studies, Tamale	General Science
64	Robert Arhin	S.D.A SHS, Akim Sekyere	
65	Ishmael Yaw Dadson	University of Education, Winneba	Geography
66	Prof Ebenezer Owusu -Sekyere	University for Development Studies, Tamale	
67	Raymond Nsiah-Asare	Methodist Girls' SHS, Mamfe	
68	Catherine Ekua Mensah	University of Cape Cape	Ghanaian Language
69	David Sarpei Nunoo	University of Education, Winneba	
70	Prof Kwasi Adomako	University of Education, Winneba	
71	Arko Blay Augustine	University of Education, Winneba	Government
72	Josephine Akosua Gbagbo	Ngleshie Amanfro SHS	
73	Anitha Oforiwah Adu-Boahen	University of Education, Winneba	History
74	Prince Essiaw	Enchi College of Education	
75	Blessington Dzah	Ziavi SHTS	Literature-in-English
76	Juliana Akomea	Mangoase SHS	
77	Dorcas Akosua Opoku	Winneba SHS	Management in Living
78	Grace Annagmeng Mwini	Tumu College of Education	
79	Eric Abban	Mt. Marys College of Education, Somanya	Mathematics
80	Isaac Buabeng	Mamprobi Sempe 2 JHS	
81	Benjamin Ofori	Cocoa Research Institute of Ghana Primary School	Music
82	Cosmas W. K. Mereku	University of Education, Winneba	
83	Davies Obiri Danso	New Juaben SHS	
84	Prof. Joshua Alfred Amuah	University of Ghana, Legon	

85	Evans Kofi Mati	GES HQ	
86	Wilson Klebi	GES HQ	
87	Professor Emmanuel Obed Acquah	University of Education, Winneba	
88	Chris Ampomah Mensah	Bolgatanga S.H.S	Performing Arts
89	Doreen Deedee Quarcoo	University of Education, Winneba	
90	Dr. Latipher Osei Appiah-Agyei	University of Education, Winneba	
91	Albert Sackey	KNUST SHS	Physical Education and Health (Core and Elective)
92	Ebenezer Ewiah-Quarm	Nkroful Agric SHS	
93	Evans Asare Yeboah	Adisadel College	
94	John Benedict Nyarko	Adisadel College	
95	Mary Aku Ogum	University of Cape Coast	
96	Dr Linus Kweku Labik	KNUST	Physics
97	Sylvester Affram	Kwabeng Anglican SHTS	
98	Anthony Mensah	Abetifi Presbyterian College of Education	RME
99	Clement Nsorwineh Atigah	Tamale SHS	
100	Eliel Keelson	Kwame Nkrumah University of Science and Technology	Robotics
101	Isaac Nzoley	Wesley Girls High School	
102	Jemima Ayensu	Holy Child Girls SHS, Cape Coast	Social Studies
103	Mohammed Adam, Ph.D.	University of Education, Winneba	
104	Simon Tengan	Wa Senior High Technical School	
105	Franklina Kabio-Danlebo	University of Ghana	Spanish
106	Mishael Annoh-Achampong	University of Media, Art and Communication	
107	Augustina Gloria Henyo	West African Examinations Council	Inclusive Education
108	Dr. Gideon Kwesi Obosu	University of Cape Coast	
109	Dr. Daniel Fobi	University of Education, Winneba	
110	Dr. Martha-Pearl Okai	University of Cape Coast	
111	Francis Kweku Essel	Ashesi University	
112	Richard Doku	Mampong/Akw SHTS For The Deaf	
113	Yao Mati Abotsi	Ghana Blind Union	
114	Seth Kwame Ativor	Okuapemman SHS, Akropong	

115	Bernard Duorinaah	Presbyterian College of Education	
116	Evans Odei	Achimota Senior High School	

S/N	Subject	Name of Reviewer	Institution
1	Accounting	Ms. Ivy Eklemet	Univ. of Professional Studies, Accra
2	Additional Mathematics	Francis Tornyenor	Pope John SHS & Minor Seminary, Koforidua
3	Agricultural Science	Selina Acheampong	Univ. College of Agriculture and Environmental
4	Agriculture	Mr. Godwin B. K. Doli	Municipal Educ. Office, Amasaman
5	Arabic	Abdullah Musah Abdullah	Univ. of Media Arts & Communication, UniMAC
6	Art and Design Studio	Ernest Kwasi Elelakpodia	Hope College, Gomoa Fetteh
7	Art and Design Foundation	Ernest Kwasi Elelakpodia	Hope College, Gomoa Fetteh
8	Automotive & Metal Technology	Okyere Kojo Alex	Ada College of Education
9	Aviation & Aerospace Engineering	Dr. Augustine Akuoko Kwarteng	Univ. of Mines and Technology
10	Biology	Rev. Joseph Kweku Delanyo	formerly of Hope College, Gomoa Fetteh
11	Biomedical Science	Dr. Irene Adzo Agbo	Univ. of Professional Studies, Accra
12	Building Construction & Woodwork Technology	Mr. Alex A. Appah	Christ Calvary Prep. Sch.
13	Business Management	Mr. Emmanuel Boakye	Ghana Employers Association
14	Chemistry	Joyce Okreyewa Odei	Hope College, Gomoa Fetteh
15	Clothing and Textiles	Rosemary Quarcoo	Department of Clothing and Textiles, UEW
16	Design & Communication Technology	Esme Serwaa Boateng	Ghana National College, Cape Coast
17	Economics	Dr. Kofi Kamasa	Department of Management Studies, UMaT
18	Electrical & Electronics Technology	Dr. Emmanuel Ampoma Affum	Telecom Engineering Department, KNUST
19	Engineering	Dr. Albert Kotawoke Awopone	Univ. of Skills Training & Entreprenuerial Development
20	English Language	Prof. Philip Gborsong	University of Cape Coast

21	Food and Nutrition	Sylvia Baaba Yankey	
22	French	Gregory Nana Kobina Nketsia Mensah	Mfantsipim School, Cape Coast
23	General Science	Joyce Okreyewa Odei	Hope College, Gomoa Fetteh
24	Geography	Prof Kofi Adu Boahen	University of Education, Winneba
25	Ghanaian Languages	Prof. Regina Caesar	University of Education, Winneba
26	Government	Clement Adu Acheampong	Prempeh College SHS, Kumasi
27	History	Prof Wilson Yayoh	Univertsity of Cape Coast
28	Information Communication Technology	Felicia Archeresuah	Nkoronza Technical Institute
29	Manufacturing Engineering	Dr. Frank Kwabena Nyarko	Kwame Nkrumah Univ. of Science and Technology
30	Mathematics	Ezekiel Osei Bonsu	Bono East Regional Education Office, Nkoranza
31	Management in Living	Ms. Anna Holdbrooke	Swedru Senior High School
32	Music	Prof Mark-Millas Fish	University of Education, Winneba
33	Physical Education and Health Core	Francis Maxwell Ayamba	Atebubu College of Education
34	Physical Education and Health Elective	Sulemana Ahmed Tijani	Atebubu College of Education
35	Performing Arts	Dr. Godfred Asare Yeboah	University of Education, Winneba
36	Physics	Peter Bekoe	Our Lady of Mount Carmel Girls SHS, Techiman
37	Religious and Moral Education	Christain Kwarteng Mensah Oppong	Prempeh College, Kumasi
38	Robotics	Dr. Yaw Okraku-Yirenki	Kofi-Annan Centre of Exellence in ICT
39	Social Studies	Samuel Larbi	St Louis Girls SHS, Kumasi
40	Spanish	Prof. Jonson Asunka	University of Ghana Legon

SECTION 1: MOMENTS AND GRAVITATION

STRAND: MECHANICS AND MATTER

Sub-Strand: Basic Physics

Week 1

Content Standard: *Demonstrate knowledge and understanding of moments*

Learning Outcome: *Use the concept of moments to determine the mass of a body*

Week 2

Content Standard: *Demonstrate knowledge and understanding of gravitation.*

Learning Outcome: *Explain the concept of gravitation.*

INTRODUCTION AND SECTION SUMMARY

This section introduces fundamental principles in classical mechanics, focusing on the concepts of **moments, equilibrium**, and **gravitation**. These concepts are essential for understanding the behaviour of physical systems under the influence of forces and for analysing both static structures and dynamic motion in natural and engineered environments.

The first part of the section explores the concept of a **moment**, which describes the turning effect of a force acting at a distance from a pivot (see **Year 1, week 4**; types of motion). This leads to the **principle of moments**, a key condition for achieving rotational balance. Building on this, the section covers the **conditions required for equilibrium**, including both translational and rotational forms. The concept of **centre of gravity** is also introduced as the effective point of weight distribution in a body, which plays a central role in determining stability. Different **states of equilibrium**—stable, unstable, and neutral—are examined to provide a complete understanding of how objects respond to small disturbances. Practical applications, such as calculating **reactions at supports** in beams or structures, are also presented to reinforce these concepts. It may be necessary to resolve a force into two components to solve more complex problems (see **Year 2, week 2**; vectors).

The second part of the section is devoted to **gravitation**, beginning with Newton's Law of Universal Gravitation. This law explains the mutual attraction between masses and provides a foundation for understanding gravitational field strength and potential energy. The section then establishes the relationship between gravitational acceleration (g), the universal gravitational constant (G), and planetary parameters. These principles are applied to the analysis of **satellite motion**, including the derivation of **orbital period** and conditions for **circular orbits** (see **Year 2, week 15;** circular motion). The concepts of **escape velocity** and **weightlessness** are also introduced to explain motion in space and the conditions experienced by orbiting bodies.

The weeks and the indicators covered by the section are:

- *Week 1*

  Explain moments.

  State the principle of moments

  State the conditions necessary for a body to be in equilibrium.

  Calculate the reactions provided by supports.

- *Week 2*

  State Newton's law of universal gravitation.

  Deduce the relationship between acceleration due to gravity g and universal gravitational constant G.

  Deduce the period of rotation of a satellite moving in a circular orbit.

  Explain weightlessness.

Year 1	**Week 5** Describe the various types of motion, i.e. circular, oscillatory, rectilinear, spin and random
Year 2	**Week 1** Resolve vectors into their components. Determine the resultant of two vectors. **Week 15** Explain circular motion and give some examples of circular motion. Explain and calculate centripetal force.

SUMMARY OF PEDAGOGICAL EXEMPLARS

This section recommends varied and interactive teaching approaches to help learners grasp the core ideas of moments, equilibrium, and gravitation. Teachers are encouraged to use real-life examples, simple classroom experiments, and enquiry-based activities to build understanding through observation and guided discovery.

To teach **moments and equilibrium**, practical demonstrations with metre rules, weights, and everyday tools are suggested to illustrate turning effects and balance. Activities involving the **centre of gravity** and **states of equilibrium** help learners visualise stability using hands-on methods. For **gravitation**, the use of questioning, comparisons, and guided derivations allows learners to explore gravitational fields, orbital motion, and related concepts.

The exemplars promote collaboration, critical thinking, and problem-solving. Teachers are guided to create a learning environment where learners are actively engaged, supported in exploring key relationships, and encouraged to apply concepts to real-world situations. These strategies aim to deepen understanding and develop the skills necessary for effective reasoning in physics.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Explain moments. State the principle of moments. State the conditions necessary for a body to be in equilibrium. Calculate the reactions provided by supports.	Level 3	*Practical*, *Homework*
State Newton's law of universal gravitation. Deduce the relationship between acceleration due to gravity g and universal gravitational constant G. Deduce the period of rotation of a satellite moving in a circular orbit. Explain weightlessness.	Level 4	*Classwork*, *Discussion*

WEEK 1

Learning Indicators

1. *Explain moments*
2. *State the principle of moments*
3. *State the conditions necessary for a body to be in equilibrium*
4. *Calculate the reactions provided by supports*

FOCAL AREA: MOMENTS AND EQUILIBRIUM

Moments and Turning Effect of Forces

When a force is applied to an object, it can cause the object to move linearly or rotate. The rotational effect of a force about a fixed point, called a pivot or fulcrum, is known as a moment. Moments are the rotational counterparts of forces and are crucial for understanding how objects turn or balance.

A ***moment*** is the turning effect produced by a force acting on a body about a fixed point or pivot.

The size of a moment depends on two factors: the magnitude of the force and the perpendicular distance from the pivot to the line of action of the force. This perpendicular distance is often called the **moment arm** or **lever arm**. The mathematical expression for the moment M is

$$M = F \times d$$

where:

- F is the magnitude of the force (in Newtons, N),
- d is the perpendicular distance from the pivot to the line of action of the force (in metres, m).

Only the component of the force perpendicular to the lever arm contributes to the moment. If the force is applied at an angle, the effective component causing rotation is Fsinθ, where θ is the angle between the force and the lever arm.

Moments have direction: they can be clockwise or **anticlockwise**. By convention, one direction is taken as positive (usually anticlockwise) and the other as negative. The **net moment** on an object is the algebraic sum of all individual moments, taking their directions into account.This concept explains many everyday phenomena. For example, when using a spanner to loosen a bolt, a longer spanner increases the distance d, thereby increasing the moment for the same applied force, making it easier to turn the bolt. Similarly, pushing a door near its hinges requires much more force than pushing at the handle farthest from the hinges because the moment arm is shorter near the hinges.

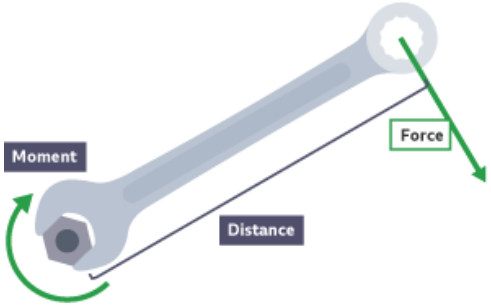


Figure 1.1: *Diagram of a spanner being used to turn a bolt.*

Centre of Gravity: The Balance Point of Weight

The **centre of gravity (CoG)** is the point in a body where the entire weight of the body can be considered to act. It is essentially the average location of the weight distribution. Understanding the CoG is vital for analysing balance and stability.

Importance of CoG

a. Balance: If an object is supported exactly at its CoG, it will balance without tipping.

b. Stability: The position of the CoG relative to the base of support determines the object's stability.

c. Movement: When a body moves, its CoG follows a smooth trajectory, even if the body itself rotates.

Determining the CoG

a. Symmetrical objects: For uniform shapes like rectangles and spheres, the CoG lies at the geometric centre.

b. Irregular objects: The CoG can be found experimentally by suspending the object from different points and drawing vertical plumb lines; the intersection of these lines locates the CoG.

c. Knife-edge balancing: For rods and flat objects, the CoG lies directly above the point or line where the object balances on a knife-edge.

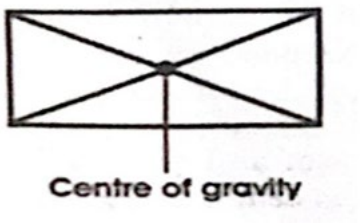


Figure 1.2: *The geometric centre of a uniformly shaped object is the location of its CoG*

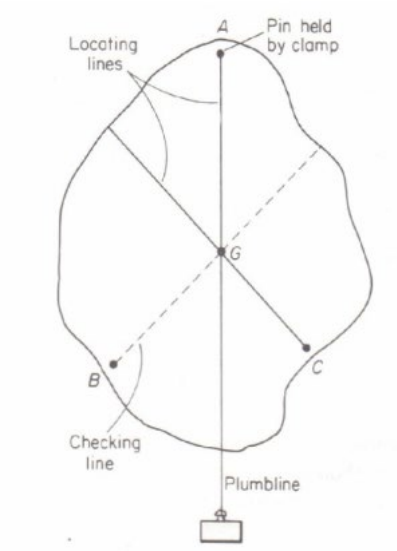


Figure 1.3: *Black and white technical diagram showing an irregularly shaped object with three marked points labelled A, B, and C along its edge. The diagram illustrates a method for finding the centre of gravity of an irregular object using plumblines drawn from different points of suspension*

Equilibrium: When Forces and Moments Balance

An object is in equilibrium when it is either at rest or moving with constant velocity, meaning it experiences no net acceleration. Equilibrium is a state of balance where the forces and moments acting on the object cancel out perfectly.

Static Equilibrium occurs when a body is **at rest and remains at rest**. Example: A book resting on a table.

Dynamic Equilibrium refers to a body **moving with constant velocity** (no acceleration). Here, the forces and moments are still balanced, but the body is in motion. Example: a parachutist descending at terminal velocity.

For either static or dynamic equilibrium to occur, two fundamental conditions must be met simultaneously:

1. Translational equilibrium: The sum of all forces acting on the object must be zero. This ensures there is no linear acceleration. Mathematically, this is expressed as:

$$\sum \vec{F} = 0$$

2. Rotational equilibrium: The **sum of all moments** about any point must be zero. This ensures there is no angular acceleration or rotation. Mathematically:

$$\sum \vec{F} = 0$$

States of Equilibrium

Not all equilibria are the same. The behaviour of an object when slightly disturbed defines its **state of equilibrium**. There are three types:

a. **Stable Equilibrium:** If an object is displaced slightly and it tends to return to its original position, it is in stable equilibrium. This occurs when the CoG is at its lowest possible position, and the vertical line through the CoG remains inside the base of support. An example is a ball resting at the bottom of a bowl; if nudged, it rolls back to the centre.

b. **Unstable Equilibrium:** If a slight displacement causes the object to move further away from its original position, it is in unstable equilibrium. This happens when the CoG is at its highest point, and the vertical line through the CoG falls outside the base of support when displaced. A pencil balanced on its tip illustrates this; any small disturbance causes it to topple.

c. **Neutral Equilibrium:** If an object is displaced slightly and neither returns to its original position nor moves further away but stays in the new position, it is in neutral equilibrium. This occurs when the CoG remains at the same height regardless of displacement. A ball resting on a flat horizontal surface is a good example; when pushed, it stays where it is moved without rolling back or away.

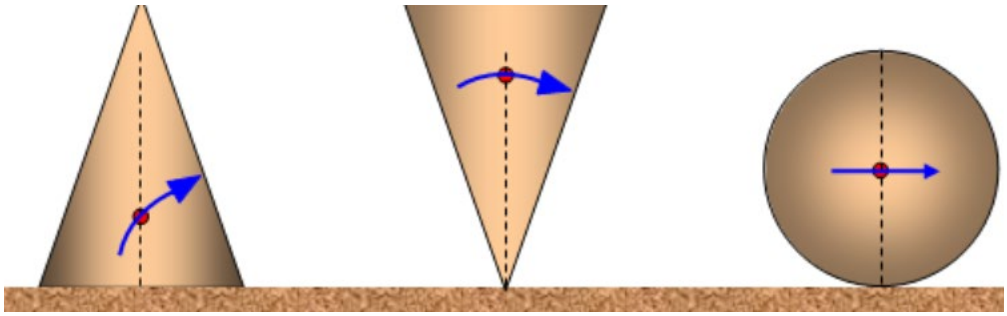


Figure 1.4: *Three objects are shown with a dotted line to indicate the line of action of their weight—a cone on its base, a cone on its tip, and a sphere. They demonstrate the three types of equilibrium*

The Principle of Moments: Balancing Rotations

The **Principle of Moments** is a powerful tool derived from the rotational equilibrium condition. It states that for an object in equilibrium, the sum of the clockwise moments about any pivot must equal the sum of the anticlockwise moments about the same pivot.

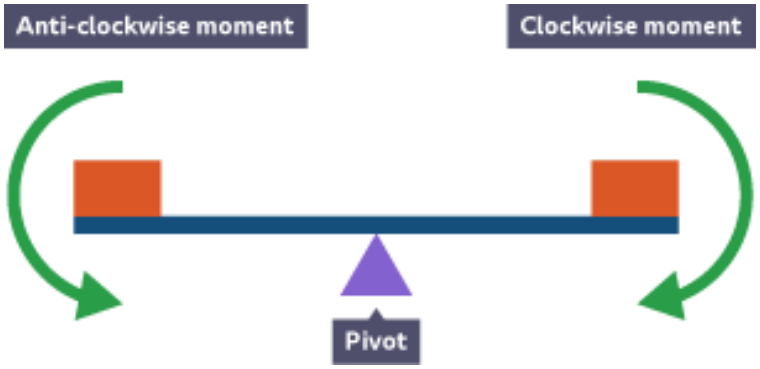


Figure 1.5: *A simple seesaw diagram showing moments*

This principle allows us to solve problems involving levers, beams, and other rigid bodies by balancing moments rather than forces alone. It simplifies calculations, especially when some forces or distances are unknown.

For example, if a 50 kg person (weight approximately 490 N) sits 0.8 metres from a seesaw pivot, a child weighing 25 kg (weight approximately 245 N) must sit on the opposite side at a distance d such that:

$$490 \times 0.8 = 245 \times d$$
$$d = 1.6\ m$$

Thus, the child must sit 1.6 metres from the pivot to balance the seesaw.

Couples and Torque: Pure Rotational Effects

A **couple** consists of two equal and opposite forces, parallel but not acting along the same line. Unlike a single force, a couple produces **pure rotation** without any resultant linear force.

The **torque** produced by a couple is given by:

$$\tau = F \times d$$

where F is the magnitude of one of the forces and d is the perpendicular distance between the forces.

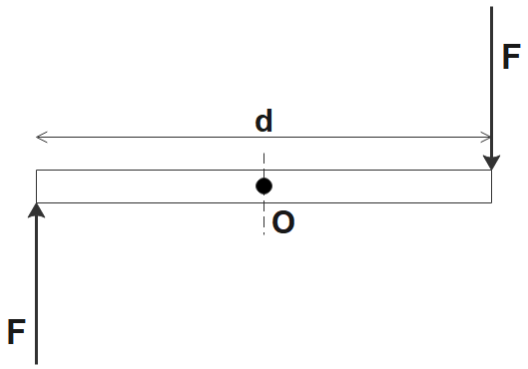


Figure 1.6: *A couple acting on a horizontal bar, which will cause the bar to rotate clockwise.*

Couples are fundamental in many mechanical systems. For example, turning a steering wheel involves applying a couple: the hands exert equal and opposite forces on opposite sides of the wheel, creating torque that rotates it without translating the wheel.

Calculating Reactions at Supports

In structures like beams and bridges, supports exert reaction forces to maintain equilibrium. Calculating these reactions is essential for structural design and safety.

Approach to Calculation

1. **Identify all forces:** Include applied loads, weights, and unknown reaction (support) forces.
2. **Apply translational equilibrium:** Sum of vertical forces equals zero.
3. **Apply rotational equilibrium:** Sum moments about a convenient point equals zero.
4. **If necessary: solve simultaneous equations** to find unknown reactions.

Worked Example

A 6 m beam is supported at both ends. A 300 N load acts 2 m from the left support. Assume the mass of the beam is negligible. Let the reaction at the left support be RA and the reaction at the right support be RB. Calculate RA and RB.

- Vertical force balance:

$$R_A + R_B = 300\ N$$

- Moment balance about left support (R_A):

  Anticlockwise moment = clockwise moment

$$R_B \times 6 = 300 \times 2$$

$$R_B = 100\ N$$

$$R_A = 300 - 100 = 200N$$

Real-World Applications of Moments and Equilibrium

The principles of moments and equilibrium are widely applied across various fields:

- **Levers:** Tools such as crowbars and scissors use the principle of moments to amplify force, enabling heavy objects to be moved with less effort.
- **Bridges and Structures:** Engineers calculate reaction forces and moments to ensure structures can safely bear loads without collapsing or deforming.
- **Biomechanics:** Human posture and movement rely on maintaining equilibrium; muscles generate moments to keep the body balanced.

Everyday Tools: Wrenches, bottle openers, and door handles all exploit moments to make tasks easier.

Learning Tasks

1. Define a moment.
2. Investigate turning effect using everyday tools.
3. Explore moments using a balanced metre rule and verify the principle of moments.
4. Determine the centre of gravity of an irregular shape using a plumb line method.
5. Solve problems involving a uniform beam in equilibrium and calculate support reactions.
6. Classify states of equilibrium (stable, unstable, neutral) using physical models.

Pedagogical Exemplars

Project-Based Learning

Ask learners, individually or in pairs, to identify at least two real-life situations where a turning effect is involved—such as opening a door or using a bottle opener. For each example, guide them to draw a simple diagram showing the pivot, point of force application, and direction of the force. Prompt them to describe how the size of the force and its perpendicular distance from the pivot affect the turning effect. Encourage learners to use their examples to define moment in their own words. Select a few responses to display on the board and use these to reinforce the formal definition and formula

Experiential Learning

Provide learners with a variety of levers (e.g., rulers, rods, or flat wooden strips) and known weights. Let them explore different force-distance combinations and verify moment calculations. Discuss how moment changes with distance from pivot.

Demonstrate moments using a metre rule balanced on a pivot. Attach known weights at varying distances and guide learners to calculate the moment of a counterbalancing mass (Moment = Force × Distance). Let learners predict outcomes before testing. Instruct them to record force, distance, and verify the principle of moments.

Hang irregular cardboard shapes from different points. Let learners trace vertical lines using a plumb line. The point where all lines meet is the centre of gravity. Guide learners through the activity and relate to real objects.Use a cone on a flat surface. Tilt it slightly and observe whether it returns (stable), moves further away (unstable), or stays in a new position (neutral). Let learners classify each state of equilibrium with justifications.

Enquiry-Based Learning

Display diagrams of bodies in different resting positions (e.g., cone, sphere, cube). Ask learners to predict the type of equilibrium and justify their reasoning.Present a scenario of a person using a wheelbarrow or a seesaw. Ask learners to sketch a diagram, mark forces, and apply the principle of moments to explain balance and rotation.

Problem-Based Learning

Provide learners with a worksheet containing diagrams of uniform beams in horizontal equilibrium. Each diagram shows point loads, distances from a pivot, and unknown support reactions or missing forces.

Collaborative Learning

Assign small groups a common tool or machine (e.g., scissors, nutcracker, crane). They research how moments and equilibrium apply, draw labelled diagrams, and present findings to the class.

Key Assessment Level 3: Practical

Note

ONE assessment should be chosen depending on availability of resources. Learners should complete Key Assessment 1 if the equipment is available or the alternative assessment if not.

1. Balance a metre rule at the 50 cm mark using your finger or another pivot. Hang a 100 g mass at various distances (e.g., 10 cm, 15 cm, 20 cm) from the pivot. For each setup, place a counterbalancing mass (mass chosen should remain constant throughout the experiment) on the opposite side and record the required force and distance to achieve balance. Record distance of counterbalancing mass for each of the positions of the 100g hanging mass. Calculate the moment (force × distance) of the counterbalancing mass for each trial. Plot a graph of moment (y-axis) against distance (x-axis). State the relationship shown by the graph.

(10 marks)

2. A metre rule is suspended horizontally and balanced on a pivot. Masses of different values are hung on both sides. The rule balances when a **100 g mass is 20 cm** to the left and a **150 g mass is placed on the right**.
   a. Calculate the exact position (distance from pivot) of the 150 g mass for balance.
   b. State the **conditions for equilibrium** based on the setup.
   c. Explain how the result confirms these conditions.

(9 marks)

3. A uniform wooden plank, 8m long, is balanced on two supports at 1m from each end. The weight of the plank is 1500N.
   a. A child of mass 20kg sits 3m from the left-hand end of the plank. What is the support force at each of the supports?
   b. The child gets off the plank and a large mass of 300kg is placed to the left of the left-hand support. Will the plank topple?

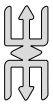
(12 marks)

PLC Session 1

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



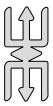
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***practical***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the practical (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 2

Learning Indicators

1. *State Newton's law of universal gravitation*
2. *Deduce the relationship between acceleration due to gravity g and universal gravitational constant G*
3. *Deduce the period of rotation of a satellite moving in a circular orbit*
4. *Explain weightlessness*

FOCAL AREA: GRAVITATIONAL FIELDS AND SATELLITE MOTION

Gravity is one of the fundamental forces shaping the universe. From holding planets in orbit to determining the weight we experience on Earth, gravity governs the motion of celestial bodies and objects alike. To facilitate these concepts effectively, it is essential to understand the nature of gravitational fields, the laws governing gravitational attraction, the behaviour of satellites, and phenomena such as escape velocity and weightlessness.

Gravitational Fields: The Invisible Force Around Masses

Every mass in the universe generates a **gravitational field**; an invisible region of space where other masses experience an attractive force. This field extends outward indefinitely, weakening with distance but never truly disappearing. The gravitational field is a vector field, meaning it has both magnitude and direction. At any point in space, the **gravitational field strength** indicates the force per unit mass that a small test mass would experience if placed there.

The **gravitational field strength** g at a point is defined as:

$$g = \frac{F}{m}$$

where F is the gravitational force experienced by a test mass m. The direction of g is always toward the centre of mass of the object creating the field. Near the surface of Earth, this strength is approximately 9.81 N/kg, but it varies depending on the celestial body and the distance from its centre.

Newton's Universal Law of Gravitation

Sir Isaac Newton formulated the Universal Law of Gravitation, which mathematically describes the gravitational force between two point masses.

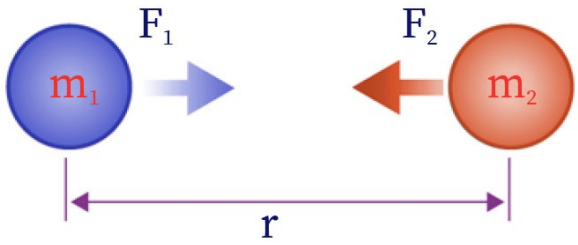


Figure 1.7: *A diagram showing two spheres, of masses m^1 and m^2, separated by a distance r, pulling on one another with equal and opposite gravitational forces.*

According to this law, every two masses attract each other with a force proportional to the product of their masses and inversely proportional to the square of the distance between their

centres:

$$F \propto \frac{m_1 m_2}{r^2}$$

$$F = \frac{G m_1 m_2}{r^2}$$

Here, G is the universal gravitational constant (G = 6.67 × x $10_{-11}Nm_2kg_{-2}$) m_1 and m_2 are the masses, and r is the distance between their centres of mass.

Relation between Universal Gravitation Constant (G) and acceleration of free fall at the surface of the earth

Consider a body of mass m **on the surface** of the earth of mass M. Let the radius of the earth be R. Force of attraction between the body and the earth is given by:

$$F = \frac{GmM}{R^2}$$

but $F = mg$ (i.e. weight of the body)

$$\frac{GmM}{R^2} = mg$$

$$g = \frac{GM}{R^2}$$

This inverse-square relationship means the gravitational pull weakens rapidly as one moves away from the mass.

Gravitational Potential

While gravitational field strength describes the force per unit mass, gravitational potential V represents the potential energy per unit mass at a point in the field. It is defined as the work done by an external agent in bringing a small test mass from infinity to that point without acceleration.

By definition, gravitational potential, V is given by:

$$V = \int_{\infty}^{R} \frac{GM}{R^2} dR$$

$$V = \left[\frac{-GM}{R}\right]_{\infty}^{R}$$

$$V = -GM\left(\frac{1}{R} - \frac{1}{\infty}\right)$$

$$V = \frac{-GM}{R}$$

The negative sign indicates that gravitational forces are attractive, and that work is done by the field when moving a mass closer. The gravitational potential becomes more negative as one approaches the mass, reflecting the increasing binding energy.

Gravitational potential energy (GPE)

GPE is the energy an object possesses because of its position within a gravitational field. It represents the work done to move the object from a reference point (usually taken at infinite distance, where gravitational influence is negligible) to its current position against the gravitational force.

In simpler terms, GPE measures the potential an object has to do work due to its location relative to a mass that creates a gravitational field. For example, lifting a book onto a shelf increases its gravitational potential energy because work is done against gravity to raise it.Gravitational potential energy U of a body of mass m is defined as the product of mass m and the gravitational potential V i.e.

$$U = Vm$$

but $V = \frac{GM}{r}$

$$U = \frac{GMm}{r}$$

Orbital Period and Geostationary Satellites

As a satellite moves with circular motion, the resultant force must act towards the centre of the circle; it is a centripetal force:

$$F = \frac{mv^2}{R}$$

The centripetal force on the satellite is provided by the gravitational force.

Centripetal force = Gravitational force on satellite

$$\frac{mv^2}{R} = \frac{GmM}{R^2}$$

Where, m = mass of satellite

R = Radius of the orbit

M = mass of the earth

Simplifying

$$v^2 = \frac{GM}{R}$$

But

$$v = \frac{distance}{time} = \frac{circumference}{period} = \frac{2\pi R}{T}$$

Substituting the formula for linear velocity $v = \frac{2\pi R}{T}$

$$\left(\frac{2\pi R}{T}\right)^2 = \frac{GM}{R}$$

$$\frac{4\pi^2 R^2}{T^2} = \frac{GM}{R}$$

$$T^2 = \left(\frac{4\pi^2}{GM}\right) \times R^3$$

This is known as **Kepler's Third Law**, which states that the time period squared of a satellite orbiting a given astronomical body is proportional to its orbital radius cubed.

Geostationary satellites are a special category orbiting Earth at approximately 35,786 km above the equator. They revolve once every 24 hours, matching Earth's rotation. This synchronisation makes them appear stationary over a fixed point on Earth's surface, which is invaluable for communication, weather monitoring, and broadcasting.

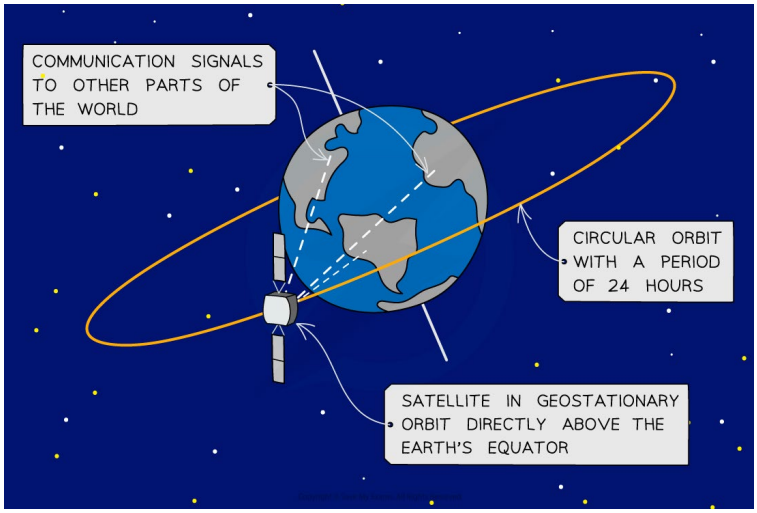


Figure 1.8: *Diagram showing a satellite in orbit around Earth.*

Escape Velocity

To break free from a planet's gravitational pull without further propulsion, an object must reach the escape velocity. This velocity ensures the object's kinetic energy equals or exceeds the gravitational potential energy binding it to the planet.

Setting kinetic energy equal to gravitational potential energy:

$$\text{Kinetic energy} = \text{Gravitational potential energy}$$

$$\frac{1}{2}mv^2 = \frac{GmM}{R}$$

$$v^2 = \frac{2GM}{R}$$

$$\text{but } gR_2 = GM_2$$

$$v^2 = \frac{2gR^2}{R}$$

$$v^2 = 2gR$$

$$v = \sqrt{2gR}$$

Weightlessness: The Illusion of No Gravity

Astronauts experience weightlessness not because gravity is absent but because they are in continuous free fall around Earth. Both the spacecraft and the astronauts inside fall toward Earth at the same rate, creating a sensation of zero weight.

In this state, there is no normal force pushing against the astronauts, which is what we usually interpret as weight on Earth. This phenomenon is essential to understand when discussing life and experiments conducted in space.

Learning Tasks

1. Compare Newton's Law of Gravitation with Coulomb's Law by identifying similarities in mathematical form and differences in force type and application.
2. Derive and calculate the acceleration due to gravity using values for Earth's mass and radius, and confirm the known value of 9.8 m/s².
3. Calculate escape velocity for Earth or other planets using the provided formula and interpret what the result means for space travel.
4. Research and present on different types of satellites (e.g., communication, weather) including their orbits, functions, and applications.
5. Explain the concept of weightlessness in orbit through group discussion, highlighting the role of continuous free fall and Earth's gravity.

Pedagogical Exemplars

Talk for Learning

Introduce the concept by dropping different objects and discussing why they fall. Guide learners to use lines and arrows to draw gravitational field patterns around Earth and compare with those near smaller masses.

Enquiry-Based Learning

Guide learners to recall Coulomb's law, then compare it with Newton's gravitational law. Ask them to identify the similarities in inverse-square relationships and difference in force type (electric vs. gravitational). Lead them to express the gravitational law as a general formula.

Using questioning, lead learners to derive the relationship between gravitational field strength g, mass of Earth M, radius R, and the gravitational constant G. Provide values for Earth and ask learners to compute g, confirming the known value 9.8 m/s^2.

Problem-Based Learning

Present the formula $F = G\frac{m_1 m_2}{r^2}$ and and use example problems to calculate gravitational force between objects. Let learners compare how force changes with distance and mass. Connect with earlier lessons on circular motion. Guide learners to set gravitational force equal to centripetal force, leading to the formula $T = 2\pi\sqrt{\frac{r^3}{GM}}$. Provide a worked example using the Moon's orbit around Earth and follow up with practice problems. Use diagrams showing concentric circles around Earth to represent gravitational potential. Present the formula $V = -\frac{GM}{r}$ and use examples to calculate gravitational potential and GPE at different distances from Earth. Pose the question: "What speed is needed for a rocket to leave Earth without returning?" Guide learners to use the formula:

$$v_e = \sqrt{\frac{2GM}{r}}$$

Let them calculate escape velocity at Earth's surface and interpret what it means.

Provide the mass and radius of Mars or the Moon. Ask learners to calculate the escape velocity and compare it with Earth's. Let them discuss why rockets require less fuel to leave smaller planets.

Provide a set of problems varying in difficulty:

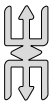
- Calculate g on different planets using their mass and radius.
- Calculate gravitational force between two planets.
- Determine how g changes as altitude increases above Earth.
- Include challenge tasks: derive escape velocity or solve for R when g is known.

Collaborative Learning

Show visuals or models of the Moon and artificial satellites. Ask learners to list differences and similarities. Guide a discussion on the uses of artificial satellites (e.g., communication, weather). Assign pairs or small groups to research and present on a type of satellite (communication, weather, navigation, etc.). Encourage inclusion of orbit type (e.g., polar, geostationary), functions, and everyday applications. Let groups use posters, voice notes, or simple models.

Show learners a documentary on astronauts living and working in space. After observing the documentary, facilitate a discussion linking gravitational effects to daily life activities in orbit. Prompt learners to reflect on cooperation in space missions, inclusion, and training for all genders. Connect weightlessness to orbital motion.

Key Assessment: Group Project



Note

These assessment tasks are examples. You may assign only one or both if time will permit.

1. a. Write down the formula for the gravitational force between two masses and the formula for the weight of a body on Earth's surface. [2 marks]

   b. Using these formulas, derive the expression for gravitational field strength g in terms of G, Earth's mass M, and Earth's radius r. [4 marks]

   c. If Earth's mass were to double while its radius remained constant, calculate by what factor would g change. Explain the implications of this change for objects on Earth's surface. [4 marks]

10 marks

2. The acceleration due to gravity on Earth is approximately **9.8 m/s²**, and on the Moon, it is **1.6 m/s²**.A satellite of mass **500 kg** is in orbit **600 km above Earth's surface**.

   a. Use the formula for g to explain why gravity is weaker on the Moon. [3 marks]

   b. Calculate the acceleration due to gravity at 600 km above Earth's surface. [*(*

($Take\ Earth's\ radius\ =\ 6.4\ \times\ 10^{6}\,m,\ G\ =\ 6.67\ \times\ 10^{-11}\,Nm^{2}/kg^{2}, M\ =\ 6.0\ \times\ 10^{24}kg$)

   c. Justify how an increase in altitude would affect the satellite's orbital velocity.

10 marks

HINT

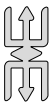


Assign Group Project to learners and give them reasonable time to complete it. Use the SS App to generate the project as well as the rubric. Learners' projects should be marked immediately, and scores entered into the SAP.

PLC Session 2

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



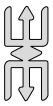
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the project (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through the problem individually for 3–4 minutes
   c. the group then works through it together the problem, step by step
   d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not 'How do I teach this?' but how do I teach it for learners to understand?*

- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 1 Review

This section has focused on two key areas within the strand of Mechanics and Matter: **Moments and Equilibrium** and **Gravitation and Satellite Motion**. Over the past two weeks, learners should have developed both conceptual understanding and problem-solving skills related to how forces act on bodies and influence their motion and stability—on Earth and in space.

In the **first week**, the emphasis was on the concept of **moments**—the turning effect produced by a force acting at a distance from a pivot. Learners should have explored the

relationship between force, distance, and rotational effect, and understood how to calculate moments using the formula:

$$Moment = Force \times Perpendicular\ distance\ from\ the\ pivot$$

They should have been introduced to the **principle of moments**, which states that for a body in equilibrium, the sum of the clockwise moments must equal the sum of the anticlockwise moments. Through practical activities and problem-based exercises, learners should have applied this principle to solve problems involving **beams**, **levers**, and **unknown support reactions**. Additionally, they should have studied the **centre of gravity**, learning how to determine it experimentally and how it affects the stability of objects. Learners should also have examined the **conditions for equilibrium**, distinguishing between **static and dynamic equilibrium**, and identifying the **three states of equilibrium**: stable, unstable, and neutral.

During the **second week**, attention shifted to the topic of **gravitation**. Learners should have been introduced to **Newton's Law of Universal Gravitation**, understanding how every mass attracts another with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them. They should have derived and interpreted the formula for **gravitational field strength**, $g = \frac{GM}{R^2}$, and explained the variation of g with distance from the centre of a planet. This concept connects directly to the understanding of **weight**, **gravitational potential energy**, and the **difference in gravity on other celestial bodies**, such as the Moon.

The section also covered the motion of **satellites** in orbit. Learners should have been guided through the derivation of the formula for the **orbital period** of a satellite in a circular orbit and introduced to **geostationary satellites**, their characteristics, and practical applications. In addition, the concept of **escape velocity** was explained, allowing learners to understand the minimum speed required for an object to break free from a planet's gravitational field. Lastly, the idea of **weightlessness** was clarified, highlighting that astronauts feel weightless not because gravity is absent, but because they are in continuous free fall while in orbit.

By the end of the two-week period, learners should have acquired the ability to explain and apply the principles of moments and equilibrium, describe and compute gravitational effects, and analyse satellite motion using mathematical and conceptual models. These foundational concepts set the stage for further exploration in physics and real-world applications in engineering, astronomy, and space science.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 1

Rubrics/Marking scheme

Question 1

Experimental Setup[2 marks]	*2 marks*	*• Balances metre rule correctly at 50 cm mark* *• Ensures rule is level before adding masses* *• Sets up stable pivot point• Arranges workspace safely and neatly*
	1 mark	*• Metre rule balanced but with some instability* *• Some setup issues that were eventually corrected* *• Basic working arrangement achieved*
Data Collection [2 marks]	*2 marks*	*• Records at least 3 different positions for 100g mass (e.g., 10cm, 15cm, 20cm)* *• For each position, finds and records counterbalance mass and position • Measurements taken with precision• Records all data in clear table with appropriate units • Repeats any anomalous measurements*
	1 mark	*• Records fewer positions or incomplete data* *• Some measurements missing or imprecise* *• Basic table structure with some organisation issues* *• Some units missing*
Moment Calculations [2 marks]	*2 marks*	*• Correctly calculates moment for each trial (force × distance)* *• Uses consistent units (e.g., N cm or N m)• Shows working for calculations• Includes moments for both sides of rule• Verifies that moments on each side are approximately equal (balanced)*
	1 mark	*• Some calculations correct but with errors• Inconsistent units or conversions* *• Limited working shown• Basic understanding demonstrated• Some verification of balance*
Graph Construction [2 marks]	*2 marks*	*• Creates graph with moment on y-axis, distance on x-axis• Appropriate scales with both axes starting at origin• Clearly labelled axes with units• Data points plotted accurately• Neat presentation with ruler used for lines• Line of best fit drawn appropriately• Title included*
	1 mark	*• Graph constructed with minor issues• Axes labelled but some information missing• Points plotted with some inaccuracies• Scale choices make reading difficult• Line of best fit attempted*
Relationship Identification [2 marks]	*2 marks*	*• Clearly states that graph shows direct/linear proportionality* *• Explains that as distance increases, moment increases proportionally* *• May identify that graph passes through origin* *• May note that slope represents the force (100g or ~1N)* *• Correctly interprets physical meaning of relationship*

	1 mark	• *Basic identification of relationship* • *Limited explanation of proportionality* • *Some understanding demonstrated*

What you should expect to see

1. **Setup:** A metre rule balanced at the 50cm mark on a pivot or fulcrum insert space to become 10 cm
2. **Procedure**
    - 100g mass placed at specific distances from centre insert space to become (e.g., 10cm, 15cm, 20cm)
    - For each position, student finds where to place another mass on opposite side to balance
    - Both distances and masses recorded in a table
3. **Calculations**
    - Moment = Force × Distance from pivot
    - Force = mass × 9.8 (or simply using mass in grams as force value)
    - Both sides should have approximately equal moments when balanced
4. **Graph**
    - Should show a straight line going through the origin (0,0)
    - As distance increases, moment increases in direct proportion
5. **Conclusion**
    - The relationship is directly proportional (when distance doubles, moment doubles)
    - This illustrates the principle of moments: a smaller force at a greater distance can balance a larger force at a smaller distance

Question 2a. Correct Calculation of Moment (5 marks)

- **State principle of moments** (∑clockwise moment = ∑anticlockwise moment)

$$100 \times 20 = 150 \times x$$

1 mark

- **Use correct equation:**

$$100 \times 20 = 150 \times x$$

1 mark

- **Rearrangement** and **solution for x:**

$$x = \frac{100 \times 20}{150} = 13.33\ cm$$

2 marks

- **Correct final answer with unit**

$$= 13.33\ cm$$

1 mark

b. Conditions for Equilibrium (2 marks) State both conditions:

Resultant force acting on the object is zero

1 marks

(or Sum of upward forces = sum of downward forces for 1 mark ONLY)

Sum of clockwise moments = sum of anticlockwise moments

1 mark

c. Explanation of Result (2 marks)

- Explain / demonstrate how equal and opposite moments lead to balance

1 mark

- Explain that there must be an upward support force at the pivot equal to the combined weight of the system

1 mark

Question 3

a. **Correct Use of the Principle of Moments (4 marks)**

- State the principle of moments clearly:"Sum of clockwise moments = sum of anticlockwise moments"

1 mark

- Set up the correct moment equation about one support (e.g., left support): $(1500 \times 3) + (20 \times 9.81 \times 2) = S_r \times 6$, where Sr is the right-hand support force

2 marks

- Solve correctly for Sr:

$$S_r = \frac{4892.4}{6} = 815.4N$$

2 marks

- State that resultant force = zero, so forces upwards = forces downwards
- Sl + 815.4 = total weight of plank + child = 1696.2 N
- Sl = 880.8 N

3 marks

b. **Establishing whether the plank will topple**

- Correct approach: state that at the point of toppling Sr = 0

1 mark

- Set up the correct moment equation about the left-hand support:

$$(1500 \times 3) = (300 \times 9.81 \times x)$$

1 mark

- Solve for x: x=1.53 m

1 mark

- State that this means that the plank will not topple, as the point of toppling is beyond the end of the plank.

1 mark

WEEK 2

Question 1

1.

- $F = G(m_1m_2/r^2)$
- $W = mg$

2 marks

2.

- Weight equals gravitational force: $W = F$ or $mg = G(Mm/r^2)$
- M identified as Earth's mass, r identified as Earth's radius
- Algebraic cancellation of m (object's mass) from both sides of equation
- Final expression correctly stated as: $g = G(M/r^2)$

4 marks

3.

- Uses expression $g = G(M/r^2)$ from part (b)
- States original case: $g_1 = G(M/r^2)$, states new case with doubled mass: $g_2 = G(2M/r^2)$
- Calculates ratio: $g_2/g_1 = 2$ (or clearly states g would double)
- Implications discussed using terms such as: "doubled weight," "increased gravitational attraction," "more force needed to lift objects," "structural stress on buildings/organisms," "changes to motion/falling"

4 marks

Question 2

1.

- Learner states the formula: $g = \frac{GM}{R^2}$
- Explains that the Moon has **less mass** and a **smaller radius** than Earth
- Concludes that this results in a **weaker gravitational pull** on the Moon

3 marks

2.

- $r = 6.4 \times 10^6 + 6.0 \times 10^5 m$

- Correct substitution of values into :, $g = \frac{GM}{R^2}$:
  $G = 6.67 \times 10^{-11}$, $M = 6.0 \times 10^{24}$, $r = 7.0 \times 10^{6}$
- Reasonable calculation of value (**~8.2 m/s²** is expected)
- Unit seen

4 marks

- Explains that satellite needs to balance **centripetal force** with gravity, or states formulae:
  Gm_subscript_1 m_subscript_2 / r^2 = m v^2 / r
- Rearranges to make v the subject
- Mentions that **lower gravity** at higher altitude means **lower orbital speed needed**

3 marks

SECTION 2: THERMAL EXPANSION AND ITS APPLICATIONS

STRAND: ENERGY

Sub-Strand: Heat Energy

Week 3

Content Standard: *Demonstrate knowledge and understanding of heat as agent of expansion of states of matter.*

Learning Outcome: *Explain how expansion occurs in solids, liquids and gases.*

INTRODUCTION AND SECTION SUMMARY

This section explains how heat causes materials to expand. When a substance is heated, its particles move faster and spread out. This makes the material grow in size—either in length, area, or volume (see **Year 1, week 1**; dimensional analysis). The section focuses on three types of expansion: **linear** (length), **area** (surface), and **volume** (space). It also shows how to calculate how much a material expands and how different materials expand at different rates.

Important examples of expansion are discussed, such as railway tracks bending in the sun, power lines sagging on hot days, and metal parts needing space to expand in machines (see **Year 1, week 8**; thermometric substances). The section also introduces **bimetallic strips**, which bend when heated and are used in thermostats and other devices.

A special part of this section is about water. Unlike most substances, water expands when cooled from 4°C to 0°C. This helps explain why ice floats and how fish survive in cold lakes.

Overall, this section helps explain what thermal expansion is, how it works in different materials, how to calculate it, and why it is important in daily life and engineering.

The weeks and the indicators covered by the section are:

Week 3:Explain linear, area and volume expansivities.

Calculate the linear, area, and volume expansivities of metals.

Group metals in increasing order of expansion property using their linear expansivities.

Year 1	**Week 2** Determine the dimensions of common quantities, e.g., velocity, acceleration, mass, length, time, weight, energy and force.**Week 8**Explain thermometric substances and their associated characteristics. Describe the features and uses of different types of thermometers.

SUMMARY OF PEDAGOGICAL EXEMPLARS

The teaching approaches in this section focus on helping learners understand thermal expansion through direct observation, guided discussions, hands-on activities, and problem-solving tasks. Lessons begin with videos and demonstrations that show how materials expand when heated. These are used to spark interest and introduce key ideas in a simple and visual way.

Discussions are encouraged to help learners connect what they see with what they already know. Real-life examples, such as expanding bridges or sagging power lines, are used to explain how expansion affects structures and materials in everyday life.

Learners also take part in small research projects, where they explore how devices like bimetallic strips work and where they are used. Through these tasks, they learn to gather information, explain ideas clearly, and work with diagrams.

Hands-on experiments, such as heating a bimetallic strip or freezing water in sealed containers, help learners observe physical changes directly. These activities make abstract ideas more understandable.

Data interpretation and calculations are included to build mathematical skills. Learners work with real values of expansion for metals and use formulas to solve related problems.

Overall, the teaching methods in this section aim to make learning active and practical. They guide learners to observe, ask questions, apply knowledge, and understand how thermal expansion affects the world around them.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Explain linear, area and volume expansivities. Calculate the linear, area, and volume expansivities of metals. Group metals in increasing order of expansion property using their linear expansivities.	Level 3	Individual Class exercise, Role play

WEEK 3

Learning Indicators

1. *Explain linear, area and volume expansivities*
2. *Calculate the linear, area, and volume expansivities of metals*
3. *Group metals in increasing order of expansion property using their linear expansivities*

FOCAL AREA: THERMAL EXPANSION AND ITS APPLICATIONS

Thermal Expansion

Thermal expansion is the **increase in size** of a material when its **temperature rises**. This occurs because heating increases the kinetic energy of atoms or molecules, causing them to vibrate more and move slightly farther apart. As a result, the material expands in length, area, or volume depending on its shape and state.

At the microscopic level, particles in solids are tightly packed but vibrate around fixed positions. When temperature increases, these vibrations become more energetic, pushing particles apart and increasing the material's dimensions. In liquids and gases, particles move more freely, so expansion is generally more significant.

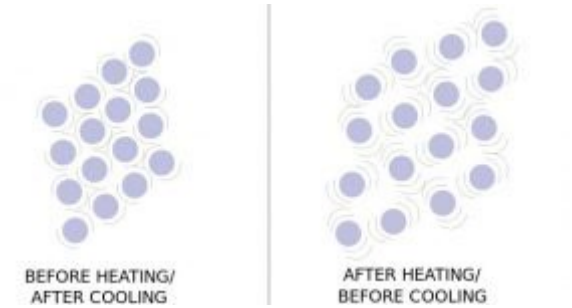


Figure 2.1: *A cluster of closely packed particles moving slightly further apart from one another when heated.*

Key effects of expansion include:

- **Structural Damage and Stress:** Materials fixed rigidly without room to expand can develop internal stresses when heated. For example, bridges and railway tracks expand on hot days. Without proper design features like **expansion joints** (gaps that allow free expansion), these structures can buckle or crack, leading to costly repairs or accidents.
- **Sagging of Power Lines:** Electrical cables suspended between pylons expand and sag on hot days due to thermal expansion. This sagging prevents excessive tension that could snap the cables in cold weather when they contract.
- **Fitting and Clearance Issues:** Metal parts in engines and machines expand when heated. Engineers design components with appropriate clearances (e.g., pistons slightly smaller than cylinders) to prevent jamming or excessive wear during operation.
- **Everyday Examples**
    - Loosening stuck jar lids by heating the metal lid causes it to expand, making it easier to unscrew.

- Thermometers rely on liquid expansion (mercury or alcohol) to indicate temperature changes.
- Hot water heaters include expansion tanks to accommodate water volume increases and avoid damage.

- **Thermal Fatigue**Repeated heating and cooling cycles cause materials to expand and contract, potentially leading to fatigue and failure over time, especially in engines and aircraft.

Bimetallic Strips

A **bimetallic strip** consists of two different metals bonded together, each with different coefficients of linear expansion. When heated, the metal with the higher expansion coefficient expands more, causing the strip to bend.

How it works

- Both metals start at the same length at a reference temperature.
- Upon heating, the metal with higher expansivity lengthens more.
- Because the two metals are rigidly bonded, the strip bends, with the metal that expands more on the outer curve.
- Cooling reverses the bending.

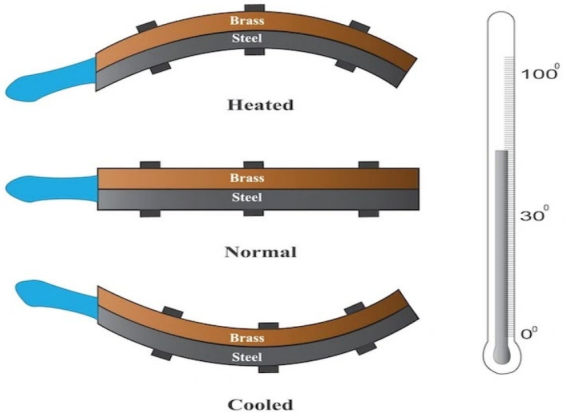


Figure 2.2: *Diagram showing a bimetallic strip made of brass and steel in three different temperature conditions*

Applications of bimetallic strips

- **Thermostats:** The bending strip opens or closes electrical contacts to regulate temperature by switching heaters or coolers on/off.
- **Thermometers:** Spiral bimetallic strips move a pointer over a temperature scale.
- **Thermal switches:** Used in appliances and safety devices to cut off current when overheating.
- **Materials:** Common pairs include steel and brass or steel and copper. The difference in expansion coefficients creates the bending effect.

Types of Expansion

Linear Expansion

Linear expansion refers to the change in length of an object due to temperature change. It is most applicable to objects where one dimension (length) is much larger than the other two, such as rods, wires, or beams.

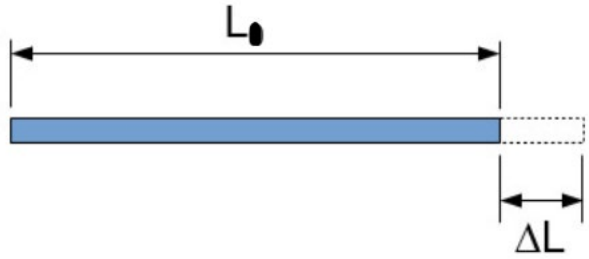


Figure 2.3: A horizontal blue rectangular bar with its left end fixed and its right end extended to the right. The original length of the bar is labelled as L subscript one (L^1), indicated by a double-headed arrow above the bar. The extension at the right end is shown with a dashed outline, and the extra length is labelled as delta L (ΔL) with a double-headed arrow below the extension. This image represents a bar undergoing elongation, likely due to tension or thermal expansion.

Linear Expansivity (α): The fractional increase in length per unit temperature change.

$$\alpha = \frac{\Delta l}{l_1 \times \Delta\theta}$$

Where

- Δl = change in length
- l_1 = initial length
- $\Delta\theta$ = temperature difference

New length

$$l_2 = l_1(1 + \alpha\Delta\theta)$$

Area expansion

Area expansion applies to two-dimensional objects like metal sheets or plates. When heated, both length and width expand, increasing the surface area.

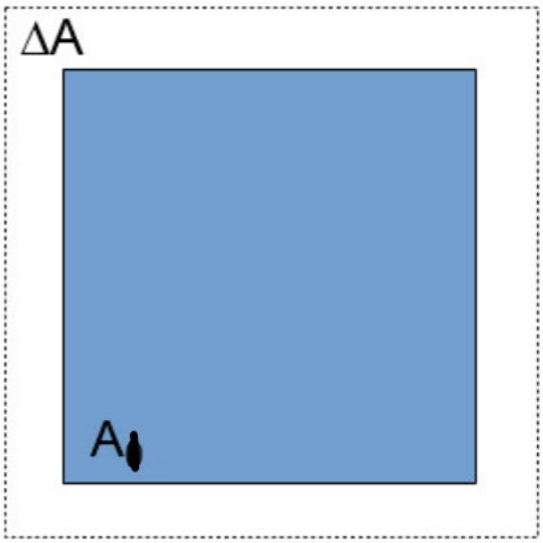


Figure 2.4: *A diagram showing two nested squares. The larger square is outlined with a dashed line, and the smaller square inside is filled with a solid blue colour. In the top left corner of the larger square, the text "ΔA" is written, and in the bottom left corner of the blue square, the text "A^1" is written. The blue square is centred within the larger square, leaving a border of white space around it.*

Area (Superficial) Expansivity (β): The fractional increase in surface area per unit temperature change.

$$\beta = \frac{\Delta A}{A_1 \times \Delta\theta}$$

Where

- ΔA= change in area
- A_1 = initial length
- $\Delta\theta$ = temperature difference

New area

$A_2 = A_1(1 + \beta\Delta\theta)$

$$A_2 = A_1(1 + \beta\theta) \quad \ldots\ldots (1)$$

Original area of sheet, $A_1 = l_1 \times b_1$

Where l_1 = original length, b_1= original breadth

Final area after rise in temperature, $A_2 = l_2 \times b_2$

But from linear expansivity, $l_2 = l_1(1 + \alpha\theta)$, $b_2 = b_1(1 + \alpha\theta)$

$$A_2 = l_2 \times b_2 = l_1(1 + \alpha\theta) \times b_1(1 + \alpha\theta)$$

$$A_2 = l_1 b_1 (1 + \alpha\theta)^2$$

$$A_2 = l_1 b_1 [1 + 2\alpha\theta + (\alpha\theta)^2]$$

$\alpha^2 \approx 0$ (since α is small)

$$A_2 = l_1 b_1 [1 + 2\alpha\theta] \quad \ldots\ldots (2)$$

Comparing (1) and (2)

$$\beta = 2\alpha$$

Volume Expansion

Volume expansion refers to the change in volume of a three-dimensional object, such as solids, liquids, or gases, due to temperature change.

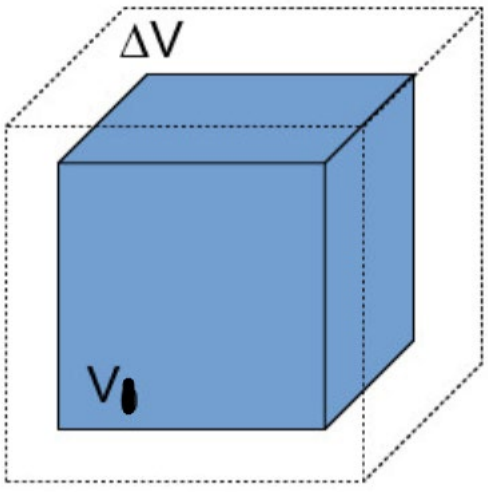


Figure 2.5: A diagram of two cubes, one inside the other. The inner cube is solid blue and labelled with "V¹" at the lower left corner of its front face. The outer cube is shown with dashed lines and is slightly larger, surrounding the blue cube. The outer cube is labelled with "ΔV" at the upper left corner of its front face. The image visually represents a change in volume, with the blue cube as the original volume (V) and the dashed cube as the increased volume (V plus ΔV)

Volume (Cubical) Expansivity (γ): The fractional increase in volume per unit temperature change.

$$\gamma = \frac{\Delta V}{V_1 \times \Delta\theta}$$

Where

- ΔV = change in volume
- V_1 = initial volume
- $\Delta\theta$ = temperature difference

New volume

$V_2 = V_1(1 + \gamma\Delta\theta)$

$$V_2 = V_1(1 + \gamma\theta) \quad \ldots\ldots (1)$$

Original volume of sheet, $V_1 = l_1 \times b_1 \times h_1$

Where l_1 = original length, b_1= original breadth, h_1 = original height

Final volume after rise in temperature, $V_2 = l_2 \times b_2 \times h_2$

But from linear expansivity, $l_2 = l_1(1 + \alpha\theta)$, $b_2 = b_1(1 + \alpha\theta)$, $h_2 = h_1(1 + \alpha\theta)$,

$V_2 = l_2 \times b_2 \times h_2 = l_1(1 + \alpha\theta) \times b_1(1 + \alpha\theta) \times h_1(1 + \alpha\theta)$

$V_2 = l_1 b_1 h_1 (1 + \alpha\theta)^3$

$V_2 = l_1 b_1 h_1 (1 + 3\alpha\theta + 3\alpha^2\theta^2 + \alpha^3\theta^3$

But $\alpha^2 \approx \alpha^3 \approx 0$ (since α is small)

$V_2 = l_1 b_1 h_1 (1 + 3\alpha\theta) \ldots\ldots$ (2)

Comparing (1) and (2)

$\gamma = 3\alpha$

Grouping Metals by Linear Expansivity

Different metals expand at different rates when heated. The **coefficient of linear expansion** $\alpha\alpha$ varies depending on the metal's atomic structure and bonding.

Here is a typical ordering of common metals by increasing linear expansivity (approximate values in $\times 10^{-6} K-1$):

Metal	Coefficient of Linear Expansion α 10^{-6} K^{-1})
Steel	11–13
Cast Iron	~10

Brass	19–21
Copper	16.5–17.5
Aluminium	22–24
Zinc	30
Lead	29–31

- Steel and cast iron have relatively low linear expansivities, making them suitable for structural applications where minimal expansion is desired.
- Aluminium and brass expand more and require allowances for thermal movement in design.
- Zinc and lead have high expansion rates and are used in applications where expansion can be tolerated or compensated.

Anomalous Expansion of Water: A Unique Behaviour

Water exhibits an unusual behaviour between 0°C and 4°C known as **anomalous expansion**:

- As water cools from room temperature down to 4°C, it behaves normally and contracts.
- However, between 4°C and 0°C, water **expands** instead of contracting.
- This occurs because water molecules form a more open hexagonal structure (similar to ice) as they approach freezing, increasing volume and decreasing density.
- This anomaly explains why ice floats on water and why aquatic life can survive beneath frozen surfaces in winter.

Understanding this behaviour is critical for explaining natural phenomena such as lake stratification and the survival of fish in cold climates.

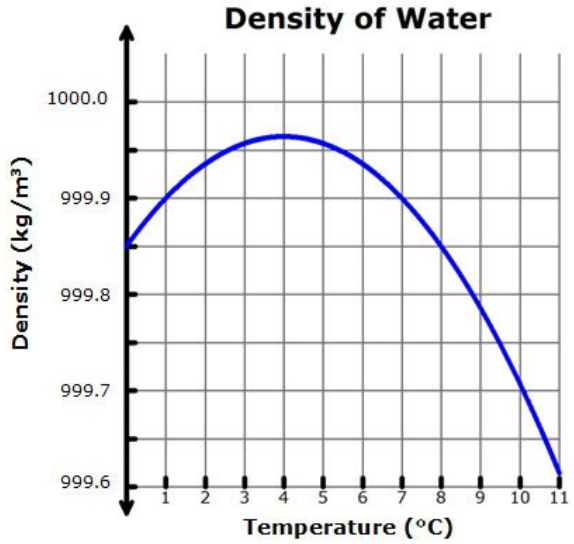


Figure 2.6: *A line graph showing the relationship between the density of water and its temperature.*

Learning Tasks

1. Observe and discuss short video clips showing thermal expansion in solids, liquids, and gases; identify and explain the changes observed in each state of matter.
2. Conduct a structured research and poster activity on the bimetallic strip, including its function, applications, and diagrammatic illustration.
3. Perform and observe a demonstration using a bimetallic strip or ball-and-ring apparatus; identify and explain the type of expansion taking place.
4. Rank materials by expansivity using a provided table, and relate the values to their uses in engineering and construction.
5. Solve numerical problems involving linear, area, and volume expansion; compare results for different materials under varying conditions.

Pedagogical Exemplars

Talk for Learning

Begin with short videos showing heat effects on solids (e.g., railway tracks), liquids (e.g., mercury in thermometers), and gases (e.g., balloon inflation). Use the clips to initiate a discussion on thermal expansion across different states of matter.

Facilitate a discussion where learners identify effects of expansion in daily life (e.g., jammed doors, bridges expanding). Show pictures or videos of expansion joints on bridges and cracked pavements to highlight engineering applications.

Experiential Learning

Use a demonstration with a bimetallic strip or ball-and-ring apparatus. Ask learners what is changing and introduce the three types of expansivity — linear (length), area (surface), and volume (bulk). Provide clear definitions and examples for each.

Provide sealed water-filled containers to freeze. Learners observe container deformation or cracks and connect it to the anomalous expansion of water. Use this to discuss the biological and environmental significance (e.g., aquatic life survival in winter).

Enquiry-Based Learning

Give learners a table of linear expansivity values for metals such as copper, iron, and aluminium. Ask them to rank the materials from lowest to highest expansivity, then discuss how this influences their application in construction and engineering.

Project-Based Learning

Assign a structured research task. Give headings such as: “What is a bimetallic strip?”, “How does it work?”, “Where is it used?”. Learners create a brief report or poster, including diagrams. Include optional extension: investigate other devices relying on expansion.

Problem-Based Learning

Provide learners with guided examples and a worksheet with varied questions on calculating linear, area, and volume expansion. Let learners solve problems involving different materials and conditions, and compare which materials expand more.

Key Assessment Level 3: Individual Class Exercise

Question 1

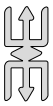
Role-play a conversation between a vulcaniser and an apprentice about why car tires expand on hot afternoons.

10 marks

PLC Session 3

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***individual class exercise***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 2 Review

This section focused on the topic of **Thermal Expansion and Its Applications** under the Heat Energy sub-strand. The lessons introduced how heat causes materials—solids, liquids, and gases—to expand due to increased particle motion. Three forms of expansion were studied: **linear**, **area**, and **volume**, along with the formulas used to calculate each type.

Learners examined how different materials expand at different rates by comparing **linear expansion coefficients**. They grouped metals based on these values and discussed practical implications in engineering, such as the use of expansion joints in bridges.

The section also explored the **bimetallic strip** and its application in devices like thermostats and switches. Additionally, the **anomalous expansion of water** was introduced, highlighting its importance in nature, especially for aquatic life in cold climates.

By the end of the week, learners were expected to explain thermal expansion, carry out calculations, interpret expansion data, and relate the concept to real-life examples and devices.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 3

Question 1

Use the table below to award a grade to the learner; you should identify which description in the 'specific things to look for' matches their work most accurately.

Component	Mark Level	Specific Things to Look For
Character Portrayal[2 marks]	*2 marks*	*• Clear distinction between vulcaniser (expert) and apprentice (learner) roles• Realistic conversation style (vulcaniser explaining, apprentice asking questions)• Use of appropriate language for each character• Maintained roles throughout performance*
	1 mark	*• Some distinction between characters but inconsistent• Limited role development• Some breaking of character*
Basic Gas Expansion Explanation [2 marks]	*2 marks*	*• Mentions that air/gas molecules move faster when heated • Explains that faster molecules hit tire walls more frequently/harder • States that this increased molecular motion causes pressure increase • May use simple analogies to explain concept*
	1 mark	*• Some mention of heat causing expansion but limited detail • Basic understanding demonstrated*
Tire Pressure Discussion [2 marks]	*2 marks*	*• Explains how outside temperature affects tire pressure readings • Mentions specific examples (e.g., morning vs. afternoon pressure differences) • Discusses ideal pressure ranges • Explains how to adjust for temperature when checking pressure*
	1 mark	*• Basic mention of temperature-pressure relationship • Limited examples or practical applications • Discussion of pressure, with some inaccuracies*
Safety Implications [2 marks]	*2 marks*	*• Discusses dangers of over-inflation (blowouts, reduced traction) • Explains dangers of under-inflation (excessive wear, reduced handling) • Mentions how to check/adjust pressure safely • Connects temperature changes to safety concerns • Provides practical advice for hot weather*
	1 mark	*• Some safety concerns mentioned • Connection to temperature effects mentioned but limited*

Dialogue Quality & Flow *[2 marks]*	*2 marks*	• *Natural conversation with appropriate questions and answers* • *Logical progression of ideas* • *Balanced participation from both characters* • *Creative use of scenario-specific language* • *Clear volume and articulation*
	1 mark	• *Basic conversation structure*

SECTION 3: ELECTRIC CIRCUITS, RESISTANCE, AND KIRCHHOFF'S LAWS

STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Sub-Strand: Direct Current

Week 4

Content Standard: *Demonstrate an understanding of current electricity and its related quantities.*

Learning Outcome: *Using the knowledge on current electricity to solve problems involving resistance and power in electrical circuits.*

Week 5

Content Standard: *Demonstrate knowledge and understanding of the structure and working principles of resistors.*

Learning Outcome: *Characterise resistors through calculation, identification and propose suitable resistors for a given electrical circuit.*

Week 6

Content Standard: *Demonstrate knowledge and understanding of Kirchhoff's laws of electrical network.*

Learning Outcome: *Explain the Kirchhoff's laws and applications.*

INTRODUCTION AND SECTION SUMMARY

This section builds upon ideas from Years 1 and 2, including **Year 1, week 15;** conservation of charge and **Year 2, week 8**; electrical potential difference.

This section introduces learners to the principles of electric circuits and how electrical energy is controlled, distributed, and analysed. Learners begin by applying Ohm's Law in simple circuits and build on this by studying how resistors and variable resistors influence current and voltage (see **Year 1, week 14**; charge carriers in conductors). Finally, they explore network analysis using Kirchhoff's Laws and examine how galvanometers function and are adapted into common electrical instruments

(see **Year 2, week 17**; force on a current-carrying wire). These concepts provide the analytical tools to understand modern electrical systems used in homes, schools, workshops, and national infrastructure.

The weeks and the indicators covered by the section are:

- ***Week 4***

  Explain the key terminologies of circuitry and how they are related to one another.

  Express Ohm's law and its relationship to electrical resistance; ohmic and non ohmic conductors

- ***Week 5***

  Describe and demonstrate the structure and working principle of resistors and their arrangements in circuits.

  Describe and demonstrate the types of variable resistors i.e., potentiometers and rheostats and their working principles.

- ***Week 6***

  State Kirchhoff's laws of electrical network.

  Determine the current flowing through a branch in an electrical network.

  Discuss how a galvanometer can be adapted as an ammeter and a voltmeter.

Year 1	**Week 15** Explain the conservation of charge and its behaviour. Differentiate between the two charges (positive and negative).**Week 14**Explain how charge carriers in conductors, semiconductors and insulators behave
Year 2	**Week 8**Determine the electric field strength/intensity at a point due to a point charge. Define and calculate potential difference**Week 17**Describe the force exerted on a current-carrying conductor in a magnetic field. Discuss the factors that affect the magnitude of the magnetic force on a current-carrying conductor in a magnetic field

SUMMARY OF PEDAGOGICAL EXEMPLARS

The pedagogical strategies across this section are designed to provide learners with an engaging, experiential understanding of electrical principles through hands-on inquiry, simulations, and structured problem-solving. In Week 4, circuit-building tasks, accessible tactile diagrams, and real appliance analogies are used to help learners explore Ohm's Law and the roles of current, voltage, and resistance in circuit behaviour. Week 5 expands on this foundation with practical identification of resistors using colour codes, guided construction of series and parallel circuits, and interactive use of variable resistors such as potentiometers and rheostats to control real-time circuit responses. Learners engage in collaborative circuit diagnostics and design exercises. In Week 6, learners use schematic diagrams, simulations, and physical circuit models to apply Kirchhoff's Laws, solving for unknown current and voltage values through logical reasoning and algebraic representation. They explore the galvanometer's adaptation into ammeters and voltmeters, connecting theoretical knowledge to instrument function and use. Each week encourages inclusive and differentiated delivery to accommodate diverse learning needs, including learners who require tactile, signed, or visual support.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Explain the key terminologies of circuitry and how they are related to one another. Express Ohm's law and its relationship to electrical resistance; ohmic and non ohmic conductors.	Level 4	*Gamification*, *Homework*
Describe and demonstrate the structure and working principle of resistors and their arrangements in circuits. Describe and demonstrate the types of variable resistors i.e. potentiometers and rheostats and their working principles.	Level 3	*Demonstration*, *Group classwork*
State Kirchhoff's laws of electrical network. Determine the current flowing through a branch in an electrical network. Discuss how a galvanometer can be adapted as an ammeter and a voltmeter.	Level 4	*Constructed response*

WEEK 4

Learning Indicators

1. *Explain the key terminologies of circuitry and how they are related to one another*
2. *Express Ohm's law and its relationship to electrical resistance; ohmic and non ohmic conductors*

FOCAL AREA 1: ELECTRIC CIRCUITS AND OHM'S LAW

Electricity is a fundamental part of physical science, and the study of electric circuits offers the foundation for understanding how electrical systems work. Electric circuits are used in lighting homes, charging mobile phones, powering electrical appliances, and operating life-saving equipment in hospitals. A firm grasp of the principles behind electric current, voltage, resistance, and their interrelationships is essential for the study of both physics and practical engineering.

What is an Electric Circuit?

An electric circuit is a complete pathway through which electric charges move. For charges to flow continuously, the circuit must be closed; there must be no breaks in the path. A simple circuit consists of a power source (like a battery), conducting wires, and a load (such as a light bulb or resistor).

HINT

Use tactile or large-print diagrams to support learners with limited vision or hearing when introducing circuit components.

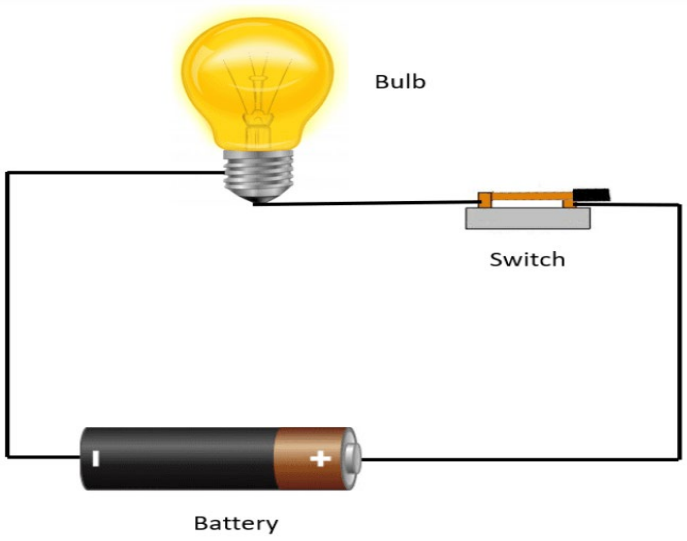


Figure 3.1: *Simple electrical circuit diagram*

Electric Current (I)

The flow of electric charge in a conductor is called **electric current**, symbolised by I, and measured in **amperes (A)**. A current of one ampere represents one coulomb of charge passing a point in the circuit each second. Though electrons flow from negative to positive, current is conventionally described as flowing from positive to negative.

Tip: *Emphasise this convention clearly to avoid confusion between actual electron flow and the assumed direction of current.*

Potential difference and Electromotive Force (EMF, ⊠)

To drive this flow, a **potential difference** or **voltage** is required. Voltage, symbolised by V and measured in **volts (V)**, provides the energy needed to move charges through a circuit. It can be thought of as an electrical pressure pushing the charges. A household socket in Ghana typically supplies 230 V, while batteries used in torches or radios may provide 1.5 V or 9 V.

Electromotive Force (EMF)

Electromotive force, abbreviated **EMF** and symbolised by **ε**, is the **energy supplied by a source** (like a battery or generator) **per unit charge** to move electric charges through a circuit. It represents the work done on each coulomb of charge to push it around the circuit.

- EMF is measured in volts (V), the same unit as voltage.
- It can be thought of as the maximum potential difference a source can provide when no current is flowing (and therefore no energy is lost due to internal heating in the battery).
- The formula relating EMF, voltage, current, and internal resistance (r) of a source is:

$$\varepsilon = V + Ir$$

where V is the terminal voltage (the voltage provided to the load in the circuit), I is the current, and r is the internal resistance of the source.

Resistance (R)

Opposing the flow of current is **resistance**, denoted by R and measured in **ohms (Ω)**. Resistance is a property of a material or component that slows down the movement of electric charges. Thinner wires, longer cables, and poor-quality materials often increase resistance, which can be observed in the heating of appliance cords or dimming of bulbs in overloaded circuits.

Ohm's Law

In the 1820s, the physicist Georg Simon Ohm discovered a simple relationship between current, voltage, and resistance.

Ohm's Law states that the current passing through a metallic conductor or wire is directly proportional to the potential difference across its ends provided the temperature and other physical conditions remain constant.

Ohm's Law, and is expressed mathematically as:

$V \propto I$

$V = IR$

This equation shows that the voltage across a component is the product of the current flowing through it and its resistance. It can also be rearranged as:

$$I = \frac{V}{R}, \qquad R = \frac{V}{I}$$

Ohmic and Non-Ohmic Conductors

Materials that obey Ohm's Law are known as **ohmic conductors**. In these materials, the current increases linearly with voltage. Their resistance remains constant, and the graph of voltage versus current is a straight line passing through the origin. Copper wires used in standard household wiring are examples.

On the other hand, **non-ohmic conductors** do not follow this linear pattern. The resistance of these materials may change with temperature or voltage.

Examples of non-ohmic conductors:

- An example is a **light-emitting diode (LED)**, often used in battery-powered lamps. The current through an LED remains negligible until a certain threshold voltage is reached, after which the current increases rapidly.
- The filament of an incandescent bulb, whose resistance increases as it heats up.

A frequently encountered misconception is the idea that electric current is used up by components in a circuit. This is not the case. In a series circuit, the same current flows through all components. What gets "used" is the energy carried by the current, which is transformed into light, heat, or other forms of energy.

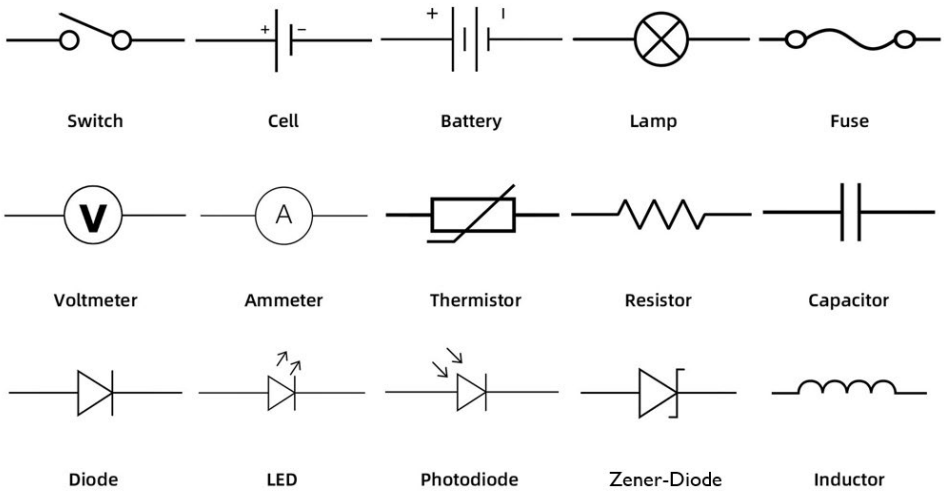
In everyday life across Ghana, the principles of electric circuits are constantly at work. For example, when charging a mobile phone with a power bank, a process called **voltage regulation** ensures that the phone receives just the right amount of voltage and current. If the voltage is too high, it could damage the phone's battery; if it's too low, charging becomes slow or inefficient. Power banks contain internal circuits that adjust the output to match the phone's requirements — applying **Ohm's Law** to balance voltage and current safely.

Similarly, in **carpentry workshops, hair salons, or street food stalls**, it is common to see multiple appliances plugged into one extension board. These include electric saws, pressing irons, blenders, or rice cookers — all of which draw significant current. When too many high-power devices run at the same time, the **total resistance in the extension board may drop**, causing **a surge in current**. This excess current generates heat in the wires due to **resistive heating** (as predicted by the formula), leading to **overheating** or even fire. In such cases, the wire insulation may melt or sockets may burn out — a direct consequence of excessive current passing through circuits not designed for such loads.

In homes and markets across Ghana, these same principles often contribute to electrical fires. Poor wiring, substandard extension cables, and the overloading of circuits with refrigerators, fans, rice cookers, and deep freezers are common causes of overheating. During peak hours in markets, when traders use multiple bulbs and appliances on single extension boards, the risk of electrical sparks and fire increases significantly. Understanding how Ohm's Law relates to current surges and overheating can help prevent such disasters through better planning, safer wiring, and informed appliance use.

Electrical Symbols for Circuit Diagrams

Understanding standard electrical symbols is essential for reading and drawing circuit diagrams. Here are some common symbols used in electric circuits:



Learning Tasks

1. Work in groups to find the definition, unit, symbol, and example of current, voltage, resistance, power, and energy, then present your findings to the class.
2. Use a circuit simulation to change voltage and resistance, observe how the current changes, and explain what you notice.
3. Test different electrical components, measure current and voltage, draw a V–I graph, and decide if each component obeys Ohm's Law.
4. Solve a problem about an appliance with reduced current by calculating resistance before and after, then suggest a better material for the component.

Pedagogical Exemplars

Collaborative Learning

Assign learners to small groups to research definitions of terms such as current, resistance, potential difference, emf, power, and energy. Each group presents their findings with the correct unit, symbol, and example usage. Combine findings into a class concept map showing how the terms relate.

Talk for Learning

Introduce common electrical symbols (battery, resistor, switch, bulb, ammeter, voltmeter). Use flashcards or labelled diagrams to familiarise learners with each. Then, ask learners to draw and interpret basic circuit diagrams. Let them explain what each symbol represents and how components connect to form a working circuit.

Provide learners with a matching exercise that links key terms: voltage, current, resistance, and power. Include definitions, symbols, units, and relationships (e.g., how increasing resistance affects current at constant voltage).

Enquiry-Based Learning

Introduce a circuit simulation. Direct learners to manipulate voltage and resistance independently and together. Prompt them to observe how current changes and explain these changes using the formula V=1R. Let learners experiment with:

- A circuit with constant resistance and varying voltage
- A circuit with constant voltage and varying resistance
- A circuit where both resistance and voltage change

Let Learners record and interpret outcomes, identifying how changes in voltage and resistance affect current and circuit performance.

Pose the guiding question: What affects the brightness of a bulb in a circuit? Support learners in designing simple investigations where one factor (voltage or resistance) changes while others remain fixed. Have them record brightness and current, then explain the results using Ohm's Law.

Present a real-world problem: A community library uses a 12V solar battery and needs lighting that won't drain the battery quickly. Guide learners to compare bulbs by calculating current using Ohm's Law. Let them test their bulb choices in a circuit (physical or simulated), observe brightness, and justify their preferred option using calculations and observations.

Experiential Learning

Instruct learners to test various components (e.g., resistors, bulbs, diodes). Let them measure current and voltage at different points and plot simple V–I graphs. Help them identify which components

follow Ohm's Law (ohmic) and which do not (non-ohmic) and explain the differences in behaviour.

Present a relatable scenario: Lights flicker in a tailoring shop when an iron is used. Help learners reconstruct the scenario in a circuit, introduce varying loads, and observe the impact on brightness and current. Discuss why the flickering occurs and guide learners to propose practical solutions.

Problem-Based Learning

Give learners a variety of circuit problems to solve using V=IR, such as finding the current when voltage and resistance are given, or determining resistance from voltage and current. Include problems that apply to everyday contexts, like household devices or simple lighting setups.

Key assessment Level 4: Gamification

1. A phone charger has a voltage of 5 V and is designed to safely charge phones using a current of 2 A. However, a certain low-quality charging cable has a resistance of 1.5 Ω due to its thin wires and poor connectors. Using Ohm's law, determine whether this cable will allow the charger to deliver the full current to the phone. Explain your reasoning and suggest a practical solution based on your calculation

[10 marks]

PLC Session 4

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

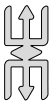
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***gamification***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 5

Learning Indicators

1. *Describe and demonstrate the structure and working principle of resistors and their arrangements in circuits*
2. *Describe and demonstrate the types of variable resistors i.e., potentiometers and rheostats and their working principles*

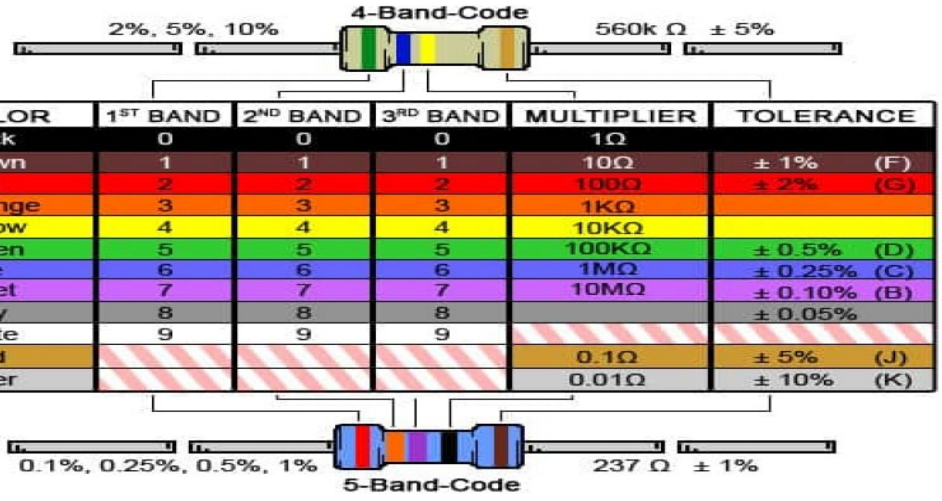
FOCAL AREA: RESISTORS, VARIABLE RESISTORS, AND THEIR APPLICATIONS IN CIRCUITS

Electric circuits rely on resistors to regulate the flow of electric current and protect components from damage. A resistor is a passive electrical device that resists the flow of charge. It transforms electrical energy into heat, reduces current to safe levels, and divides voltage between parts of a circuit. In Ghana, resistors are found in a wide range of devices—such as mobile phone chargers, radios, blenders, electric irons, and LED lamps—making their study both relevant and practical.



Figure 3.2: *Two cylindrical electronic resistors with coloured bands. The coloured bands indicate the resistance value and tolerance of each resistor.*

Resistors come in different shapes and sizes, but most have two metal leads and a body made of resistive material like carbon, metal oxide, or wound wire. The value of resistance is measured in ohms (Ω) and is either written directly on the component or indicated through a colour code.



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

Figure 3.3: *Resistor colour code chart with a table showing colours, corresponding numbers for each band, multiplier values, and tolerance percentages. The chart includes two diagrams: one for a 4-band resistor and one for a 5-band resistor, each with coloured bands and example values. The table lists colours from black to silver, with columns for 1st, 2nd, and 3rd bands, multiplier, and tolerance. For example, black is 0,*

brown is 1, red is 2, and so on. Multipliers range from 1Ω (black) to 0.01Ω (silver), and tolerances range from ±1% (brown) to ±10% (silver). The chart helps identify resistor values based on band colours.

HINT

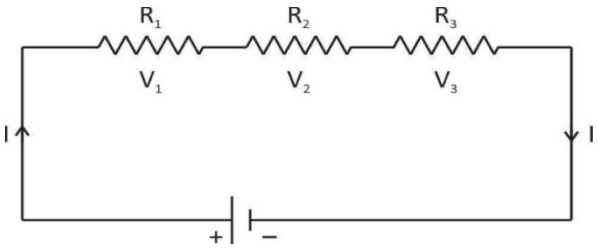
Use large, tactile colour code charts and labelled sample resistors to support learners who are visually impaired or new to the concept.

Resistor Arrangements in Circuits

Resistors can be arranged in circuits in two main ways: **in series** and **in parallel**.

In a **series connection**, resistors are joined end to end, so the same current flows through each component. The total resistance increases and is equal to the sum of the individual resistances.

Proof



The same current flows through all parts of the circuit (I). The applied potential difference is equal to the sum of the potential difference across separate resistors ($V = V_1 + V_2 + V_3$). The total resistance circuit of a series circuit is equal to the sum of separate resistances ($R = R_1 + R_2 + R_3$).

From Ohm's law

$$V = IR$$

$$V_1 = IR_1, V_2 = IR_2 . V_3 = IR_3$$

$$V = V_1 + V_2 + V_3$$

$$IR = IR_1 + IR_2 + IR_3$$

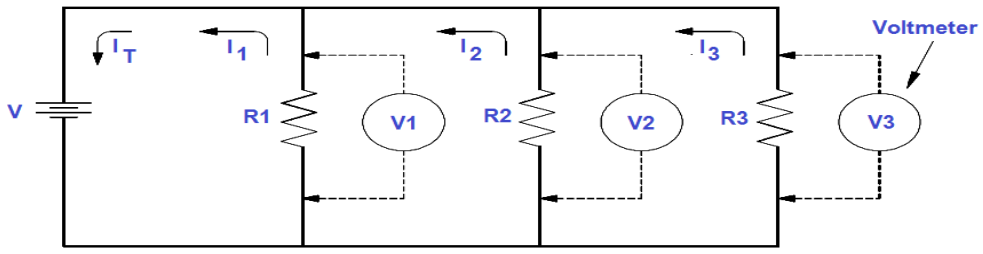
$$IR = I(R_1 + R_2 + R_3)$$

$$R = R_1 + R_2 + R_3$$

This setup is seen in old Christmas lights, where one bulb failure affects the rest.

In a **parallel connection**, resistors are connected across the same two points. The voltage across each branch is the same, but the current splits. The equivalent resistance in a parallel circuit is always less than the smallest individual resistance, and the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual resistances.

Proof



The potential difference across each resistor is the same(V). The total current is equal to the sum of the currents I the separate resistor ($I = I_1 + I_2 + I_3$).

From Ohm's law

$$V = IR$$

$$I = \frac{V}{R}, I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2} I_3 = \frac{V}{R_3}$$

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{V}{R} = V(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3})$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Most household lighting systems in Ghana are wired in parallel so that one bulb going off does not affect the others.

Tip: *Build physical series and parallel circuits with bulbs and resistors, and use multimeters to measure and compare total resistance, current, and voltage. This helps learners observe how circuit configurations influence electrical behaviour.*

Factors Affecting Resistance and Resistivity

The resistance R of a resistor or conductor depends on several factors, which are crucial for learners to understand the behaviour of resistors in circuits:

a. **Resistivity of the material ρ**: Different materials have different inherent resistivities, which is a measure of how strongly a material opposes current flow. For example, copper has low resistivity, while carbon or metal oxides have higher resistivity. Resistivity is a constant for each material and is measured in ohm-metres (Ω·m).

b. **Length l**: Resistance is directly proportional to the length of the resistor or conductor. The longer the resistor, the more resistance it offers because electrons collide more frequently with atoms in a longer path.

c. **Cross-sectional area A**: Resistance is inversely proportional to the cross-sectional area. A thicker resistor or wire has less resistance because it provides more paths for the current to flow.

d. **Temperature**: Resistance typically increases with temperature for conductors because atoms vibrate more at higher temperatures, causing more collisions with electrons. However, in some materials like semiconductors, resistance may decrease with temperature.

The relationship between these factors is given by the formula:

$$\rho = \frac{RA}{l}$$

Where

R = resistance (ohms, Ω)

ρ = resistivity of the material (Ω m)

l = length of the resistor (m)

A = cross-sectional area (m^2)

Additional factors such as impurities in the material can also affect resistance by disrupting the flow of electrons.

Beyond fixed resistors, many circuits require resistors whose values can be adjusted. These are called variable resistors and come in two main types: potentiometers and rheostats. Variable resistors are also used in measuring circuits such as the Wheatstone bridge and its practical form, the metre bridge, which determine unknown resistances by balancing them against known ones

Potentiometer

A **potentiometer** is a three-terminal variable resistor used primarily to measure voltage or to provide a variable output voltage. Its working principle is based on the fact that:

The potential difference (voltage) across any portion of a uniform resistive wire is directly proportional to the length of that portion, provided a constant current flow through the wire.



Figure 3.4: *Image of a potentiometer*

The potentiometer consists of a **long resistive wire** of uniform cross-sectional area and resistivity, connected to a battery (called the **driver cell**) that maintains a constant current through the wire.

Because the wire's resistance is uniform per unit length, the **voltage drop per unit length** along the wire is constant. When a **sliding contact (wiper)** moves along the wire, it taps off a voltage proportional to the length of wire between one end and the wiper. By connecting the unknown voltage source and a galvanometer in a secondary circuit with the sliding contact, the wiper is moved until the galvanometer shows **zero deflection** (no current flows through it). This point is called the **balance point**. At the balance point, the voltage drop along the wire segment is exactly equal to the unknown voltage, allowing its measurement without drawing current from the source.

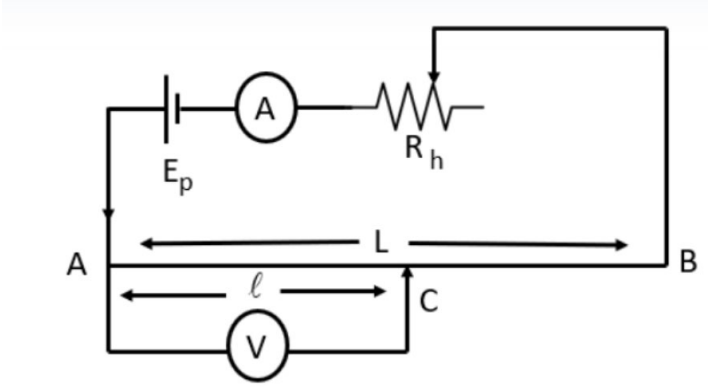


Figure 3.5: *A simple electrical circuit diagram. The circuit consists of a battery labelled Ep, an ammeter (A), a resistor labelled Rh, and a voltmeter (V). The circuit is wired as follows:*

- *The positive terminal of the battery connects to the ammeter.*
- *The ammeter connects to the resistor Rh.*
- *The resistor connects to point B.*
- *From point B, a wire runs horizontally to point A, completing the main circuit loop*
- *There is a parallel branch from point C to point A, containing the voltmeter (V).*

- *The section from A to B is labelled L, and a shorter section from C to A is labelled with a lowercase "l" (ell).*
- *Arrows indicate the direction of current flow along the wires.*

  Using Ohm's law and the properties of the wire:

- Total resistance of the wire: $R = \frac{\rho L}{A}$

  where
  ρ= resistivity of the wire material,
  L = total length of the wire,
  A = cross-sectional area.

- Voltage across length L:
  $V = IR = I\frac{\rho L}{A}$

  where I is the constant current from the driver cell.

- Voltage across a portion x of the wire:

$$V_x = I\frac{\rho x}{A} = Kx$$

where $K = \frac{I\rho}{A}$ is a constant for the wire.
Thus, the voltage across any length x is **directly proportional** to x.

The EMF of two cells may be compared by assuming that the first cell of EMF, E_1 has a null point at length L_1 and the second cell of EMF, E_2 has a null point at length L_2.

Then,

$$\frac{E_1}{L_1} = \frac{E_2}{L_2}$$

Rheostat

A **rheostat** is a type of variable resistor used to **control the flow of electric current** in a circuit by adjusting its resistance. Its working principle is based on **Ohm's law**, which states:

The current flowing through a circuit is inversely proportional to the resistance, provided the voltage remains constant.



Figure 3.6: *Image of a Rheostat*

A rheostat consists of a **resistive wire coil** wound around an insulating core, with a **sliding contact (wiper)** that moves along the coil. It has **three terminals**, but only **two are used** in operation: one fixed terminal at one end of the coil and the sliding contact terminal. By moving the wiper along the coil, the **effective length of the resistive path changes**. Increasing the length of the resistive wire in the circuit **increases resistance**, which **reduces the current** flowing through the circuit. Conversely, decreasing the length of the resistive wire **lowers resistance** and **increases current**. The voltage applied across the circuit remains constant, but the rheostat controls current by varying resistance.

Wheatstone Bridge

A Wheatstone bridge is a circuit of four resistors used to determine an unknown resistance by comparing it with known resistances. Its working principle is based on the fact that:When no current flows through the galvanometer, the ratio of the resistances in one branch is equal to the ratio of the resistances in the other branch.

The Wheatstone bridge consists of four resistors, P, Q, R and S, arranged in a diamond shape, with a cell connected across one diagonal and a galvanometer across the other. P and Q are called the ratio arms, R is a known variable resistor, and S is the unknown resistance. Each branch of the bridge acts as a potential divider. The known resistor R is adjusted until the galvanometer shows zero deflection. At this point, the bridge is said to be balanced, and the potentials at both ends of the galvanometer are equal, so no current flows through it. At balance:$P/Q = R/S$, so $S = R \times Q/P$.Like the potentiometer, the Wheatstone bridge is a null method. Because the measurement is taken when no current flows through the galvanometer, the result does not depend on the galvanometer's resistance, which makes the method very accurate. A rheostat may be connected in series with the cell to limit the current, protecting the galvanometer and preventing the resistors from heating up.

Metre Bridge

A metre bridge is a practical form of the Wheatstone bridge used in the laboratory to determine an unknown resistance. Its working principle is the same as the Wheatstone bridge, combined with the potentiometer principle that the resistance of a uniform wire is directly proportional to its length.

The metre bridge consists of a uniform resistance wire, one metre (100 cm) long, stretched along a metre rule and fixed between two thick copper strips. A known resistance R is connected in one gap and the unknown resistance S in the other. A galvanometer is connected between the junction of R and S and a sliding contact (jockey), which is pressed along the wire. The wire takes the place of the ratio arms P and Q. The jockey is moved along the wire until the galvanometer shows zero deflection. This point is the balance point. If the balance point is at length l from the end next to R, the remaining length is $(100 - l)$, and:$R/S = l/(100 - l)$, so $S = R \times (100 - l)/l$.For the most accurate results, R should be chosen so that the balance point is near the middle of the wire. The readings should also be repeated with R and S interchanged, and the average taken, to reduce errors caused by end resistances at the copper strips.

Learning Tasks

1. Use a colour code chart to identify the resistance values of resistors, then measure them with a multimeter and compare the results.
2. Build simple series and parallel resistor circuits using breadboards and measure current, voltage, and total resistance to compare with calculated values.
3. Connect a variable resistor in a circuit with a bulb or buzzer and observe how changes in resistance affect brightness or sound.
4. Use different types of wires to measure how length, thickness, and material affect resistance, then record and discuss your findings.
5. Solve problems involving resistors in series and parallel.

Pedagogical Exemplars

Talk for Learning

Present simple circuit diagrams showing resistors in series and parallel. Guide learners to identify each component by its symbol and predict how current and voltage will behave across each resistor. Learners redraw the diagrams and annotate with expected values.

Collaborative Learning

Give each group of learners a set of resistors. Ask them to use a colour code chart to write down the resistance value of each resistor. Next, guide them to confirm the values using a digital multimeter. Allow learners to compare colour code readings with measured values and discuss any discrepancies. Lead a discussion where learners identify appliances (e.g., irons, fans, radios) that use resistors. Ask: *Why do these devices need resistors?* Let Learners research one device and explain the role resistors play in its operation or protection.

Enquiry-Based Learning and Experiential Learning

Guide learners to build both series and parallel resistor circuits using breadboards, resistors, bulbs, and batteries. Let them observe bulb brightness and use multimeters to measure current, voltage, and total resistance. Ask learners to compare measured values with calculated values using known formulas.Show learners different types of variable resistors (potentiometer, rheostat). Demonstrate their use in controlling current or voltage in a circuit. Let learners connect them to a bulb or buzzer and observe how adjusting the knob changes brightness or sound. Discuss the use of variable resistors in real-world devices like volume controls or dimmer switches.

Pose the question: *How does changing resistance affect current flow in a circuit?*Instruct learners to connect a bulb or buzzer to a power source using a variable resistor (potentiometer or rheostat). As resistance is varied, let them observe and record changes in brightness or sound. Help them relate observations to the formula. $I = \frac{V}{R}$

Provide wires of different lengths, materials (e.g., copper, nichrome), and thicknesses. Learners test each wire in a circuit, measure resistance using a multimeter, and record how length, cross-sectional area, and material type affect resistance. Guide learners to conclude how these physical factors influence resistance.

Problem-Based Learning

Provide structured worksheet problems involving resistors in series, parallel, and combinations. Guide learners to show all steps: calculating individual resistances, total resistance, current, and voltage drops. Use both numerical and real-world context problems (e.g., home lighting circuits).

Provide learners with problems based on $R = \frac{\rho L}{A}$. Tasks should include comparing resistance for different wire lengths, thicknesses, and materials (e.g., copper vs. nichrome), and explaining how resistance changes with temperature in real-world cases.

Key Assessment Level 3: Demonstration

Question 1

A household appliance is designed to operate at 240 V and draws a current of 5 A. A technician replaces one of its components with a new component of the same dimensions but made of a different material. After the change, the appliance still works, but now the current drops to 3 A when connected to the same 240 V supply.

a. Calculate the original and new resistance of the appliance using Ohm's law.

b. Analyse whether the new component likely has a higher or lower resistivity and justify the reasoning.

c. Suggest any changes to the component that could restore the original current and justify your choice.

10 marks

Question 2

a. A technician is designing a circuit that requires a total resistance of **60 Ω**. He has the following resistors available: Two **100 Ω** resistors and two **20 Ω** resistors. Using a combination of **series and parallel arrangements**, determine how the technician can connect these resistors to obtain **a total resistance of 60 Ω**. Show all steps and justify your arrangement with calculations.

10 marks

b. Draw and calculate all other total resistances that can be achieved by use of all 4 resistors listed above.

1 mark per correct solution

PLC Session 5

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

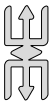
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***demonstration***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the demonstration (NTS 3k-3q).

10 minutes Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 6

Learning Indicators

1. *State Kirchhoff's laws of electrical network*
2. *Determine the current flowing through a branch in an electrical network*
3. *Discuss how a galvanometer can be adapted as an ammeter and a voltmeter*

FOCAL AREA: KIRCHHOFF'S LAWS AND GALVANOMETERS IN ELECTRICAL NETWORKS

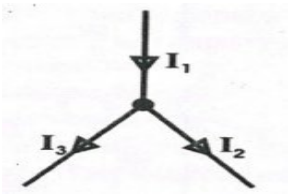
Electrical networks with multiple loops and junctions require more than Ohm's Law for analysis. Kirchhoff's Laws provide a comprehensive framework to analyse such circuits, essential in both theoretical and applied physics.

1. Kirchhoff's Current Law (KCL)

KCL states that **the algebraic sum of currents entering and leaving any junction (node) in a circuit is zero**. This law reflects the conservation of electric charge - charge cannot accumulate at a junction.

Mathematically:

$$\sum I_{in} = \sum I_{out}$$



$$I_1 = I_2 + I_3 \text{ or } I_1 - (I_2 + I_3) = 0$$

This law is commonly summarised using the mnemonic **"Currents Combine Logically"**, or simply as the conservation rule: *what goes in must come out*.

KCL is fundamental to understanding current distribution in complex circuits such as power boards, lighting grids, and industrial control panels. In practical contexts across Ghana, this principle governs current distribution in household fuse boxes, street lighting junctions, and power strips used in markets and schools.

HINT

Learners may initially struggle to visualise current splitting or combining; vector arrows and circuit junction diagrams offer important visual scaffolds.

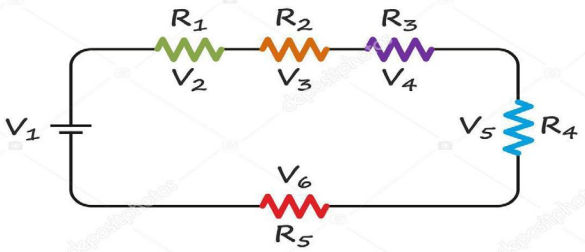
2. Kirchhoff's Voltage Law (KVL)

KVL states that **the algebraic sum of electromotive forces (EMFs) and potential drops around any closed loop is zero**. This expresses conservation of energy in electrical systems: charges gain energy from sources and lose it through resistive elements, returning with no net energy change. The law is mathematically expressed as:

$$\sum V = 0$$

Kirchhoff's Voltage Law
(Second Law)

The directed sum of the electrical potential differences (voltage) around any closed network is zero.



$V_1 + V_2 + V_3 + V_4 + V_5 + V_6 = 0$

$$E = IR_1 + IR_2 + IR_3$$

The mnemonic **"Voltages Loop to Zero"** supports retention of this principle, as does the phrase *round trip energy is spent*.

KVL is used to explain the operation of systems ranging from solar installations and vehicle electrical circuits to multi-device power networks in commercial facilities. In a closed loop containing multiple resistors and a battery, this law allows for the calculation of unknown voltages when the values of other components are known.

Combining KCL, KVL, and Ohm's Law

When KCL and KVL are applied together—alongside Ohm's Law, V=IR—they enable the systematic determination of current and voltage values in any part of a circuit. In branched networks, these laws provide a means of constructing simultaneous equations to solve for unknown quantities. Their combined use forms the analytical foundation of circuit theory and has applications in electrical diagnostics, control systems, and energy distribution networks.

HINT

Learners benefit from solving one loop and one junction problem manually before advancing to multiple-loop systems; early mastery of symbolic representation improves later fluency.

Determining Current in a Branch Using Kirchhoff's Laws

Stepwise method

1. Identify all nodes (junctions) and label currents (assume directions).
2. Apply KCL at each node: sum of currents entering = sum leaving.
3. Identify independent loops and apply KVL: sum of voltage rises and drops = 0.
4. Use Ohm's Law to express voltages in terms of currents and resistances.
5. Solve simultaneous equations for unknown currents.

Galvanometer and Its Adaptations

The concept of a **galvanometer** is closely related to the measurement of current and voltage in circuits. A galvanometer is a sensitive instrument used to detect small electric currents. It typically consists of a coil suspended in a magnetic field, which deflects a needle when current flows through it. While galvanometers are precise, their use is limited to small currents due to their low tolerance

Conversion to Ammeter

To measure larger currents, a galvanometer can be converted into an **ammeter** by connecting a low-resistance shunt in parallel with the coil. This shunt allows the majority of the current to bypass the galvanometer, protecting it from overload while enabling accurate current measurement.

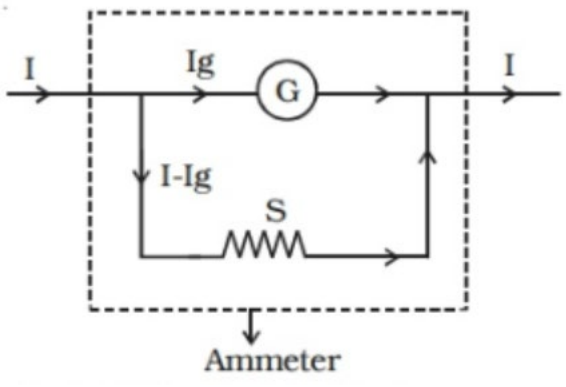


Figure 3.8: *A schematic diagram of an ammeter circuit*

$$I = I_g + I_S$$

$$I_S = I - I_g$$

$$V_s = V_G$$

$$I_S R_S = I_G R_G$$

$$(I - I_g)R_S = I_g R_G$$

Conversion to Voltmeter

To measure voltage, the galvanometer is converted into a **voltmeter** by placing a high-resistance resistor **multiplier** in series with the coil. This limits current through the galvanometer, enabling voltage measurement across components without significantly affecting the circuit.

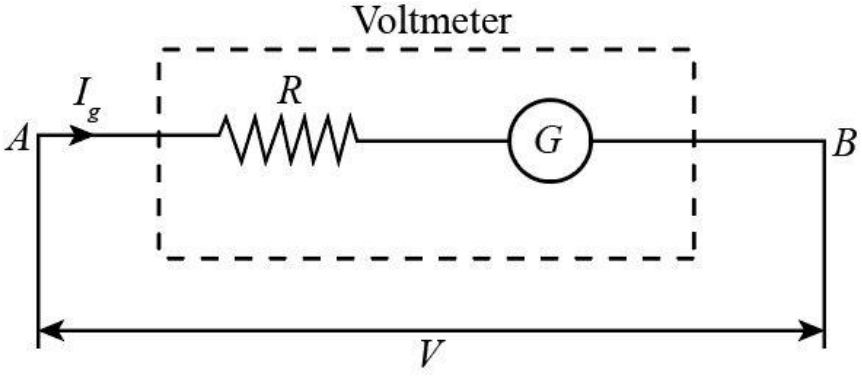


Figure 3.9: *Electrical circuit diagram showing a voltmeter connected between two points labelled A and B.*

$$V = V_M + V_G$$

$$V = I_g R_M + I_g R_G$$

These adaptations are implemented in modern multimeters, which combine galvanometer mechanisms with switching and scaling circuits to enable multifunctional measurements. In Ghana, multimeters are routinely used in electronics workshops, maintenance facilities, and classroom laboratories.

***Tip**: Providing learners with hands-on exposure to both analogue and digital multimeters, even in simulated form, greatly strengthens their conceptual understanding and appreciation for measurement accuracy.*

Kirchhoff's Laws and the functioning of galvanometers extend far beyond academic use. Their principles are applied in electrical diagnostics, solar system management, automotive repairs, and industrial automation. Understanding these laws provides a basis for logical reasoning in network analysis, enables precise interpretation of fault conditions, and supports the development of advanced skills in electronic measurement and control.

Learning Tasks

1. Use a labelled circuit diagram to identify all junctions and loops, then write and solve KCL and KVL equations with correct signs and directions.
2. Build a simple two-loop circuit, measure current at junctions and voltage around loops using multimeters, and verify KCL and KVL using your measurements.
3. Use a circuit simulator to create a circuit with multiple loops and junctions, vary voltage and resistance, and check if KCL and KVL are satisfied.
4. Convert a galvanometer into an ammeter using a shunt resistor and into a voltmeter using a series resistor, then test both in simple circuits.
5. Solve a problem to calculate the value of a shunt or series resistor needed to convert a galvanometer into an ammeter or voltmeter of a given range.

Pedagogical Exemplars

Talk for Learning

Facilitate a short discussion where learners explain why KCL and KVL are important in analysing real-world circuits. Use examples such as home lighting, multi-bulb torchlights, or car wiring.

Experiential Learning

Guide learners to assemble a simple two-loop circuit using resistors, batteries, and wires. Provide multimeters and instruct learners to measure the current entering and leaving junctions (to verify KCL) and the voltage drops around closed loops (to verify KVL). Prompt learners to compare measured values with expected theoretical results and discuss any discrepancies.

Provide a galvanometer, shunt resistors (low value), and high-resistance multipliers.(a) Instruct learners to connect a **shunt resistor in parallel** with the galvanometer to convert it to an **ammeter**. (b) Instruct learners to connect a **high resistance in series** with the galvanometer to convert it to a **voltmeter**.Let learners build both configurations and test them in simple circuits.

Enquiry-Based Learning

Introduce learners to an accessible online circuit simulator (e.g., PhET Circuit Construction Kit). Demonstrate how to build a circuit with multiple junctions and loops. Assign learners to vary resistance and voltage, record current and voltage values, and check for consistency with KCL and KVL. Encourage discussion on how simulations match or differ from physical circuits and the practical value of each method.

Problem-Based Learning

Provide learners with clear labelled circuit diagrams. Ask them to:

- Identify all junctions and loops
- Write KCL equations at junctions
- Write KVL equations for each loop
- Represent all values mathematically, indicating direction and sign conventions

Present a circuit diagram of a faulty lighting system with multiple loops and unknown currents. Guide learners to apply **Kirchhoff's Current Law (KCL)** at junctions and **Kirchhoff's Voltage Law (KVL)** in loops to form equations. Learners solve the equations to find missing currents and interpret the results in context.

Provide a worksheet with circuit diagrams involving multiple junctions and loops. Instruct learners to apply **KCL at junctions** and **KVL in loops** simultaneously to form a system of linear equations and ask learners to solve the equations step by step to find unknown currents.

Give learners diagrams of galvanometer-based meters. Ask them to label the positions of the shunt or series resistors and explain why they are connected that way. Learners describe how each configuration affects sensitivity and range.

Present problems where learners:

- Calculate required shunt resistance to convert a galvanometer (with known internal resistance and full-scale deflection current) into an ammeter of a given range
- Calculate series resistance needed to convert the galvanometer into a voltmeter.

Collaborative Learning

Set up a role-play where one learner acts as a galvanometer designer and another as a technician converting it for field use. They explain why a shunt is needed for an ammeter and a multiplier for a voltmeter, and what happens if the wrong resistor is used.

Key Assessment: Mid-Semester Examination

Question 1

Describe and explain how a galvanometer can be adapted to create a) an ammeter and b) a voltmeter.

6 marks

HINT

*Conduct **Mid-semester Examination**. It should cover the contents taught from Week 1 to 5. Refer to the **Table of Specification and Structure of the Paper**. Learners' papers should be marked immediately and scores entered into the SAP.*

Structure

Section A: 25 Multiple-choice questions

Section B: 2 Essay Questions

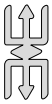
Table of specification for item construction for section A and B

Week	Learning Indicator	Types of questions	Dok Levels				Total
			1	2	3	4	
1	Explain moments State the principle of moments State the conditions necessary for a body to be in equilibrium Calculate the reactions provided by supports	MCQs	2	2	-		4
		ESSAY	-	-	-		-
2	State Newton's law of universal gravitation Deduce the relationship between acceleration due to gravity g and universal gravitational constant G Deduce the period of rotation of a satellite moving in a circular orbit Explain weightlessness	MCQs	2	2	2		6
		ESSAY	-	-	1		1
3	Explain linear, area and volume expansivities Calculate the linear, area, and volume expansivities of metals Group metals in increasing order of expansion property using their linear expansivities	MCQs	-	2	1		3
		ESSAY	-	-	-		
4	Explain the key terminologies of circuitry and how they are related to one another Express Ohm's law and its relationship to electrical resistance; ohmic and non ohmic conductors	MCQs	3	2	1		6
		ESSAY					
5	Describe and demonstrate the structure and working principle of resistors and their arrangements in circuits Describe and demonstrate the types of variable resistors i.e., potentiometers and rheostats and their working principles	MCQs	1	3	2		6
		ESSAY			1		1
		Total	8	11	8		27

PLC Session 6

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



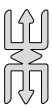
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   a. The key assessment for the week is ***mid-semester examination***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/ rubrics for the mid-semester examination (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through the problem individually for 3–4 minutes
   c. the group then works through it together the problem, step by step
   d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*

- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 3 Review

In this section, learners explored the structure and behaviour of electrical circuits. Week 4 established foundational concepts by introducing Ohm's Law and helping learners apply it in everyday contexts, from mobile charging to circuit overloading. Week 5 deepened this by focusing on resistor types and configurations and introduced variable resistors, with learners building and analysing working circuits. In Week 6, learners used Kirchhoff's Laws to analyse electrical networks and understood the scientific principles behind key instruments like galvanometers, voltmeters, and ammeters. These topics have not only sharpened learners' computational and analytical skills but have shown the relevance of circuit science in Ghanaian homes, markets, and industries.

MARKING SCHEMES FOR THE KEY ASSESSMENNTS

WEEK4

What you should expect

- Identify the problem using Ohm's Law : The charging cable has a resistance of 1.5Ω. When 2A current flows through this cable, we can calculate the voltage drop across the cable using Ohm's Law: V = IR

Voltage drop across cable = 2A × 1.5Ω = 3V

- Analyse the consequences The charger provides 5V, but 3V is lost in the cable. This means only 2V reaches the phone, which is insufficient for proper charging. Most phones require at least 4.5-5V to charge properly.
- Determine if full current can be delivered: No, the cable cannot deliver the full 2A current to the phone. The high resistance creates too much voltage drop, reducing the effective voltage at the phone.
- Provide practical solution: A better solution is to use a higher quality cable with lower resistance (0.5Ω or less). With a 0.5Ω cable, the voltage drop would only be: 2A × 0.5Ω = 1V, leaving 4V for the phone, which is much more suitable for charging.

Component	Mark Level	Specific Things to Look For
Understanding of Ohm's Law *[2 marks]*	*2 marks*	*• Correctly identifies Ohm's law (V=IR) as the relevant principle* *• Explains relationship between voltage, current, and resistance* *• Recognises that resistance affects current flow* *• Understands the cable as a resistive element in the circuit*
	1 mark	*• Mentions Ohm's law but with limited understanding* *• Some confusion about relationship between variables* *• Incomplete explanation of resistance concept*
Calculation Accuracy *[2 marks]*	*2 marks*	*• Correctly calculates voltage drop across cable: V = IR = 2A × 1.5Ω = 3V* *• Determines remaining voltage at phone: 5V − 3V = 2V* *• Shows clear working steps• Units included and correct*
	1 mark	*• Attempts calculations but with minor errors* *• Incomplete calculations* *• Missing units or incorrect application of formula*
Analysis of Charging Capability *[2 marks]*	*2 marks*	*• Clearly explains that 3V is lost in the cable* *• Concludes that only 2V reaches the phone (insufficient for proper charging)* *• Explains why this prevents full 2A charging current* *• Connects calculation to real-world charging performance*

	1 mark	*• Basic conclusion about charging problems* *• Limited explanation of voltage loss implications* *• Unclear connection between calculation and charging performance*
Practical Solution [2 marks]	*2 marks*	*• Recommends using a cable with lower resistance (specific value suggested)* *• Explains how lower resistance reduces voltage drop* *• Discusses quality factors in charging cables* *• May mention cable thickness, length, or connector quality*
	1 mark	*• Basic solution mentioned without detailed explanation* *• Limited understanding of how solution addresses the problem* *• Vague recommendations*
Safety Considerations [2 marks]	*2 marks*	*• Identifies heat generation in high-resistance cables* *• Discusses potential fire hazards or device damage* *• Explains power dissipation ($P=I^2R$) in the cable* *• Connects resistance to safety concerns*
	1 mark	*• Mentions safety concerns but with limited detail* *• Some awareness of heat issues* *• Limited explanation of physics behind safety problem*

WEEK 5

a.

- Correct formula used: $R = \frac{V}{I}$
- Original resistance calculation:
  $R = \frac{240}{5} = 48\ \Omega$
- New resistance calculation:
  $R = \frac{240}{3} = 80\ \Omega$

  Correct units and final answers clearly stated **4 marks**

b.

- Correct identification: the new component has **higher resistivity**
- Reference to resistivity formula (e.g., resistivity is directly proportional to resistance for constant dimensions)
- Conclusion; higher resistance means a higher resistivity material was used

3 marks

c.

- Suggestion of return to a low-resistivity material (e.g., copper, silver, aluminium)
- Suggestion of changing the dimensions of the new component (e.g., shorter length or greater cross-sectional area
- Justification linked to resistivity formula

3 marks

Question 2

a)

Step	Description	Marks
1	*Correct understanding of resistor combinations: formulae for adding resistors in both series and parallel stated*	*2 marks*
2	*Accurate calculation of a parallel combination, e.g., combining two 100 Ω resistors in parallel to get 50 Ω*	*2 marks*
3	*Accurate calculation of a second parallel combination, e.g., combining two 20 Ω resistors in parallel to get 10 Ω*	*2 marks*
4	*Calculates the correct total resistance for the chosen arrangement(e.g., 50 Ω from the two 100 Ω resistors in parallel + 10 Ω from the two 20 Ω resistors in parallel)*	*2 marks*
5	*Neat, clear presentation of steps and correct final answer*	*1 mark*
6	*Correct unit for resistance in final answer (Ω)*	*1 mark*

b) Correct combinations drawn and calculated

WEEK 6

a) An ammeter

Point	Explanation
1. A low resistance (shunt) is connected in parallel with the galvanometer	*This allows most of the current to bypass the galvanometer.*
2. The value of the shunt is chosen so the total current can be measured without damaging the galvanometer	*Ensures the galvanometer only carries a small, safe fraction of the current.*
3. The ammeter must have a very low total resistance	*To avoid significant voltage drop and not affect the current in the circuit.*

3 marks (both point and explanation must be seen for a mark)

b) A voltmeter

Point	Explanation
1. A high resistance is connected in series with the galvanometer	*This limits the current so the galvanometer isn't damaged when measuring voltage.*
2. The value of the series resistor is chosen so the total voltage across the combination is correct	*Allows measurement of a range of voltages.*
3. The voltmeter must have a high resistance overall	*To minimise current drawn and avoid affecting the circuit being measured.*

3 marks (both point and explanation must be seen for a mark)

SECTION 4: X-RAYS AND NUCLEAR ENERGY

STRAND: ATOMIC AND NUCLEAR PHYSICS

Week 7

Sub-Strand: Atomic Physics

Content Standard: *Demonstrate knowledge and understanding of the production of x-rays.*

Learning Outcome: *Recognise the applications of x-rays in medicine, and other industrial sectors.*

Week 8

Sub-Strand: Nuclear Physics

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

Learning Outcome: *Recognise the amount of energy released from nuclear reactions*

INTRODUCTION AND SECTION SUMMARY

This section focuses on fundamental concepts within atomic and nuclear physics, with particular emphasis on the production and applications of X-rays, as well as the processes and implications of nuclear reactions. It begins with a detailed exploration of how X-rays are generated, including the mechanisms of Bremsstrahlung and characteristic radiation within an X-ray tube. The properties of X-rays—such as their penetrating power, ionising ability, wavelength, and frequency (see **Year 1, week 22**; photon energy and **Year 2, week 20**; wave motion)—are examined to explain their diverse applications across medical, industrial, scientific, and agricultural sectors. Distinctions between soft and hard X-rays are established based on energy and penetration capabilities, laying the groundwork for understanding their practical uses and safety considerations.

The latter part of the section delves into nuclear reactions, explaining how energy can be released from the atomic nucleus through processes such as fission and fusion (see **Year 1, weeks 23 and 24**; radioactivity and balancing nuclear equations). The concept of mass-energy equivalence, as expressed in Einstein's equation $E=mc^2$, provides the foundation for calculating the energy released during these reactions. Key ideas include the mass defect, binding energy, and the conditions under which fission and fusion occur. The operation and components of a nuclear reactor are also introduced, highlighting how controlled nuclear fission is used to generate electricity. The section concludes with a discussion on radiation hazards, safety precautions, and the environmental impact associated with nuclear energy.

Overall, this section provides a comprehensive overview of how atomic and nuclear principles are applied in modern science and technology. It emphasises both the beneficial uses and potential risks

of ionizing radiation and nuclear energy, encouraging a balanced understanding of their role in contemporary life.

The weeks and the indicators covered by the section are:

- ***Week 7***

  Describe how x-rays are produced

  Distinguish between hard x-rays and soft x-rays

  Calculate the energy, frequency and wavelength of x-rays.

  Identify sectors where x-rays are applied and how they are applied

- ***Week 8***

  Calculate the energy released in a nuclear reaction

  Distinguish between fission and fusion

Describe the process of power generation using a nuclear reactor

Year 1	**Week 22:** Calculate the energy of a photon during a transition. **Week 22:** Explain radioactivity **Week 24:** Balance basic nuclear reactions.
Year 2	**Week 20:** Determine the amplitude, velocity, frequency, period, wavelength from a wave sinusoidal signal.

SUMMARY OF PEDAGOGICAL EXEMPLARS

The pedagogical strategies in this section are designed to promote active engagement and deep understanding of atomic and nuclear physics. Teaching approaches include experiential, collaborative, project-based, and problem-based learning, each aimed at developing both conceptual knowledge and practical application.

Learners explore the production and application of X-rays through multimedia simulations, visual presentations, and group research tasks. These methods help clarify the functions of components in an X-ray tube and the distinctions between soft and hard X-rays. Activities such as diagram labelling, poster creation, and matching exercises reinforce content knowledge while encouraging creative expression and critical thinking.

In the nuclear physics component, learners engage in tasks such as calculating energy released in reactions using real data and comparing fission and fusion processes. Group projects, model-building, and analytical discussions support understanding of nuclear stability, energy production, and reactor components. Role-plays and case studies are also used to highlight radiation hazards and safety practices.

Overall, the pedagogical exemplars emphasise learner participation, inquiry, and reflection, enabling the development of scientific reasoning, problem-solving skills, and awareness of real-world applications. The approach ensures that learning is both meaningful and applicable beyond the classroom.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/ or Mode
Describe how x-rays are produced Distinguish between hard x-rays and soft x-rays Calculate the energy, frequency and wavelength of x-rays. Identify sectors where x-rays are applied and how they are applied.	Level 2	*Essay type*
Calculate the energy released in a nuclear reaction. Distinguish between fission and fusion. Describe the process of power generation using a nuclear reactor.	Level 4	*Case study*, *Homework*

WEEK 7

Learning Indicators

1. *Describe how x-rays are produced*
2. *Distinguish between hard x-rays and soft x-rays*
3. *Calculate the energy, frequency and wavelength of x-rays*
4. *Identify sectors where x-rays are applied and how they are applied*

FOCAL AREA: X-RAYS: NATURE, PRODUCTION, PROPERTIES, AND APPLICATIONS

Nature and Production of X-rays

X-rays are a form of **electromagnetic radiation** characterised by extremely short wavelengths (from about 0.01 to 10 nanometres) and correspondingly high frequencies and energies. They occupy a region of the electromagnetic spectrum between ultraviolet light and gamma rays. Unlike visible light, X-rays have enough energy to penetrate many materials, including human tissue, which makes them invaluable in medical imaging and industrial inspection.

How are X-rays produced?

The most common source of X-rays is the **X-ray tube**, a vacuum tube where electrons are accelerated by a high voltage (typically tens to hundreds of thousands of volts) from a heated cathode toward a metal anode target (usually tungsten due to its high melting point and atomic number).

When the high-speed electrons collide with the anode, their kinetic energy is converted into electromagnetic radiation-X-rays-via two main processes:

1. **Bremsstrahlung Radiation (Braking Radiation):** Electrons are decelerated or deflected by the electric field of atomic nuclei in the anode. This sudden change in velocity causes the electrons to emit a continuous spectrum of X-ray energies. The spectrum ranges from zero up to a maximum energy corresponding to the electron's initial kinetic energy.
2. **Characteristic X-rays:** When an incoming electron knocks out an inner-shell electron from the anode atom, an electron from a higher energy level de-excites to fill the vacancy. The energy difference between these levels is emitted as an X-ray photon with a specific energy characteristic of the anode material.

Key points

a. The energy and intensity of produced X-rays depend on the accelerating voltage and current.

b. Tungsten is preferred for the anode because it withstands high temperatures and produces efficient X-rays.

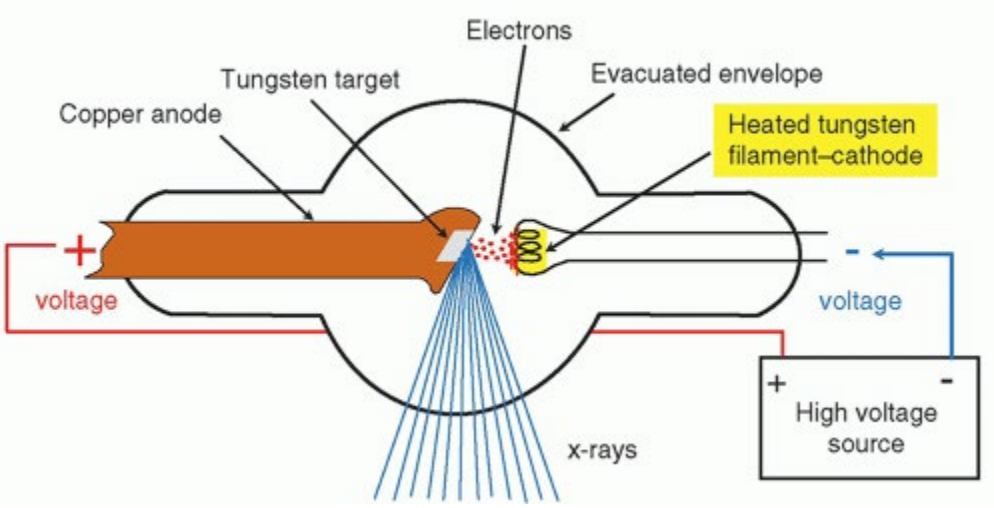


Figure 4.1: *Diagram of an X-ray tube*

How the X-ray Tube Works: Functions of the Parts

a. **Filament (Cathode):** Heats up to emit electrons by thermionic emission.

b. **Anode (Target):** Usually tungsten, chosen for its high melting point and atomic number, converts electron kinetic energy into X-rays.

c. **Glass Envelope:** Maintains vacuum to allow free electron movement.

d. **Cooling System:** Often a rotating anode or cooling fins to dissipate heat generated.

e. **High Voltage Supply:** Accelerates electrons from cathode to anode.

The X-rays exit the tube through a thin window and are directed toward the object or patient for imaging or analysis.

Properties and Characteristics of X-rays

a. **Penetration Power:** X-rays can pass through soft tissues but are absorbed by denser materials like bones or metals. This property is the basis for medical imaging and industrial inspection.

b. **Ionising Ability:** X-rays can knock electrons out of atoms, creating ions. This ionisation can damage living cells, which is why exposure must be controlled.

c. **No Mass or Charge:** X-rays are photons, so they have no mass or electric charge, allowing them to travel in straight lines and not be deflected by electric or magnetic fields.

d. **Wavelength and Energy:** Their short wavelengths correspond to high energies, typically from 100 eV to over 100 keV.

e. **Fluorescence:** X-rays can cause certain materials to emit visible light, which is used in detectors and imaging screens.

Types of X-rays: Soft and Hard

a. **Soft X-rays**

- Lower energy (<10 keV), longer wavelength
- Less penetrating, absorbed by air and thin materials
- Used in surface imaging and some medical applications like mammography.

b. **Hard X-rays**

- Higher energy (>10 keV), shorter wavelength
- More penetrating, pass through bones and dense objects
- Used in general radiography, CT scans, industrial inspection.

Energy of X-rays

The energy of an X-ray photon is directly related to its frequency and inversely related to its wavelength:

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

where:

- E is the photon energy (Joules),
- h is Planck's constant ($h = 6.6 \times 10^{-34}\ Js$),
- f is frequency (Hz),
- c is speed of light (m/s),
- λ is wavelength (m).

In practical terms, the energy of X-rays produced depends on the accelerating voltage in the X-ray tube: higher voltage produces higher energy (harder) X-rays.

Applications of X-rays: From Medicine to Industry

X-rays have revolutionised many fields:

a. **Medicine**
   i. **Radiography:** Imaging bones, chest, and dental structures.
   ii. **Computed Tomography (CT):** Produces detailed cross-sectional images.
   iii. **Radiotherapy:** Uses high doses of X-rays to kill cancer cells.

b. **Industry**
   i. **Non-destructive Testing:** Detecting cracks or flaws in metal parts without damage.
   ii. **Security:** Scanning luggage and cargo for contraband or threats.

c. **Science**
   i. **X-ray Crystallography:** Determining atomic and molecular structures of crystals.
   ii. **Material Analysis:** Studying composition and defects.

d. **Agriculture**
   i. **Checking Seed Quality:** X-rays can show if seeds are healthy or damaged inside. This helps select the best seeds for planting to get better crops.
   ii. **Detecting Plant Diseases and Pests:** X-rays can find pests or diseases inside fruits or grains early, so farmers can treat them before they spread.
   iii. **Studying Soil and Roots:** Scientists use X-rays to see how roots grow and how soil is structured, which helps improve watering and soil care.
   iv. **Quality Control After Harvest:** X-rays check fruits, nuts, and grains for internal damage or defects before they reach the market.

e. **Sterilising Seeds and Food:** X-rays can kill germs and pests on seeds or food without

chemicals, making them safer and cleaner.

Hazards and Safety Precautions

Because X-rays are ionizing, they can damage living tissue. Safety is paramount.

Hazards include

a. DNA damage leading to mutations or cancer.

b. Radiation burns.

c. Acute radiation sickness at high doses.

d. Genetic effects on reproductive cells.

Safety measures

a. **Shielding:** Lead aprons, thyroid collars, and barriers protect patients and staff.

b. **Distance:** Operators keep a safe distance or stay behind protective screens.

c. **Time:** Minimise exposure duration.

d. **Controlled Areas:** X-ray rooms are clearly marked, and access limited during use.

e. **Monitoring:** Personnel wear dosimeters to track exposure.

f. **Proper Training:** Only qualified personnel operate X-ray equipment.

g. **Equipment Maintenance:** Regular checks ensure safety features work correctly.

Learning Tasks

1. Observe a simulation or video of X-ray production and identify the roles of the cathode, anode, and accelerating voltage, then describe how X-rays are produced.
2. Create a poster or slide presentation showing the steps in X-ray production, including labelled diagrams, properties, and everyday uses.
3. Complete a worksheet that matches X-ray properties to their applications and compare soft and hard X-rays based on energy and penetration.
4. Research how X-rays are used in different sectors (e.g., medicine, security, industry) and explain which type of X-ray is used and why.
5. Solve problems using the formula E=hf to calculate the energy of X-rays, then decide whether they are hard or soft X-rays based on their energy.

Pedagogical Exemplars

Talk for Learning

Lead a discussion on the biological effects of excessive exposure to X-rays. Use real-world examples (e.g., protective lead aprons for radiographers). Ask learners to list **safety precautions** and explain the importance of shielding and minimising exposure time.

Enquiry-Based Learning

Guide learners to observe a multimedia simulation or video on how X-rays are produced in an X-ray tube. Pause at key moments to discuss the roles of the cathode, anode, and accelerating voltage. Prompt learners to identify the production process, characteristics, and uses of X-rays as they observe.

Collaborative Learning

Assign groups to create a brief **poster or slide presentation** showing the steps in X-ray production. Instruct them to include labelled diagrams, key properties, and real-life applications. Display posters for peer feedback.

Provide each group with a different sector (e.g., medicine, security, industry). Ask them to research specific applications of X-rays in that sector and present findings. Ensure they identify the type of X-ray (hard or soft) relevant to the use.

Problem-Based Learning

Present learners with a table of **X-ray properties** (e.g., high frequency, ability to penetrate materials, travel in straight lines). Compare **hard and soft X-rays** based on energy and penetration. Let learners complete a worksheet matching properties to applications.

Revise the photon energy formula E=hf from Year 1. Provide problems where learners calculate the frequency or energy of X-rays based on given potential differences or energy levels. Use differentiated worksheets with scaffolds for support or extension

Key Assessment Level 2: Essay

1. Describe what happens to high-speed electrons when they strike the metal target in an X-ray tube and explain how this leads to the emission of X-rays.

4 marks

2. A radiographer uses soft X-rays instead of hard X-rays for imaging soft tissues. Explain why soft X-rays are more suitable for this purpose.

5 marks

3. An X-ray photon has a wavelength of $5.0 \times 10^{-11}\ m$. Calculate its energy and interpret whether it is a hard or soft X-ray.

$$h = 6.63 \times 10^{-34}\ Js, c = 3.0 \times 10^{8}\ ms^{-1}]$$

5 marks

PLC Session 7

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***essay***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the essay (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 8

Learning Indicators

1. *Calculate the energy released in a nuclear reaction*
2. *Distinguish between fission and fusion*
3. *Describe the process of power generation using a nuclear reactor*

FOCAL AREA: NUCLEAR REACTIONS AND ENERGY GENERATION

Nuclear Reactions

Nuclear reactions involve changes within the nucleus of an atom, resulting in the release or absorption of energy. This energy release can be explained by Einstein's famous equation, $\mathbf{E=mc^2}$, which establishes the equivalence of energy (E) and mass (m), with c representing the speed of light. In nuclear reactions, a small amount of mass can be converted into a tremendous amount of energy.The energy released in a nuclear reaction, often referred to as the Q-value, can be calculated by determining the difference in mass between the reactants and the products. If the total mass of the products is less than the total mass of the reactants, energy is released (exothermic reaction). Conversely, if the products have greater mass, energy must be supplied for the reaction to occur (endothermic reaction). This mass difference, or mass defect, is directly proportional to the energy released.

Mass Defect and Binding Energy

The mass defect is the difference between the mass of a nucleus and the sum of the masses of its individual nucleons (protons and neutrons). This "missing" mass is converted into the binding energy, which is the energy that holds the nucleus together. The greater the binding energy per nucleon, the more stable the nucleus. When nucleons combine to form a nucleus, energy is released, which is why the mass of the nucleus is less than the sum of the individual nucleons.

Calculating Energy Release (Q-value)

The Q-value is calculated using the formula: $Q = (m_{reactants} - m_{products}) \times c^2$

where:

Q is the energy released (or absorbed)

is the total mass of the reactants

is the total mass of the products

c is the speed of light (approximately 3 x 108 m/s)

Units: If mass is in atomic mass units (amu), energy can be expressed in MeV (megaelectron volts). 1 amu = 931.5 MeV/c^2

Nuclear Fission and Fusion

Nuclear Fission

Nuclear fission is the process in which a heavy nucleus splits into two or more smaller nuclei, along with the release of a significant amount of energy.

Fission is typically initiated by bombarding a heavy, unstable nucleus, such as uranium-235, with a neutron. This causes the nucleus to become highly unstable, leading it to split. In addition to the smaller nuclei, several neutrons are also released, which can trigger further fission reactions, leading to a chain reaction. This chain reaction is the basis for nuclear power generation and atomic weapons.

Chain Reaction: The neutrons released in a fission event can induce fission in other nearby nuclei, creating a self-sustaining chain reaction.

a. Critical Mass: The minimum amount of fissile material needed to sustain a chain reaction.

b. Control: In nuclear reactors, control rods are used to absorb neutrons and regulate the chain reaction.

Energy Release: Fission releases a large amount of energy because the binding energy per nucleon is greater for the fission products than for the original heavy nucleus.

Applications

a. Nuclear power plants use controlled fission to generate electricity.

b. Nuclear weapons use uncontrolled fission for explosive energy.

Nuclear Fusion

Nuclear fusion is the process in which two or more light nuclei combine to form a heavier nucleus, also releasing a substantial amount of energy.

Fusion occurs under extreme conditions of high temperature and pressure, such as those found in the core of the Sun. A common example is the fusion of hydrogen isotopes (deuterium and tritium) to form helium. Fusion releases even more energy per unit of mass than fission. It is the process that powers the Sun and other stars. Scientists are working to develop controlled fusion for energy production on Earth.

Conditions for Fusion

c. High Temperature: To overcome the electrostatic repulsion between the positively charged nuclei.

d. High Pressure: To increase the probability of collisions between the nuclei.

Energy Release: Fusion releases even more energy per unit of mass than fission because the binding energy per nucleon is significantly greater for the lighter nuclei involved in fusion than for the heavier nuclei.

Examples of Fusion

e. Deuterium-Tritium Fusion: $2H + 3H \rightarrow 4He + n + \text{energy}$

f. Proton-Proton Chain: The primary fusion process in the Sun.

Applications

- The sun and stars generate energy through fusion.
- Fusion reactors are experimental and promise clean energy in the future.

Comparison between Fission and Fusion

Aspect	Nuclear Fission	Nuclear Fusion
Process	Splitting heavy nucleus into smaller ones	Combining light nuclei into heavier nucleus
Natural Occurrence	Does not occur naturally	Occurs naturally in stars (e.g., Sun)
Energy Released	High, but less than fusion	Three to four times more than fission
Energy Requirement	Requires neutron bombardment	Requires extremely high temperature and pressure
Byproducts	Produces long-lived radioactive waste	Minimal radioactive waste
Applications	Nuclear reactors, atomic bombs	Stars, experimental fusion reactors
Safety Concerns	Radioactive waste, meltdown risk	Technical challenges in containment

The Nuclear Reactor

A nuclear reactor is a device designed to control nuclear chain reactions, primarily for the purpose of generating electricity.

Components of a Nuclear Reactor

a. **Fuel**: Typically, enriched uranium, providing the material for fission. Enrichment- the process of increasing the concentration of the fissile isotope (e.g., uranium-235) in the nuclear fuel.

b. **Moderator**: A substance (e.g., water, graphite) that slows down neutrons to increase the probability of fission. Slow neutrons, called thermal neutrons, are more likely to be captured by uranium-235 nuclei and cause fission.

c. **Control Rods:** Rods made of neutron-absorbing material (e.g., cadmium, boron) that can be inserted or withdrawn to control the rate of the chain reaction. Control rods absorb neutrons, preventing them from causing further fission reactions. Inserting the rods slows or stops the chain reaction; withdrawing them increases the reaction rate.

d. **Coolant:** A fluid (e.g., water, liquid sodium) that circulates through the reactor core to remove heat. The coolant removes the heat generated by fission, preventing the reactor core from overheating.

e. **Pressure Vessel**: A strong container that houses the reactor core and coolant under high pressure. The pressure vessel is designed to withstand the high temperatures and pressures within the reactor.

f. **Steam Generator:** (in some designs) A heat exchanger where the heat from the coolant is used to boil water, producing steam. In some reactor designs (pressurised water reactors or PWRs), a steam generator isolates the radioactive coolant from the turbine system.

g. **Turbine and Generator:** The steam drives a turbine, which is connected to a generator to produce electricity. The turbine converts the thermal energy of the steam into mechanical energy, which the generator then converts into electrical energy.

h. **Containment Structure**: A robust structure that surrounds the reactor to prevent the release of radioactive materials in case of an accident. The containment structure is a critical safety feature, designed to contain any radioactive releases from the reactor core.

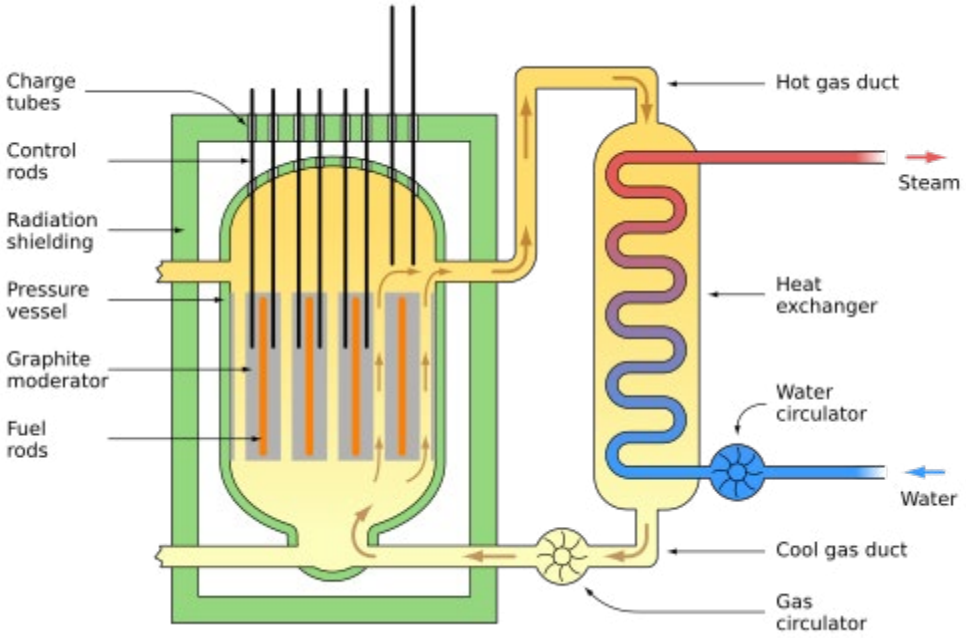


Figure 4.2: *Diagram of a nuclear reactor system*

Working Principle

Neutrons strike fuel nuclei, causing fission and releasing energy as heat. Control rods adjust to maintain a steady reaction rate. Moderator slows neutrons to sustain fission. Heat is transferred by the coolant to generate steam. Steam drives turbines connected to electric generators.

Hazards from Radiation and Precautions for Disposal

Hazards of nuclear radiation

a. **Biological Damage:** Ionizing radiation can damage DNA, causing mutations, cancer, and cell death.

b. **Acute Effects:** High doses cause radiation sickness, burns, and can be fatal.

c. **Long-term Effects:** Increased cancer risk and genetic mutations.

d. **Environmental Contamination:** Radioactive materials can pollute air, soil, and water, affecting ecosystems.

Safety precautions (similar to those used in environments producing x-rays):

a. **Shielding:** Use of lead, concrete, or water barriers to block radiation.
b. **Distance:** Increasing distance from radiation sources reduces exposure.
c. **Time:** Minimising exposure duration lowers dose.
d. **Protective Clothing:** Lead aprons, gloves, and goggles for workers.
e. **Waste Disposal:**
    i. **Low-level waste:** Stored in sealed containers in shallow landfills.
    ii. **High-level waste:** Vitrified (turned into glass) and stored deep underground in geological repositories.
f. **Regulations:** Strict international and national guidelines (e.g., IAEA) govern radiation use and waste disposal.
g. **Monitoring:** Use of dosimeters to track radiation exposure of workers.

Learning Tasks

1. Research Einstein's mass-energy relation $E = \Delta mc^2$ using real examples from nuclear reactions, and present the findings as a group poster or short presentation.
2. Use atomic mass data to calculate the mass defect and binding energy per nucleon for selected nuclei, then discuss how this relates to nuclear stability.
3. Compare nuclear fission and fusion using diagrams or animations, and complete a table showing differences in source nuclei, products, energy output, and required conditions.
4. Build a poster or model showing either the fission or fusion process, including inputs, outputs, and where each process occurs.
5. Label and explain the function of nuclear reactor components, then complete a matching or diagram-reconstruction activity to reinforce understanding.

Pedagogical ExemplarsTalk for Learning

Use side-by-side video animations or diagrams showing both fission and fusion processes. Guide learners to compare the source nuclei, products, conditions required, and energy output. Follow up with a discussion.

Enquiry-Based Learning

Play a short documentary or clip on the Chernobyl accident. Ask learners to reflect on the cause, consequences, and what safety lessons were learned. Use follow-up questions to connect with radiation hazards.

Problem-Based Learning

Provide learners with atomic mass data of selected nuclei. In groups, guide them to calculate mass defect and binding energy per nucleon. Use this to discuss nuclear stability.

Project-Based Learning / Collaborative Learning

Assign a research task where learners explore Einstein's mass-energy relation $E = \Delta mc^2$, using real examples from nuclear reactions. Let them present findings in brief group presentations or visual posters.

Guide learners to work in groups to create a poster or 3D model showing how fission or fusion occurs, including inputs, outputs, and energy released. Each group explains which process occurs in stars or reactors.Provide a labelled diagram of a nuclear reactor. In pairs, ask learners to explain the function of key components (fuel rods, moderator, control rods, coolant). Reinforce with a matching activity or jumbled diagram reconstruction.

Set up a role-play where learners act as nuclear workers, doctors, and environmental officers explaining radiation dangers and how to handle waste. Complement with a worksheet identifying warning signs and protective equipment.

Key Assessment Level 4: Case Study

1. Given a scenario where a country faces a choice between investing in nuclear fusion or continuing with nuclear fission for energy production, construct a reasoned argument for which option should be chosen, considering efficiency, sustainability, cost, and environmental impact.

10 marks

2. A single uranium-235 nucleus undergoes fission. The total mass of the reactants is 236.0526 u, and the total mass of the products is 235.8473 u.
   a. Calculate the energy released in this reaction in MeV.
   b. If 1 kg of uranium-235 undergoes complete fission, calculate the total energy released in Joules.
   c. Strategically analyse how this amount of energy compares to the combustion of 1 kg of coal, which releases approximately 3×10^7 J. What does this suggest about the advantages of nuclear power? [e=1.6x10-^{19} C]

11 marks

PLC Session 8

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*

- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***case study***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the case study (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 4 Review

This section has focused on two key areas within the strand of Atomic and Nuclear Physics: X-rays and Their Applications and Nuclear Reactions and Energy Generation. Over the past two weeks, learners should have developed both conceptual understanding and analytical skills related to how atomic and nuclear processes are harnessed for practical uses in medicine, industry, and energy production.

In week 7, the emphasis was on understanding the nature and production of X-rays. Learners should have explored how X-rays are generated in an X-ray tube when high-speed electrons collide with a metal target, producing electromagnetic radiation through Bremsstrahlung (braking radiation) and characteristic radiation. They should have studied the structure and function of key components of the X-ray tube—including the cathode, anode, focusing cup, and high-voltage supply—and understood how changes in voltage influence the energy of emitted X-rays. Learners should also have distinguished between soft X-rays (low energy, low penetration) and hard X-rays (high energy, deep penetration), identifying their specific applications across various sectors.

In addition, learners were expected to understand and apply the relationship between energy, frequency, and wavelength of X-rays using the formula: $E = hf = h\frac{c}{\lambda}$

They should have applied this knowledge to calculate the energy of X-rays and determine whether they are classified as soft or hard. Furthermore, the properties of X-rays—including their ionizing ability, straight-line travel, and fluorescence—were connected to real-world uses in medical imaging, industrial inspection, security scanning, and agricultural quality control. The week concluded with a focus on radiation hazards and safety measures, emphasising the importance of shielding, exposure limits, and protective equipment.

During week 9, attention shifted to the topic of nuclear reactions and energy production. Learners should have been introduced to the concept of mass-energy equivalence through Einstein's equation $E=mc^2$, and used it to calculate the energy released in nuclear reactions. The idea of mass defect and binding energy was explored to explain why energy is released when nuclei undergo fission or fusion. Learners should have distinguished between nuclear fission—the splitting of a heavy nucleus—and nuclear fusion—the merging of light nuclei—and compared their processes, energy outputs, fuel requirements, and environmental impacts.

They should also have studied the structure and operation of a nuclear reactor, identifying the roles of fuel rods, moderator, control rods, coolant, and containment structure in maintaining a controlled chain reaction. The concept of Q-value was introduced to calculate energy release from mass differences, using data in atomic mass units (amu). In addition, the section addressed the hazards of radiation, including biological effects and contamination risks, and examined safe waste disposal methods and regulatory guidelines for handling radioactive materials.

By the end of the two-week period, learners should have acquired the ability to explain the production and properties of X-rays, perform calculations involving photon energy, differentiate between fission and fusion, and describe how nuclear energy is harnessed and managed safely. These concepts provide a strong foundation for further study in medical physics, nuclear technology, and energy systems.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 7

Rubrics

Question 1

- When electrons hit, they can knock electrons out of target atoms
- When electrons in the target atoms rearrange (de-excite), X-rays are produced
- Alternatively, fast electrons can slow down suddenly when hitting the target, releasing X-rays
- Most of the energy becomes heat, only some few becomes X-rays.

4 marks

Question 2

- Soft X-rays have lower energy than hard X-rays
- Soft X-rays don't penetrate as deeply as hard X-rays
- Soft X-rays are partially absorbed by soft tissues, creating visible differences in the image
- Hard X-rays would mostly pass through soft tissues, creating little contrast (like taking a photo with too much light)
- The right X-ray energy needs to be chosen for the specific tissue being examined

5 marks

Question 3

Step	Marks
1. Correct formula used: $E = \frac{hc}{\lambda}$	*1 mark*
2. Substitution of values: $E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{5.0 \times 10^{-11}}$	*1 mark*
3. Correct calculation: $E = 3.978 \times 10^{-15}\ J$	*1 mark*
4. Identification that the wavelength is very short (in the range of hard X-rays)	*1 mark*
5. Correct conclusion: It is a hard X-ray due to high energy and short wavelength	*1 mark*

5 marks

WEEK 8

Question 1

Use the table below to award a grade to the learner; you should identify which description in the 'what to look for' matches their work most accurately.

Component	Mark Level	What to Look For
Basic Understanding of Technologies *[2 marks]*	*2 marks*	*• Correctly identifies that fusion joins atomic nuclei together while fission splits them* *• Mentions at least one primary fuel for each (fusion: hydrogen isotopes; fission: uranium or plutonium)* *• May mention current status (fission – established technology; fusion – still in development)*
	1 mark	*• Shows partial understanding of the difference between fusion and fission* *• Basic processes discussed*
Analysis: Efficiency & Sustainability *[2 marks]*	*2 marks*	*• Discusses energy output potential of both technologies* *• Mentions fuel availability and longevity for both options* *• Makes reasoned comparison between the options*
	1 mark	*• Some mention of energy output or fuel supply* *• Some comparison between options*
Analysis: Cost & Practicality *[2 marks]*	*2 marks*	*• Discusses development/construction costs for both technologies* *• Mentions timeline considerations (fusion is future technology, fission is available now)* *• Addresses operational costs or economic factors* *• Considers practical implementation challenges*
	1 mark	*• Some mention of cost factors* *• Limited discussion of timeline or practical challenges* *• Simplistic cost analysis*
Analysis: Environmental Impact & Safety *[2 marks]*	*2 marks*	*• Discusses waste products and management for both technologies* *• Addresses safety concerns and accident potential* *• Mentions radiation considerations* *• Compares environmental footprint of both options*

	1 mark	*• Some mention of environmental or safety factors* *• Limited comparison between options* *• Simple environmental analysis*
Argument Quality & Conclusion *[2 marks]*	*2 marks*	*• Takes a clear position on which option should be chosen* *• Provides logical reasoning for position* *• Addresses potential counterarguments* *• Shows balanced consideration of factors* *• Conclusion follows from presented evidence*
	1 mark	*• Takes a position with simple rationale* *• Mention of opposing viewpoints*

Question 2

a.

Step	Marks
1. Correct calculation of mass defect: $\Delta m = 236.0526\,u - 235.8473\,u = 0.2053\,u$	*1*
Use of correct conversion factor of 931MeV/u: $E = \Delta m \times 931 = 0.2053 \times 931 = 191.2\,MeV$	*1*
Correct final answer with unit: $E = 191.2\,MeV$	*1*

3 marks

b.

Step	Marks
1. Correct number of moles in 1kg *= mass/molar mass* *= 1000g/235gmol−1* *= 1/0.235*	
2. Correct number of atoms in 1 kg of U−235: $\frac{1}{0.235} \times 6.02 \times 10^{23} = 2.56 \times 10^{24} atoms$	*1*
3. Convert energy per atom from MeV to joules: $191.2\,MeV = 191.2 \times 1.602 \times 10^{-19}\,J$	*1*

4. Multiply energy per atom by total atoms: $E = 2.56 \times 10^{24} \times 3.06 \times 10^{-17} \approx 7.84 \times 10^{7}\ J$	*1*

4 marks

c.

Criteria	Marks
1. Comparison made using numerical ratio or qualitative reasoning (e.g., nuclear ≫ coal)	*1*
2. Explanation of what the difference in energy implies about nuclear energy efficiency	*1*
3. Conclusion drawn on advantages (e.g., higher energy density, less fuel required, etc.)	*1*
4. Balanced argument including at least one disadvantage of nuclear fission.	*1*

4 marks

SECTION 5: ASTRONOMY AND COSMOLOGY

STRAND: MECHANICS AND MATTER

Sub-Strand: Basic Physics

Week 9 & 10

Content Standard: *Demonstrate knowledge and understanding of the basics of space science.*

Learning Outcome: *Use the knowledge in space science to explain the world beyond the earth.*

INTRODUCTION AND SECTION SUMMARY

This section introduces learners to the vast and fascinating field of astronomy. Building on their earlier understanding of matter and energy, learners now explore the structure of the universe, its origins, and the celestial objects it contains. They learn about galaxies, the formation of stars and planets, and the observable phenomena that occur in space, such as meteors and comets. The section also helps learners understand the difference between scientific and cultural explanations of the universe, encouraging them to value local knowledge systems alongside global scientific models.

Learners will compare cultural beliefs about the sky with scientific interpretations, investigate how the universe has evolved over time, and explore the importance of space science to Ghana's development. Through engaging tasks, inclusive activities, and real-life connections, this section aims to spark curiosity, develop scientific reasoning, and foster respect for both traditional knowledge and modern research.

The weeks and the indicators covered by the section are:

- ***Week 9***

  Explain the universe and its composition as applied to astronomy and cosmology.

  Explain how our indigenous culture benefits from and applies to astronomy and cosmology.

  Explain the formation of the sun, planets and stars.

- ***Week 10***

  Describe galaxies and their various types - elliptical, spiral, irregular, quasars, blazers, Lenticular, active, seyfert.

  Explain how extra solar objects such as Comets, Asteroids and Constellations affect our culture and society.

SUMMARY OF PEDAGOGICAL EXEMPLARS

The pedagogical exemplars for this section combine talk for learning, experiential activities, and collaborative strategies to help learners interpret and apply knowledge about galaxies, celestial phenomena, and cultural astronomy. Learners engage in discussions, model construction, storytelling, and visual presentations to compare scientific explanations with traditional beliefs. These approaches encourage deeper understanding through comparison, classification, and context-based reasoning. All activities are designed to be inclusive, using tactile materials, visual aids, and accessible formats to ensure participation by all learners, including those with visual or hearing impairments.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Explain the universe and its composition as applied to astronomy and cosmology. Explain how our indigenous culture benefits from and applies to astronomy and cosmology. Explain the formation of the sun, planets and stars.	Level 2	Constructed response, essay
Describe galaxies and their various types; elliptical, spiral, irregular, quasars, blazers, Lenticular, active, Seyfert. Explain how extra solar objects such as Comets, Asteroids and Constellations affect our culture and society.	Level 2	Constructed response, essay

WEEK 9

Learning Indicators

1. *Explain the universe and its composition as applied to astronomy and cosmology*
2. *Explain how our indigenous culture benefits from and applies to astronomy and cosmology*
3. *Explain the formation of the sun, planets and stars*

FOCAL AREA: THE UNIVERSE: ORIGIN, STRUCTURE, AND CULTURAL PERSPECTIVES

The universe is everything—literally. It includes all space, time, energy, and matter. Every galaxy, star, planet, comet, rock, cloud of gas, drop of water, and grain of sand, as well as things we cannot see—like dark matter and energy—all exist within the universe.

Figure 5.1: *Scan the QR code to observe a video on the explanation of the Big Bang Theory and how the Universe began.*

We live on a small planet called Earth, which orbits a star called the Sun, located in a galaxy called the Milky Way. The Milky Way is just one of billions of galaxies. These galaxies, in turn, are scattered across the vast universe, with unimaginable distances between them.

Astronomy helps us study the objects in the universe—stars, planets, moons, asteroids, and galaxies. Cosmology, a branch of astronomy, studies the origin and evolution of the universe itself.

One of the most important questions scientists ask is: Where did the universe come from? While many ideas have been proposed, the most accepted scientific explanation is the Big Bang Theory.

The Big Bang Theory is a scientific model that explains how the universe began. It suggests that the universe started from an extremely small, hot, and dense point about 13.8 billion years ago. Then, in a fraction of a second, it began to expand—and it is still expanding today.

This doesn't mean there was an "explosion." The Big Bang was an expansion of space itself. The expansion of space is a key idea in understanding how the universe changes over time. It means that the space between galaxies is stretching, like dots on the surface of a balloon getting farther apart as the balloon inflates. This expansion does not mean galaxies themselves are growing larger, but rather that the space between them is increasing. When astronomers observe distant galaxies, they see that the light coming from them is stretched out—this is called **redshift**, and it is strong evidence that the universe is expanding in all directions. The idea comes from the **Big Bang Theory**, which suggests that the universe began as a tiny, hot, and dense point and has been growing ever since. Importantly, the expansion of space doesn't happen into something else—space itself is growing, carrying galaxies along with it. This helps us understand why galaxies appear to be moving away from each other the farther they are from us.

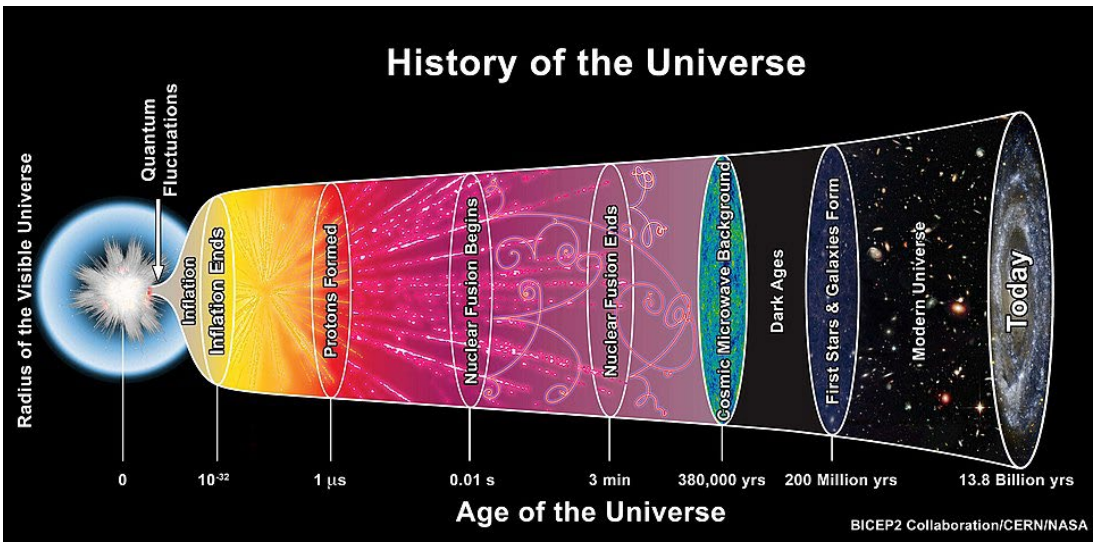


Figure 5.2: *A colourful, cone-shaped timeline illustrating the history of the universe.*

The theory is supported by strong evidence:

- The redshift of galaxies – showing that galaxies are moving away from us
- Cosmic microwave background radiation – leftover energy from the early universe
- The relative abundance of elements, like hydrogen and helium, which match predictions

Important Note for Teachers:

The Big Bang is a scientific theory, not a proven fact. This means it is a well-tested explanation supported by evidence, but it is open to refinement as new discoveries are made.

The universe contains many types of objects. These include:

a. Stars – Huge balls of hot glowing gas. They produce energy through nuclear fusion. Our Sun is a star.

b. Planets – Objects that orbit stars. They do not emit their own light. Earth is one of eight planets orbiting the Sun.

c. Moons – Objects that orbit planets. Earth's moon affects tides and has phases.

d. Galaxies – Massive collections of billions of stars. The Milky Way is our galaxy.

e. Nebulae – Clouds of gas and dust where stars are born.

f. Asteroids and comets – Small rocky or icy objects moving through space.

g. Meteors – Also called shooting stars; bits of rock that burn up in Earth's atmosphere.

h. Dark matter and dark energy – Invisible substances that make up most of the universe. We know they exist by the way galaxies move, but we do not yet fully understand them.

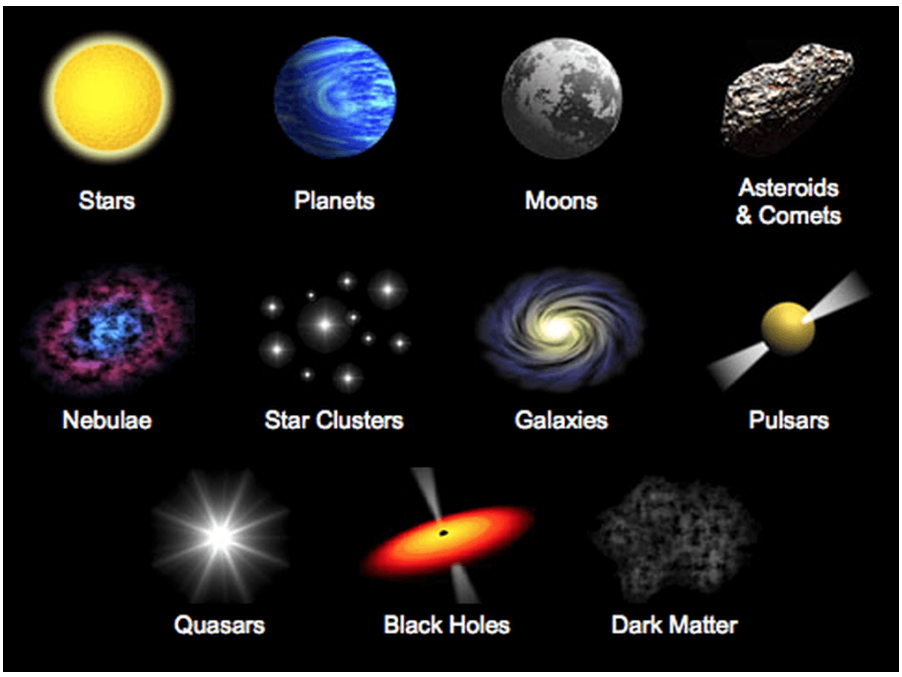


Figure 5.3 A grid of twelve illustrated astronomical objects.

Inclusive Tip: *Use tactile models for learners with visual impairments (e.g., a 3D model of the solar system or raised diagrams of galaxies). For deaf learners, provide captions or signed explanations of video animations showing how stars and galaxies form.*

All stars, including our Sun, are born in giant clouds of gas and dust called nebulae. Here's how it happens:

1. Gravity pulls gas and dust together, forming a dense ball called a protostar.
2. As it collapses, the temperature and pressure at the centre increase.
3. When the centre becomes hot enough, nuclear fusion begins—hydrogen atoms combine to form helium, releasing energy.
4. The star begins to shine. This is the birth of a main-sequence star.

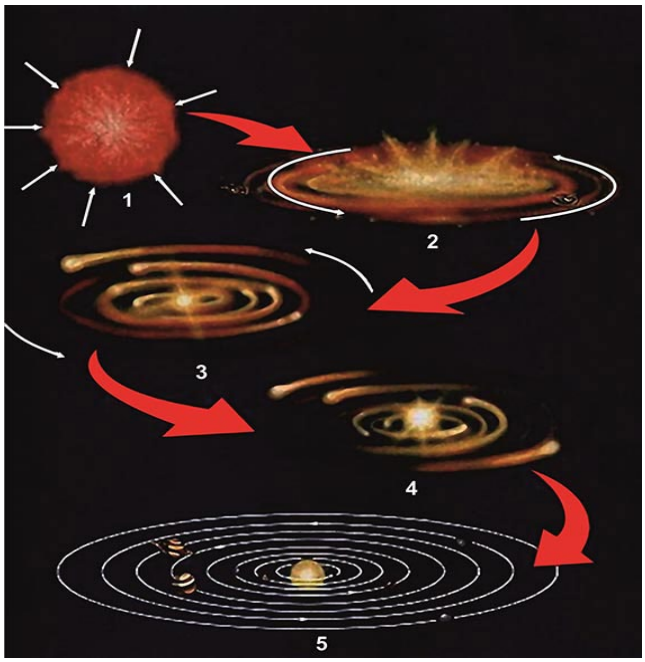


Figure 5.4: *Sequence of five stages showing the formation of the solar system, illustrated with swirling clouds and arrows.*

Around the newly formed star, the leftover gas and dust form a rotating disc. Over time, this material sticks together to form:

- Planets
- Moons
- Asteroids and comets

This process is called accretion. Accretion is the process by which small particles of dust and gas in space come together to form larger objects like planets.

It begins in a protoplanetary disk, a flat, rotating ring of material that surrounds a young star. This disk is made up of tiny grains of rock, ice, and gas. At first, these grains stick together through weak forces like static electricity, forming pebbles and small rocks. As these rocks grow, their gravity increases, pulling in more material around them. Over time, they become planetesimals—large, solid objects that can be tens or hundreds of kilometres across. When planetesimals collide and stick together, they form even larger bodies called protoplanets.

Eventually, these grow into the planets we know today. Accretion is a slow process, taking millions of years, but it explains how planets form naturally from the leftover material after a star is born. You can think of it like raindrops in a cloud combining to make larger drops—gravity acts like a glue that pulls more and more material together. Earth, along with the other planets in our solar system, formed this way about 4.6 billion years ago.

Before modern science, people used observation and tradition to understand the sky. In many cultures, including those in Ghana and across Africa, the stars, the Moon, and the Sun were carefully studied to guide farming, fishing, festivals, and religious ceremonies.

For example:

- Farmers looked at star patterns to decide when to plant or harvest.
- The phases of the Moon were used to plan market days, funerals, or rituals.
- Many communities passed down folktales and songs that describe how stars appeared or what they meant.

This knowledge is passed on orally and remains important in many areas today. It may not use the same language as science, but it reflects careful observation and deep understanding.

Science and culture are not enemies—they are two ways of understanding the same world. Scientific astronomy explains how stars and planets form and how the universe behaves. Cultural astronomy reflects how people interpret what they see in the sky and how they connect it to life.

Key Takeaways for Teachers

- The Big Bang Theory explains the universe's origin, but it is not the only explanation.
- The universe is made of many components: stars, planets, galaxies, and more.
- Stars and planets form through natural processes involving gravity and nuclear fusion.
- Indigenous cultures offer valuable knowledge based on sky observation.
- Teachers should support both scientific understanding and cultural appreciation.

Learning Tasks

1. Construct a timeline or diagram showing the formation of the universe, stars, and planets.
2. Classify celestial bodies into groups and present them in a structured display or chart.
3. Compare scientific and cultural views of the universe using interviews, texts, or videos.
4. Create a diagram or model to explain how stars and planets are formed.

Pedagogical Exemplars

Talk for Learning

a. Discuss what the universe means by guiding learners to think about "everything that exists" and listing visible and invisible components.

b. Use a balloon to simulate the expansion of the universe and introduce the Big Bang Theory as a scientific explanation.

c. Use analogies such as cosmic cities (galaxies) and flour becoming dough (accretion) to explain complex concepts.

d. Use printed or projected space images and prompt learners to describe differences between nebulae, galaxies, and stars.

e. Compare a traditional story about the sky with a scientific explanation, encouraging learners to share their thoughts on each.

Experiential Learning

a. Guide learners to build a tactile or visual timeline showing stages of the universe's formation from the Big Bang to galaxy formation.

b. Guide learners to create 3D or textured models of galaxies and solar systems using clay, cardboard, or everyday materials.

c. Demonstrate star formation using simple props (e.g. sponge and water for collapsing gas clouds) and explain gravity and heat buildup.

Collaborative Learning

a. Ask learners to collect local stories, proverbs, or beliefs related to the stars or moon and present them in a creative format. They should compare these with a scientific concept.

b. Learners collaboratively create a step-by-step flowchart on the formation of stars and planets, adding drawings or tactile representations.

Key Assessment Level 2: Constructed Response Essay

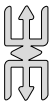
People across different cultures in Africa and Ghana have observed the sky for centuries, and modern science continues to explore the universe. Explain one way traditional or indigenous communities use the knowledge of the sun, moon, or stars in daily life.

[10 marks]

PLC Session 9

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



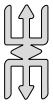
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***constructed response essay***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*

- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 10

Learning Indicators

1. *Describe galaxies and their various types; elliptical, spiral, irregular, quasars, blazers, lenticular, active, Seyfert*
2. *Explain how extra solar objects such as comets, asteroids and constellations affect our culture and society*

FOCAL AREA: EXPLORING GALAXIES AND CELESTIAL PHENOMENA: SCIENTIFIC AND CULTURAL PERSPECTIVES

In week 9, learners explored the structure of the universe and the formation of stars and planets. They learned that the universe is composed of galaxies—massive collections of stars, dust, gas, and other celestial bodies. This week builds on that foundation by taking a closer look at galaxies themselves, the celestial objects that exist beyond our solar system, and how different communities interpret what they see in the sky.



Figure 5.5: *A star-filled night sky with the Milky Way galaxy stretching diagonally across the image*

A galaxy is a vast system of stars and other matter bound together by gravity. Most galaxies contain billions of stars. Our own Sun is just one star within the Milky Way Galaxy. Galaxies are not randomly scattered in space—they are organised into structures. Galaxies gather in clusters, and clusters form superclusters, connected by massive cosmic filaments that form the large-scale structure of the universe.

Galaxies appear in different shapes and sizes. Scientists usually classify them into three main types:

- Spiral galaxies have flat, rotating discs with spiral arms that wind outward. They often contain many young stars and clouds of gas and dust. The Milky Way is a spiral galaxy.
- Elliptical galaxies are more rounded or oval in shape and are mostly made up of older stars. They tend to have very little dust or gas.
- Irregular galaxies do not have a regular shape. They may have been formed through gravitational interactions or galaxy collisions.
- Lenticular galaxies have a structure somewhere between a spiral and an elliptical galaxy. The have a central bulge and disc but lack prominent spiral arms. They are formed of mostly older stars.

Figure 5.6: *Scan the video to observe the classification of galaxies according to Hubble*

Astronomers study galaxies by observing the light they emit across different wavelengths. At the Ghana Radio Astronomy Observatory (GRAO), for example, scientists use radio waves to investigate galaxies and other distant objects that are not visible with regular telescopes. Radio astronomy makes it possible to study space even during the day or through clouds and dust that block visible light.

Beyond stars and galaxies, the universe contains other fascinating objects known as celestial phenomena. These include comets, asteroids, meteoroids, meteors, meteorites, and exoplanets. These objects vary in size, material, movement, and visibility.

A comet is a body made mostly of ice and dust. It travels in a long orbit around the Sun. As a comet approaches the Sun, the heat causes its icy surface to release gas and dust, forming a bright glowing tail that points away from the Sun (it does not 'trail behind' the comet, which is a common misconception). The tail and the fuzzy head of the comet can sometimes be seen in the sky without a telescope.

An asteroid is a rocky object that orbits the Sun, mostly found between the orbits of Mars and Jupiter in a region known as the asteroid belt. Some asteroids occasionally come close to Earth. They are irregular in shape and vary in size from small rocks to large bodies hundreds of kilometres wide.

A meteoroid is a smaller rock or metal fragment travelling through space. When a meteoroid enters Earth's atmosphere and burns up, it creates a bright streak of light known as a meteor, or what is commonly called a shooting star. If a part of the meteoroid survives the journey and lands on Earth, it is called a meteorite.

Exoplanets are planets that orbit stars outside our solar system. Thousands of them have been discovered using powerful telescopes. Some of these planets may have conditions suitable for life, which makes them a major focus of current astronomical research.

Each of these celestial objects plays a role in helping scientists understand the origin and structure of the solar system, the formation of planets, and the likelihood of life elsewhere in the universe. By comparing them, learners begin to develop a deeper understanding of how dynamic and diverse space truly is.

While science provides tools for explaining how celestial phenomena work, many cultures—including those in Ghana—have their own interpretations of what these events mean. Cultural astronomy refers to the way communities use the sky for storytelling, ritual, timekeeping, and guidance. This includes beliefs, symbols, myths, and ceremonies associated with celestial bodies and events. Eid-ul Fitr and Easter Sunday are dependent on the sighting of the crescent moon.



Figure 5.7: *Islamic Leaders in Kumasi, Ashanti Region, waiting to sight the crescent moon for the end of the Holy Month of Ramadan*

For example, in some communities, the appearance of a bright comet may be seen as a sign of change or warning. A shooting star might be interpreted as a message from ancestors, a soul transitioning, or an omen. Full moons often mark the time for communal gatherings, spiritual activities, or farming rituals. Constellations are identified in local terms and used to predict seasonal changes or navigation patterns.

These beliefs are usually passed on through oral traditions—stories, proverbs, songs, dances, and rituals—and form part of indigenous knowledge systems. Although they differ from scientific explanations, they are based on real observation and are used to organise social, agricultural, and spiritual life. This knowledge is important and should be respected as part of the broader human understanding of the cosmos.

Comparing cultural beliefs with scientific models allows learners to appreciate both ways of knowing. For example, a scientific explanation might describe a meteor as a rock burning up in Earth's atmosphere, while a cultural belief might interpret it as a star falling, sent by a spirit or a deity. Both views carry meaning—one from physical observation and the other from social or spiritual symbolism.

By exploring both scientific and cultural understandings, learners gain critical thinking skills and cultural awareness. They are encouraged not to reject one view in favour of another but to understand how different perspectives serve different purposes.

Space exploration is not only about satisfying curiosity about what lies beyond our world; it plays a crucial role in advancing technology, improving life on Earth, and preparing for the future. As learners begin to understand galaxies, stars, and celestial phenomena, it is important to see how this knowledge connects to real-world benefits.

Many of the tools and services we rely on today, such as mobile phones, satellite television, weather forecasts, and GPS navigation, are all made possible through technologies developed for space science. Even areas like agriculture and health benefit from space research. Satellites monitor soil moisture, track changes in forest cover, and observe ocean currents. In medicine, materials and techniques used in space exploration have inspired innovations in surgery and drug delivery systems.

In Ghana, space science and technology are emerging as important contributors to national development. The Ghana Space Science and Technology Institute (GSSTI) leads efforts to build capacity in astronomy, satellite technology, and atmospheric science. In Kuntunse, the Ghana Radio

Astronomy Observatory (GRAO) is already part of global space research, using radio waves to study black holes, galaxies, and pulsars. Ghana is also contributing to the African Very Long Baseline Interferometry Network, which links radio telescopes across Africa into a continent-wide observatory.



Figure 5.8: *The Ghana Radio Astronomy Observatory*

These initiatives support several important national goals. They promote science, technology, engineering, and mathematics (STEM) education by engaging young learners with the wonders of the universe. They open pathways to careers in astronomy, data science, and satellite communications—fields with growing demand across the world. They also help in addressing local challenges, such as monitoring environmental change, managing natural resources, and preparing for climate-related disasters.

For learners in Ghana, space exploration is not something far away. It is part of the country's present and future. Ghana launched a CubeSat, Ghana's first satellite – GhanaSat1 into space on February 9, 2017. This pioneering work was done by a team from All Nations University. As space science expands, it creates new possibilities for research, innovation, and international collaboration. Learners may one day find themselves working on space missions, designing satellite systems, or analysing astronomical data to understand both distant galaxies and their own communities.

By studying the universe, learners not only discover what lies beyond the sky—they also learn to ask questions, solve problems, and imagine bold solutions. In this way, astronomy becomes more than science: it becomes a tool for national growth and a path toward global relevance.

Learning Tasks

1. Research and describe the different types of galaxies using images, models, or accessible visual resources.
2. Compare comets, meteors, meteorites, asteroids, and exoplanets, identifying their features and explaining how they differ.
3. Investigate and document a cultural belief, story, or ritual in your community related to celestial objects or events.

4. Create a presentation, poster, signed video, or tactile exhibition comparing scientific and cultural interpretations of a selected celestial phenomenon.

Pedagogical Exemplars

Talk for Learning

a. Guide learners to describe the three types of galaxies—spiral, elliptical, and irregular—using visual or tactile diagrams, and compare their features in small group discussions.

b. Let Learners discuss the differences between comets, asteroids, meteors, and meteorites based on provided texts, images, or models.

c. Let Learners share cultural beliefs or stories they have heard about shooting stars, comets, or bright objects in the sky and compare them with scientific explanations.

d. Let Learners explain why space exploration is important and suggest ways Ghana benefits from astronomy, based on readings and class discussion.

Experiential Learning

Let Learners observe images or models of galaxies and construct their own representations using cardboard, fabric, or clay, with tactile elements for inclusive access.

Enquiry-Based Learning

Instruct Learners to use diagrams or simulations to trace the paths of comets and compare them with planetary orbits, recording differences in shape, speed, and composition.

Collaborative Learning

a. In groups, let learners design and present a galaxy comparison chart, illustrating types, shapes, and star content using diverse media.

b. Let Learners work in teams to prepare a comparison between scientific and cultural explanations of a chosen celestial phenomenon, sharing through role-play, storytelling, or dual-narrative displays.

c. Ask each group to selects one celestial object (e.g., comet or exoplanet), researches its features and relevance, and creates an exhibition display for peer review.

d. Let Learners map out how Ghana benefits from space science using an infographic, connecting fields like communication, weather forecasting, or STEM education.

Key Assessment Level 2: Constructed Response Essay

Question 1

a) Draw a single line from each galaxy type to match it to its characteristics (4 marks).

Spiral galaxy		Oval or spherical shape + mostly older stars
Elliptical galaxy		No definite shape + often result of galaxy collisions
Lenticular galaxy		Disc with spiral arms + contains young and old stars
Irregular galaxy		Disc without spiral arms + combination of spiral and elliptical features

b) Describe one galaxy type in detail. Give examples of what their shape, what they contain, how they are different to other galaxies and one named example of this galaxy type. (5 marks)

9 marks

Question 2

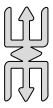
Research and write a paragraph on the **Milky Way Galaxy**: its type, features, and your location within it.

10 marks

PLC Session 10

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***constructed response essay***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 5 Review

In this section, learners explored the universe's composition and structure, beginning with the Big Bang Theory and the expansion of space. They examined different galaxy types, the formation of stars and planets, and key celestial phenomena such as comets, meteors, and exoplanets. Scientific concepts were reinforced through visual models, tactile diagrams, and comparisons with cultural beliefs, helping learners understand how both science and tradition interpret the sky.

Week 10 expanded on these ideas by introducing the practical benefits of space exploration, especially for Ghana. Learners discussed how institutions like GSSTI and GRAO contribute to national development through research, communication, and STEM education. Through inclusive, inquiry-based activities, learners connected astronomy to everyday life and gained confidence in applying scientific knowledge to real-world contexts.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 9

Sample Response (What to Expect from Students)

Example 1: Akan Agricultural Calendar. The Akan people of Ghana traditionally use observations of the sun and specific star patterns to determine their agricultural seasons. They observe the position of the sun at dawn to track seasonal changes, marking the transition between harmattan, planting season, and harvest periods. Farmers watch for specific stellar configurations to know when to prepare fields, plant yams and other crops, and when to expect rains. This celestial timing system has allowed communities to synchronize agricultural activities with natural cycles for generations, ensuring food security.

Example 2: Dogon Astronomical Knowledge. The Dogon people of Mali (West Africa) have extensive astronomical knowledge, particularly regarding the Sirius star system. They track the 50-year orbital cycle of Sirius B around Sirius A, which they incorporate into their religious and agricultural practices. Their observations help time planting seasons and religious ceremonies. This knowledge system demonstrates sophisticated astronomical understanding that has been preserved through oral tradition and remains relevant to community organisation and farming practices.

Example 3: Lunar Calendars in Ghanaian Festivals Many Ghanaian traditional festivals are timed according to lunar observations. For example, the Homowo festival of the Ga people is scheduled based on the lunar calendar, typically beginning with the sighting of a specific new moon. Similarly, the Damba festival celebrated by the Dagomba, Mamprusi, and Gonja people is timed according to lunar cycles. These celestial-based calendars ensure communities gather at appropriate times for cultural celebrations that often coincide with agricultural cycles.**What to Look For**

1. **Cultural Specificity**: Better responses will name actual Ghanaian or African ethnic groups rather than make general statements about "Africans."
2. **Authentic Practices**: Look for descriptions of genuine celestial knowledge systems from African traditions rather than invented or stereotypical examples.
3. **Practical Connection**: Strong answers will clearly explain how celestial observations directly benefit traditional life in African contexts.
4. **Contemporary Relevance**: Good responses may discuss how these traditional knowledge systems continue to have value alongside modern scientific understanding.

Component	Mark Level	Specific Things to Look For
Cultural Example Accuracy[2 marks]	*2 marks*	*• Names of a specific African/Ghanaian ethnic group (Akan, Ga, Ewe, Dagomba, etc.)* *• Describes an authentic celestial knowledge practice from African/ Ghanaian context* *• Shows understanding of how the practice relates to the specific culture* *• Provides details specific to the named community*

	1 mark	*• General reference to "Africans" or "Ghanaians" without specificity• Limited cultural details* *• Some inaccuracies in described practices* *• Superficial treatment of cultural context*
Celestial Knowledge Description [2 marks]	*2 marks*	*• Clearly explains which celestial body (sun, moon, stars) is observed in African/Ghanaian tradition* *• Describes specific observable patterns recognised in these traditions• Explains how observations create practical knowledge* *• Shows understanding of how celestial knowledge is preserved and transmitted*
	1 mark	*• Mentions celestial bodies but with limited detail* *• Vague understanding of how observations work in African context* *• Limited explanation of knowledge systems* *• Some misconceptions about traditional astronomical practices*
Practical Application [2 marks]	*2 marks*	*• Thoroughly explains how celestial knowledge is applied in traditional African/Ghanaian life* *• Connects astronomical knowledge to specific needs (farming calendars, festival timing, etc.)* *• Describes concrete benefits of this knowledge system* *• Shows how observation translates to community practices*
	1 mark	*• Basic mention of practical use without detailed explanation* *• Limited understanding of applications in African/Ghanaian context* *• Unclear connection between observation and practice* *• Superficial description of benefits*
Cultural Continuity and Context [2 marks]	*2 marks*	*• Discusses how this knowledge has been preserved in African/ Ghanaian communities* *• Explains the cultural significance and value of these practices* *• May mention how traditional knowledge connects with modern life* *• Discusses relevance to contemporary Ghanaian identity or practices*
	1 mark	*• Limited discussion of knowledge transmission in African context• Minimal explanation of cultural importance* *• Treats practices as purely historical without contemporary relevance* *• Little connection to modern Ghanaian life*
Communication Quality [2 marks]	*2 marks*	*• Well-organised, clear explanation* *• Appropriate use of terminology, possibly including local terms* *• Balanced discussion of cultural and astronomical aspects* *• Respectful treatment of traditional African knowledge systems*

	1 mark	• *Basic organisation with some clarity issues* • *Limited use of appropriate terminology* • *Imbalanced discussion* • *May unintentionally diminish value of African knowledge systems*

WEEK 10

Question 1

a)

Reference Chart

Correct Matches to Check For:

h. Spiral galaxy: disc with spiral arms + contains young and old stars

i. Elliptical galaxy: oval or spherical shape + mostly older stars

j. Irregular galaxy: no definite shape + often result of galaxy collisions

k. Lenticular galaxy: disc without spiral arms + combination of spiral and elliptical features

b)

Galaxy Description – Checklist Approach *[5 marks total]*	–	*Award marks for presence of specific elements in description:*
Basic identification	*1 mark*	• *Names one type of galaxy (spiral, elliptical, irregular, or lenticular)* • *Uses the term correctly in context*
Shape description	*1 mark*	• *Describes the basic shape using everyday language (e.g., "shaped like a disc with arms," "egg-shaped," "chaotic/no regular shape," or "like a lens / UFO shape")*
Content mention	*1 mark*	• *Mentions at least one component found in the galaxy (stars, gas, dust, black hole)* • *Uses these terms appropriately*
Comparison	*1 mark*	• *Makes at least one comparison with another galaxy type (e.g., "unlike spiral galaxies, ellipticals don't have arms")*
Example	*1 mark*	• *Names at least one specific example of their chosen galaxy type* • *Spiral galaxies: Milky Way, Andromeda (M31), Whirlpool Galaxy (M51)* • *Elliptical galaxies: M87, Centaurus A* • *Irregular galaxies: Large and Small Magellanic Clouds* • *Lenticular galaxies: NGC 5866, Spindle Galaxy*

Question 2

Reference information

The Milky Way is a spiral galaxy (specifically a barred spiral). It contains billions of stars, along with gas and dust, and has several spiral arms. There's a supermassive black hole at its centre. Our solar system is located in the Orion Arm (sometimes called Orion Spur), about 26,000 light-years from the galactic centre.

Component	Mark Level	Specific Things to Look For (No Physics Knowledge Required)
Research Effort [2 marks]	*2 marks*	• *Information goes beyond basic facts taught in class* • *Multiple sources of information evident* • *Contains specific details suggesting research (measurements, dates, proper names)*
	1 mark	• *Some evidence of basic research* • *Mostly contains information covered in class*
Galaxy Type Identification [2 marks]	*2 marks*	• *Clearly identifies the Milky Way as a spiral galaxy* • *May specify "barred spiral galaxy" (this is correct but not required)* • *May compare to other galaxy types*
	1 mark	• *Mentions it's a galaxy* • *Vague description of type*
Features Description [3 marks]	*3 marks*	• *Mentions at least 3 of these features: – Spiral arms – Central bulge/bar – Contains billions of stars – Contains gas and dust – Has a supermassive black hole at centre – Approximate size or diameter – Mention of specific regions or structures*
	2 marks	• *Mentions 2 of the features listed above* • *Provides some specific details*
	1 mark	• *Mentions only 1 feature from the list* • *Simple description*
Our Location [2 marks]	*2 marks*	• *Specifically mentions our location in one of the spiral arms* • *May name "Orion Arm" or "Orion Spur"* • *Mentions we are not at the centre but about halfway from centre to edge* • *May give approximate distance from galactic centre*
	1 mark	• *Generally mentions we are in the Milky Way* • *Vague description of location* • *Partially correct location*
Writing Quality [1 mark]	*1 mark*	• *Well-structured paragraph* • *Clear and coherent writing* • *Correct grammar and spelling* • *Uses appropriate vocabulary*

SECTION 6: ALTERNATING CURRENT

STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Sub-Strand: Alternating Current

Week 11

Content Standard: *Demonstrate knowledge and understanding of Alternating Current Theory*

Learning Outcome: *Describe alternating current and utilise the associated mathematical relationships*

Week 12

Content Standard: *Explain the AC series connected circuit*

Learning Outcome: *Illustrate and describe the behaviour of alternating current*

INTRODUCTION AND SECTION SUMMARY

This section introduces the principles and applications of alternating current (AC) and the behaviour of various components in AC circuits. It begins by exploring the fundamental nature of alternating current, highlighting how it differs from direct current through its periodic reversal in direction and the characteristic sinusoidal waveform it typically follows. The section emphasises the importance of understanding waveform features such as amplitude, frequency, period, and phase, which are essential in describing and analysing AC signals (see **Year 2, week 20**; wave motion and sinusoidal signals). Mathematical relationships are used to define instantaneous and root mean square (RMS) values, enabling accurate representation and comparison of AC with direct current in practical contexts.

The content progresses to examine how different electrical components—resistors, inductors, and capacitors—respond when connected in series within an AC circuit. Each component introduces unique phase relationships and opposition to current flow, described respectively as resistance, inductive reactance, and capacitive reactance. These properties are collectively represented by the concept of impedance, which determines the overall behaviour of the circuit. The section also covers phasor diagrams and waveform analyses to illustrate how voltage and current interact in these circuits.

Finally, the section introduces the power triangle and the concept of power factor, illustrating the distinction between real, reactive, and apparent power in AC systems. Through mathematical interpretation and visual representation, the content explains how power factor impacts efficiency in electrical systems and how it can be improved using appropriate circuit components. Overall, this section builds a comprehensive understanding of AC theory and circuit analysis, laying the groundwork for applications in electrical systems and energy management.

The weeks and the indicators covered by the section are:

- ***Week 11***

  Discuss the characteristics of alternating current/voltage.

  Distinguish between the types of AC waveforms.

  Using mathematical relationships define Alternating current and alternating voltage.

- ***Week 12***

  Describe AC circuit connections using resistors, inductors, capacitors in series.

  Describe and distinguish between reactance and impedance.

  Describe the power triangle and explain power factor using mathematical concepts.

Year 2	**Week 20:** Classify waves as longitudinal, transverse, electromagnetic, mechanical, progressive and stationary. Determine the amplitude, velocity, frequency, period, wavelength from a wave sinusoidal signal. Given the amplitude, velocity, frequency, period, wavelength of a wave, deduce the wave equation.

SUMMARY OF PEDAGOGICAL EXEMPLARS

The pedagogical exemplars in this section emphasise a blend of hands-on, discussion-based, and inquiry-driven approaches to deepen understanding of alternating current and AC circuits. Through experiential learning, learners observe and measure circuit behaviour using real and virtual tools. Talk-for-learning and collaborative tasks support the comparison of waveforms and exploration of phase relationships.

Enquiry-based and problem-solving activities guide learners to derive formulas and apply them to practical scenarios. Project-based tasks connect concepts to real-world applications such as power factor correction. These strategies promote active engagement, critical thinking, and practical application of AC circuit concepts.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/ or Mode
Discuss the characteristics of alternating current/voltage. Distinguish between the types of AC waveforms. Using mathematical relationships define alternating current and alternating voltage.	Level 3	Simulation, Research
Describe AC circuit connections using resistors, inductors, capacitors in series. Describe and distinguish between reactance and impedance. Describe the power triangle and explain the power factor using mathematical concepts.	Level 3	Essay type

WEEK 11

Learning Indicators

1. *Discuss the characteristics of alternating current/voltage*
2. *Distinguish between the types of AC waveforms*
3. *Using mathematical relationships define alternating current and alternating voltage*

Review from Years 1 and 2

1. Year 2, week 20; wave motion and sinusoidal signals

FOCAL AREA: FUNDAMENTALS OF ALTERNATING CURRENT (AC)

Alternating Current (AC) is a type of electrical current in which the direction of the flow of electric charge periodically reverses. This is different from direct current (DC), where the flow of electric charge is in only one direction.

Key characteristics of AC are:

a. **Periodic Variation:** The magnitude and direction of AC vary continuously and repeat at regular intervals called the **period (T)**.

b. **Frequency (f):** The number of complete cycles per second, measured in hertz (Hz). Frequency and period are inversely related:

$$f = \frac{1}{T}$$

c. **Amplitude:** The maximum value of current or voltage in one cycle, also called the **peak value**.

d. **Instantaneous Value:** The value of current or voltage at any specific instant in time.

e. **Waveform:** The shape of the graph of current or voltage versus time. The most common waveform is sinusoidal (sine wave).

f. **Time-varying Direction:** The current changes direction periodically, which is why AC is used for power distribution (efficient transmission over long distances).

Types of AC Waveforms

An AC waveform is a graphical representation of how the voltage or current changes over time. While various waveforms exist, the most common is the sine wave due to its efficiency in power transmission.

Common AC Waveforms

a. **Sinusoidal Waveform:** The most common type, characterised by a smooth, symmetrical oscillation. It is the waveform of AC electricity supplied by power plants.

b. **Square Waveform**: The voltage or current abruptly switches between two constant levels. Common in digital electronics and some power inverters.

c. **Triangular Waveform:** The voltage or current changes linearly with time, rising and falling at a constant rate. Used in some electronic circuits and signal generators.

d. **Sawtooth Waveform**: The voltage or current rises linearly and then drops abruptly. Used in sweep circuits and some audio applications.

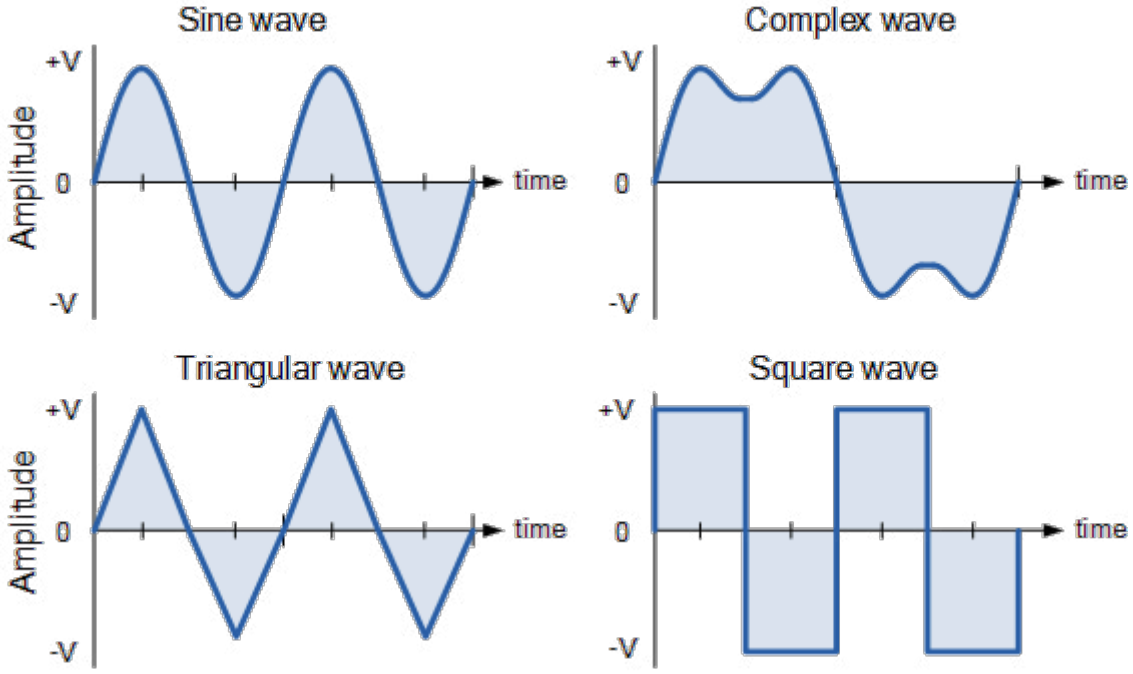


Figure 6.1: *Four graphs showing different waveforms, each with amplitude on the vertical axis and time on the horizontal axis.*

Mathematical Relationships of Alternating Current and Alternating Voltage

The instantaneous value of AC voltage or current can be represented by a sinusoidal function:

$$V(t) = V_o \sin \omega t$$
$$I(t) = I_o \sin \omega t$$

Where:

- $V(t)$ and $I(t)$ are instantaneous voltage and current at time t, respectively.
- V_o = peak (maximum) voltage
- I_o = peak (maximum) current
- $\omega = 2\pi f$ = angular frequency (radians per second)
- t = time (seconds)

These equations describe how voltage and current vary sinusoidally with time.

Root Mean Square (RMS) Values

The RMS value of AC is a measure of the effective or equivalent DC value that would deliver the same power to a load.

Rms voltage (V_{rms})

$$V_{rms} = \frac{V_o}{\sqrt{2}}$$

Rms current (I_{rms})

$$I_{rms} = \frac{I_o}{\sqrt{2}}$$

The RMS value is used for most practical applications, such as specifying the current rating of circuit breakers and the amount of current flowing through a wire. The RMS voltage is the standard way of specifying AC voltages, such as the 120 V or 240 V used in household electrical outlets.

Learning Tasks

1. Observe AC voltage on an oscilloscope and identify changes in direction, frequency, period, and zero-crossings over time.
2. Compare AC and DC waveforms using graphs, then create a table showing their differences in direction, voltage consistency, and typical uses.
3. Classify sine, square, and triangular waveforms from printed examples and match each to real-life applications.
4. Define and illustrate peak and RMS values of current and voltage in pairs, then share definitions with the class for discussion.
5. Use the formula $I(t) = I_o \sin \omega t$ and $I(t) = I_o \sin \omega t$ to to calculate current or voltage at different times, plot the waveform, and label important points like peaks and RMS.

Pedagogical Exemplars

Talk for Learning

Display side-by-side graphs of AC and DC on a projector. Guide learners to identify key differences—direction of flow, voltage consistency, and examples of usage. Ask learners to create a comparison table.

Provide learners with printed or projected samples of sine, square, and triangular AC waveforms. Let learners classify the waveforms and discuss real-world examples where each may be used (e.g., sine in mains power, square in digital signals).

Guide learners to research and derive the relationship between peak and RMS values:

- $I_{rms} = \frac{I_o}{\sqrt{2}}$
- $V_{rms} = \frac{V_o}{\sqrt{2}}$

Use simple values (e.g. $I_o = 10\,A$) to practise converting between peak and RMS values.

Experiential Learning

Use an oscilloscope connected to an AC power source and show how the current/voltage changes direction and magnitude with time. Guide learners to observe features such as frequency, period, and zero-crossings.

Connect an AC source to a multimeter and oscilloscope simultaneously. Show learners how the multimeter gives the RMS value while the oscilloscope shows the peak. Ask learners to calculate the theoretical RMS value and compare it with the reading.

Collaborative Learning

Ask learners, working in pairs, to use videos, simulations, internet, or textbooks to define:

(i) Peak current I_o ,
(ii) Peak voltage V_o,
(iii) RMS current I_{rms},
(iv) RMS voltage V_{rms}.

Have each pair write their definitions in their own words with a diagram and formula where applicable. Share and discuss to consolidate understanding.

Problem-Based Learning

Provide the general waveform equation $I(t) = I_o \sin \omega t$ or $V(t) = V_o \sin \omega t$. Ask learners to:

- calculate the current/voltage at given times (e.g., t=0.01 s,0.02 s) for a given frequency.
- plot these values on graph paper or in Excel to visualise one cycle.
- label peak, zero, and RMS points.

Provide calculation-based worksheet tasks:

- Given V_0. find V_{rms} and power.
- Given I_{rms}, calculate peak current and total energy used over a time period.

  Include real-world items like electric kettles or transformers.

Key Assessment Level 3: Research

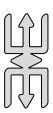
Research three types of AC waveforms (sine, square, and triangular) and compare their characteristics, the method of production and their uses.

10 marks

PLC Session 11

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

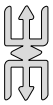
- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*

- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***research***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the research (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 12

Learning Indicators

1. *Describe AC circuit connections using resistors, inductors, capacitors in series*
2. *Describe and distinguish between reactance and impedance*
3. *Describe the power triangle and explain power factor using mathematical concepts*

FOCAL AREA: AC CIRCUITS WITH RESISTORS, INDUCTORS, AND CAPACITORS

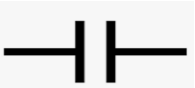
In alternating current (AC) circuits, components such as resistors (R), inductors (L), and capacitors (C) behave differently than in direct current (DC) circuits due to the time-varying nature of voltage and current. When these components are connected in series, the total voltage and current relationships depend on their individual properties and the frequency of the AC source.

Key Concepts

Resistance (R): Opposition to current flow, same as in DC circuits. Voltage and current are in phase.

Inductance (L): Property of a coil to oppose changes in current. Voltage leads current by 90°.

Capacitance (C): Property of a capacitor to store charge and oppose changes in voltage. Voltage lags current by 90°.

Component	Symbol	Unit
Resistor		Ω (Ohm)
Capacitor		F (Farad)
Inductor		H (Henry)

Purely Resistive Circuit

A purely resistive circuit contains only resistors. In such a circuit, the resistor opposes the flow of current, but it does not store energy.

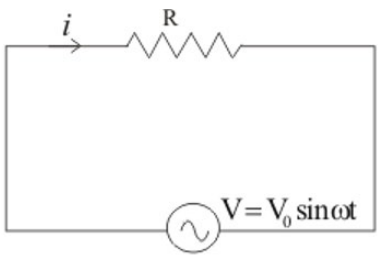


Figure 6.2: *The circuit is a basic example of an AC circuit with only a resistor.*

Behaviour in AC: When an AC voltage is applied across a pure resistor, the current flowing through it is always in phase with the voltage. This means that the voltage and current reach their maximum and minimum values at the same instant.

Ohm's Law: Ohm's Law (V = IR) applies to instantaneous values, peak values, and RMS values in a purely resistive AC circuit.

$$V(t) = I(t)\,R$$

$$V_o = I_o\,R$$

$$V_{rms} = I_{rms}\,R$$

Mathematical Formulation

Current $I(t) = I_o \sin \omega t$

Voltage $V\,(t) = V_o \sin \omega t$

Instantaneous power

$P(t) = V(t) \times I(t) = I_o \sin \omega t \times V_o \sin \omega t = I_0 V_0 sin^2 \omega t$

Average power over one cycle

$$P = I_{rms} V_{rms} = \frac{I_o}{\sqrt{2}} \times \frac{V_o}{\sqrt{2}} = \frac{I_o V_o}{2}$$

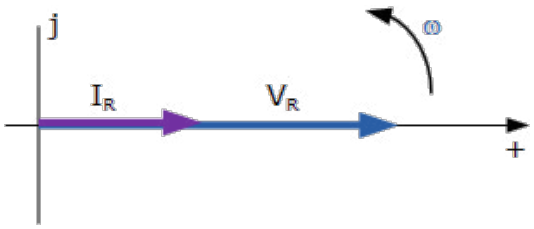


Figure 6.3: *Phasor Diagram*

- Voltage and current phasors are aligned, indicating zero phase difference.
- Both vectors rotate counterclockwise at angular frequency ω but maintain the same angle

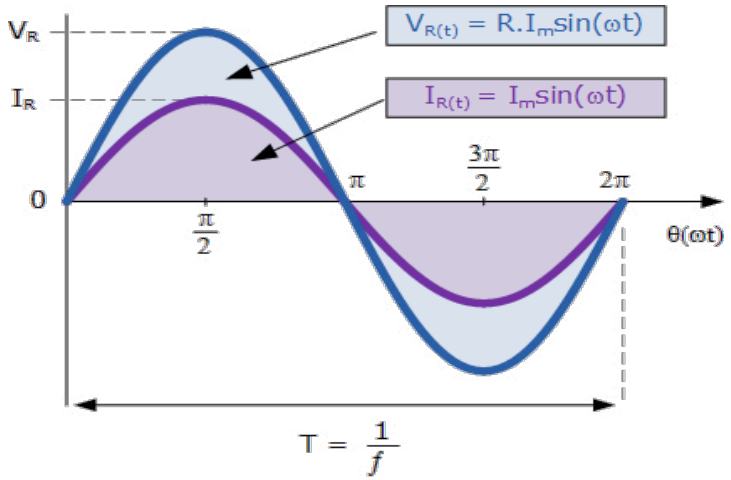


Figure 6.4: *Waveform Diagram*

- Voltage and current sinusoidal waveforms overlap perfectly.

- Instantaneous power waveform is always positive, showing continuous energy dissipation.

Purely Inductive Circuit

A purely inductive circuit contains only an inductor (a coil of wire). An inductor opposes changes in current by storing energy in a magnetic field.

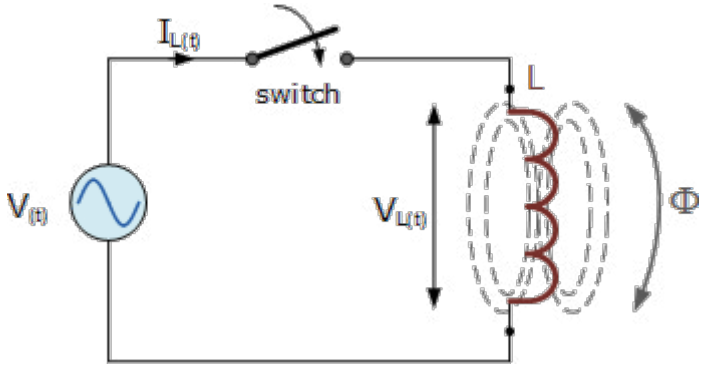


Figure 6.5: *Electrical circuit diagram showing an inductor*

Behaviour in AC: When an AC voltage is applied across a pure inductor, the current flowing through it lags the voltage by 90° (or π/2 radians). This means the voltage reaches its peak a quarter cycle before the current reaches its peak.

Inductive Reactance (X_L): The opposition to AC offered by an inductor is called inductive reactance. It is measured in ohms (Ω).

$$X_L = \frac{V_o}{I_o} \text{ but } V_o = \omega L I_o$$

$$X_L = \frac{\omega L I_o}{I_o} = \omega L$$

$$\text{Also } \omega = 2\pi f$$

$$X_L = 2\pi f L$$

Where: X_L is inductive reactance (Ω), ω is angular frequency (rad/s), f is frequency (Hz), and L is inductance (Henry, H). Inductive reactance increases with frequency.

Voltage-current relationship

- $V_o = I_o X_L$
- $V_{rms} = I_{rms} X_L$

Mathematical Formulation

Voltage $V\ (t) = V_o \sin \omega t$

Current $I(t) = I_o \sin\left(\omega t - \frac{\pi}{2}\right) = I_o \cos \omega t$

Instantaneous power

$P(t) = I(t) \times I(t) = I_o \cos \omega t \times V_o \sin \omega t = \frac{I_o V_o}{2} \sin 2\omega t$

Average power over one cycle

$P = 0$

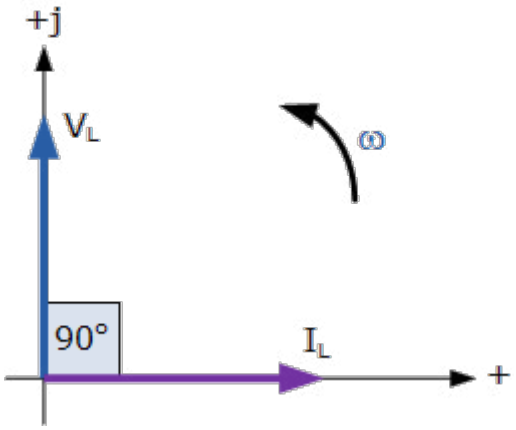


Figure 6.6: *Phasor diagram*

- Voltage phasor leads current phasor by 90.
- Current phasor is drawn perpendicular and behind the voltage phasor.

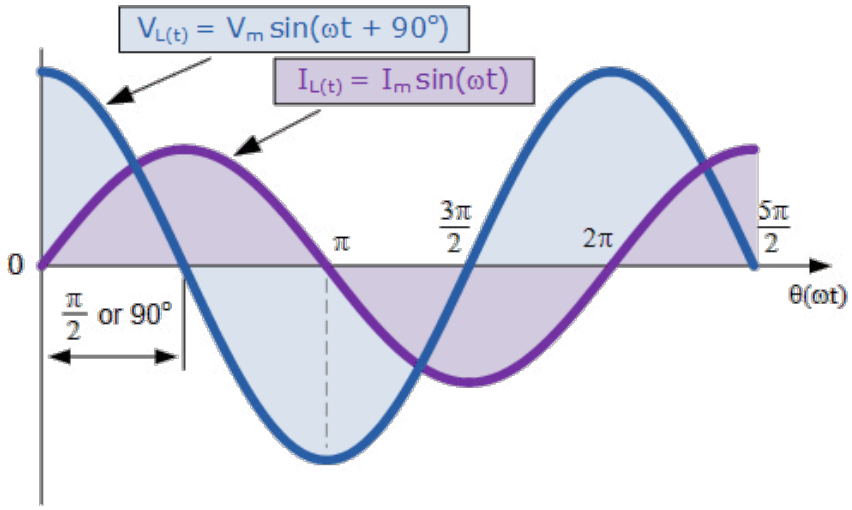


Figure 6.7: *Waveform Diagram*

- Voltage waveform leads current waveform by a quarter cycle.
- Instantaneous power waveform oscillates symmetrically above and below zero.

Purely Capacitive Circuit

A purely capacitive circuit contains only a capacitor. A capacitor stores energy in an electric field and opposes changes in voltage.

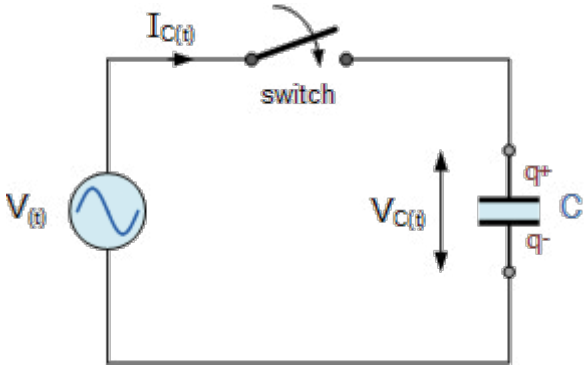


Figure 6.8: *Electrical circuit diagram featuring a voltage source, a switch, and a capacitor*

Behaviour in AC: When an AC voltage is applied across a pure capacitor, the current flowing through it leads the voltage by 90° (or π/2 radians). This means the current reaches its peak a quarter cycle before the voltage reaches its peak.

Capacitive Reactance (): The opposition to AC offered by a capacitor is called capacitive reactance. It is measured in ohms (Ω).

$$X_c = \frac{V_{rms}}{I_{rms}} \text{ or } X_c = \frac{V_o}{I_o}$$

$$\text{But } I_o = \omega C V_o \text{ Þ } X_c = \frac{V_o}{\omega C V_o} = \frac{1}{\omega C}$$

$$\text{Also } \omega = 2\pi f$$

$$X_c = \frac{1}{2\pi f C}$$

Where: X_c is capacitive reactance (Ω), ω is angular frequency (rad/s), f is frequency (Hz), and C is capacitance (Farad, F). Capacitive reactance decreases with frequency.

Voltage-current relationship

- $V_o = I_o X_C$
- $V_{rms} = I_{rms} X_C$

Mathematical Formulation

Voltage $V(t) = V_o \sin \omega t$

Current $I(t) = I_o \sin\left(\omega t + \frac{\pi}{2}\right) = I_o \cos \omega t$

Instantaneous power

$$P(t) = I(t) \times I(t) = I_o \cos \omega t \times V_o \sin \omega t = \frac{I_o V_o}{2} \sin 2\omega t$$

Average power over one cycle

$P = 0$

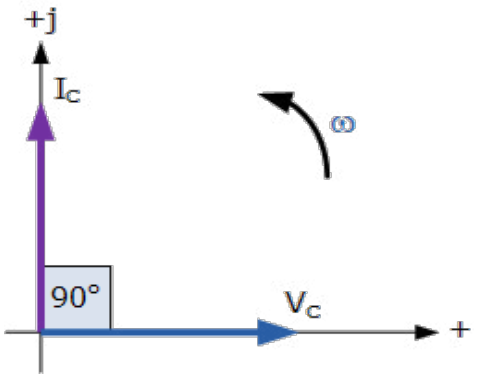


Figure 6.9: *Phasor diagram*

- Current phasor leads voltage phasor by 90.
- Current vector is drawn perpendicular and ahead of voltage vector.

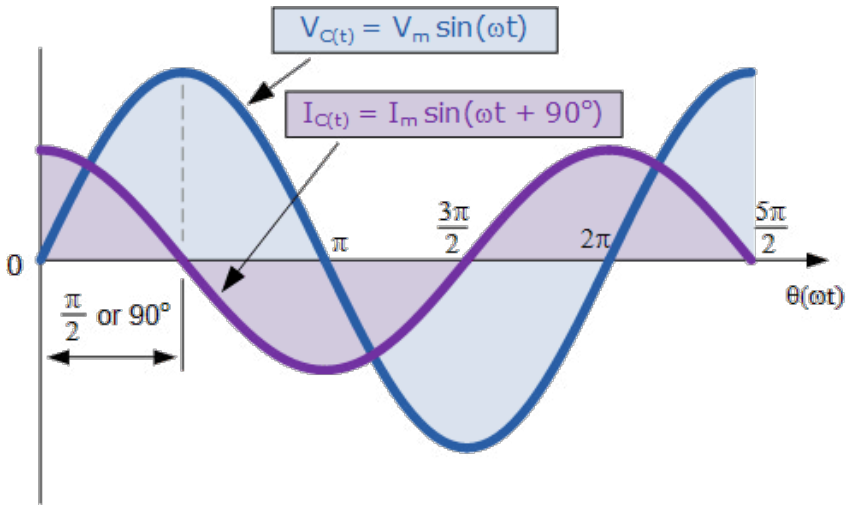


Figure 6.10: *Waveform Diagram*

- Current waveform leads voltage waveform by a quarter cycle.
- Instantaneous power oscillates symmetrically about zero.

Reactance and Impedance

Reactance (X) is the opposition to the flow of alternating current due to energy storage elements (inductors and capacitors). It is measured in ohms (Ω).

Net Reactance: In circuits with both inductance and capacitance, the net reactance is the difference between inductive and capacitive reactances: $X = X_L - X_C$

- If $X_L > X_C$, the circuit is predominantly inductive.
- If $X_C > X_L$, the circuit is predominantly capacitive.
- If $X_L = X_C$, the circuit is at resonance, and the net reactance is zero.

Impedance (Z) is the total opposition to the flow of alternating current in an AC circuit. It is the vector sum of resistance and net reactance. Impedance is also measured in ohms (Ω).

Series R-L-C Circuits

$$Z = \sqrt{(R^2 + X^2)}$$

Where:

Z is the impedance (Ω)

R is the resistance (Ω)

X is the net reactance ($X = X_L - X_C$) (Ω).

Impedance is a complex quantity that includes both magnitude and phase angle.

Z = R + jX (Rectangular form, where j is the imaginary unit)

Z = |Z|∠θ (Polar form)

Where:

$|Z| = \sqrt{(R^2 + X^2)}$ (Magnitude of impedance)

θ = arctan(X / R) (Phase angle of impedance)

AC Series Connected Circuits: R-C, R-L, and R-L-C

When resistors (R), inductors (L), and capacitors (C) are connected in series across an AC voltage source, the current flowing through each element is the same, but the voltages across each element differ in magnitude and phase. The overall behaviour depends on the combination of these components.

1. Series R-C Circuit (Resistor and Capacitor)

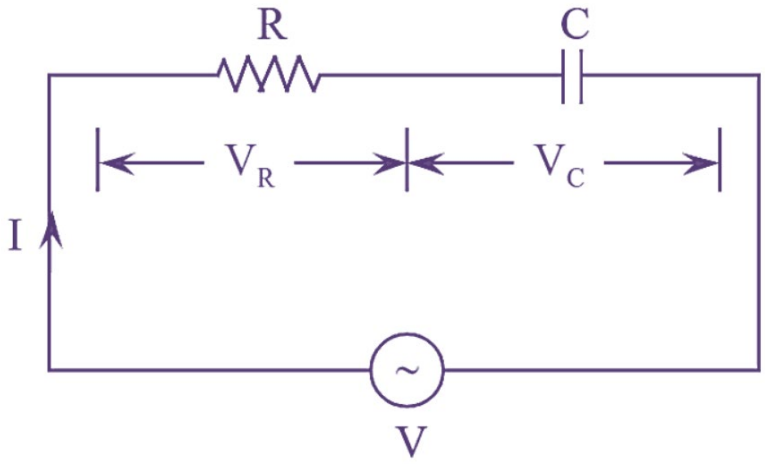


Figure 6.11: *A resistor and capacitor connected in series to an AC voltage source.*

Key Characteristics

- The current I is the same through both resistor and capacitor.
- Voltage across resistor $V_R = IR$ is in phase with current.
- Voltage across capacitor $V_C = IX_C$ lags current by 90°.
- Total voltage V across the series combination is the phasor sum of V_R and V_C.

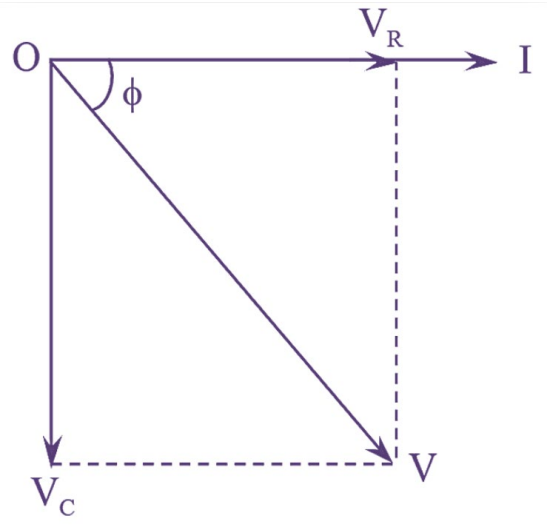


Figure 6.12: *This diagram is typically used to represent the relationship between voltages in an AC circuit with resistive and capacitive components.*

$$V^2 = V_R^2 + V_C^2$$

$$V^2 = (IR)^2 + (IX_c)^2$$

$$V^2 = I^2R^2 + I^2X_C^2$$

$$V^2 = I^2(R^2 + X_C^2)$$

$$V = I\sqrt{(R^2 + X_C^2)}$$

$$Z = \frac{V}{I} = \sqrt{(R^2 + X_C^2)}$$

$$Z = \sqrt{(R^2 + X_C^2)}$$

$$\tan\phi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R}$$

$$\phi = tan^{-1}\frac{X_C}{R}$$

2. Series R-L Circuit (Resistor and Inductor)

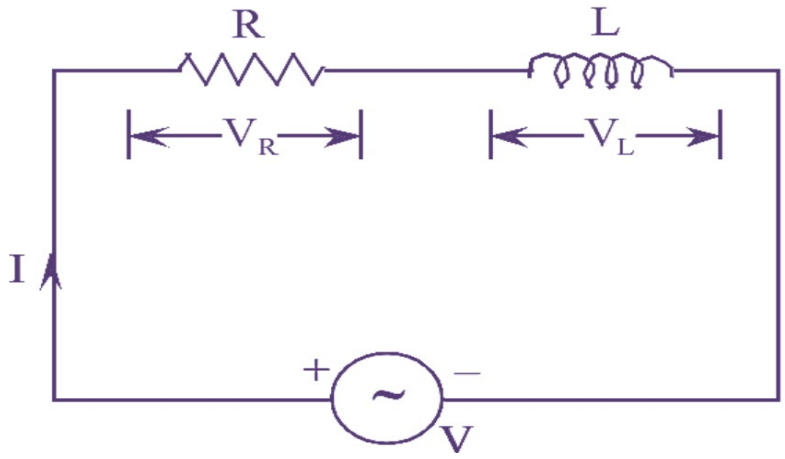


Figure 6.13: *A resistor and inductor connected in series to an AC source*

Key Characteristics

- Current I is the same through resistor and inductor.
- Voltage across resistor $V_R = IR$ is **in phase** with current.
- Voltage across inductor $V_L = IX_L$ L **leads** current by 90°
- Total voltage V is the phasor sum of V_R and V_L

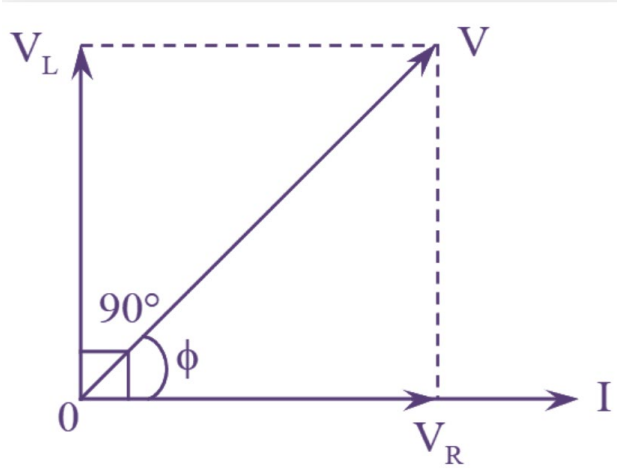


Figure 6.14: *The diagram visually represents the vector sum of voltages in the circuit*

$$V^2 = V_R^2 + V_L^2$$

$$V^2 = (IR)^2 + (IX_L)^2$$

$$V^2 = I^2R^2 + I^2X_L^2$$

$$V^2 = I^2(R^2 + X_L^2)$$

$$V = I\sqrt{(R^2 + X_L^2)}$$

$$Z = \frac{V}{I} = \sqrt{(R^2 + X_L^2)}$$

$$Z = \sqrt{(R^2 + X_L^2)}$$

$$\tan\varphi = \frac{V_L}{V_R} = \frac{IX_L}{IR} = \frac{X_L}{R}$$

$$\varphi = tan^{-1}\frac{X_L}{R}$$

3. Series R-L-C Circuit (Resistor, Inductor, and Capacitor)

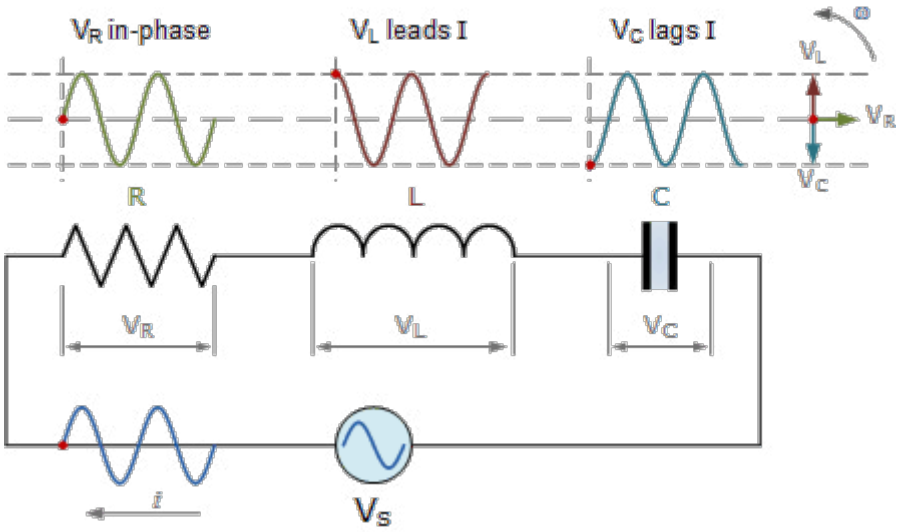


Figure 6.15: *Resistor, inductor, and capacitor connected in series to an AC source*

Key Characteristics

- Current I is the same through all elements.
- Voltages across resistor V_R, inductor V_L, and capacitor V_C differ in phase.
- Voltage across resistor V_R is in phase with current.
- Voltage across inductor V_L leads current by 90°.
- Voltage across capacitor V_C lags current by 90°.
- Since V_L and Vc are 180° out of phase, their voltages subtract in phasor form.

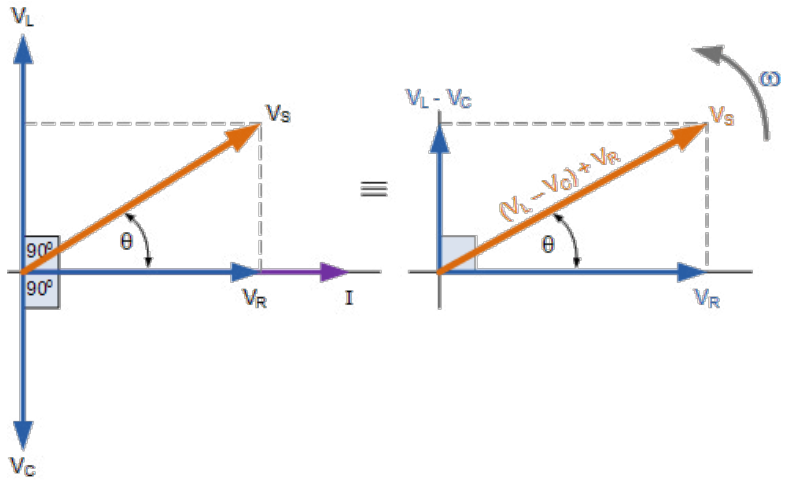


Figure 6.16: *Phasor diagram for an RLC circuit*

The image shows two vector (phasor) diagrams side by side, both representing voltages in a series RLC (Resistor-Inductor-Capacitor) AC circuit.

On the right the diagram is simplified by combining V_L and V_C into a single vertical arrow labelled V_L - V_C (since they are in opposite directions).

$$\text{If, } V_L > V_C$$

$$V^2 = V_R^2 + (V_L - V_C)^2$$

$$V_R = IR,\ V_C = IX_C,\ V_L = IX_L$$

$$V^2 = (IR)^2 + (IX_L - IX_C)^2$$

$$\text{Dividing through by } I^2$$

$$\frac{V^2}{I^2} = R^2 + (X_L - X_c)^2$$

$$\frac{V}{I} = \sqrt{R^2 + (X_L - X_c)^2}$$

$$\text{Þ } Z = \sqrt{R^2 + (X_L - X_c)^2}$$

$$\text{If, } V_C > V_L$$

$$(X_C - X_L)^2 = (X_L - X_C)^2$$

$$\text{Þ } Z = \sqrt{R^2 + (X_C - X_L)^2}$$

The phase angle is given by

$$\tan\theta = \frac{V_L - V_C}{V_R} \text{ or } \tan\theta = \frac{V_C - V_L}{V_R}$$

Resonance condition

Inductive reactance = Capacitive reactance

$$\text{i.e. } X_C = X_L \text{ and } f = f_o$$

$$\Rightarrow \frac{1}{2\pi f_o C} = 2\pi f_0 L$$

$$\Rightarrow 4\pi^2 f_0^2 LC = 1$$

$$\Rightarrow f_0^2 = \frac{1}{4\pi^2 LC}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$f_0 =$ resonance frequency

Power Triangle and Power Factor

In AC circuits, power is a more complex concept than in DC circuits due to the phase difference between voltage and current.

Types of Power

Active Power (P) / Real Power / True Power

The actual power consumed by the circuit and converted into useful work (e.g., heat, light, mechanical energy). This power is dissipated by resistive components. Measured in watts (W).
$P = V_{rms}\, I_{rms} \cos\theta$

$P = {I_{rms}}^2 R$

$P = V_R\, I_{rms}$

Reactive Power (Q)

The power that is stored and returned to the source by reactive components (inductors and capacitors). It does not do useful work but is necessary for the magnetic fields of inductors and electric fields of capacitors to operate. Measured in volt-ampere reactive (VAR).

$Q = V_{rms}\, I_{rms} \sin\theta$

$Q = {I_{rms}}^2 X_L$ (Inductive reactive power, positive)

$Q = {I_{rms}}^2 X_C$ (Capacitive reactive power, negative)

$P = V_L\, I_{rms}$ (Inductive reactive power)

$P = V_C\, I_{rms}$ (Capacitive reactive power)

Apparent Power (S)

The total power supplied by the source. It is the vector sum of active and reactive power.

Measured in volt-amperes (VA).

$S = V_{rms}\, I_{rms}$

$S = \sqrt{P^2 + Q^2}$ (from the power triangle)

Power Triangle

The power triangle is a graphical representation that illustrates the relationship between active power, reactive power, and apparent power. It is a right-angled triangle.

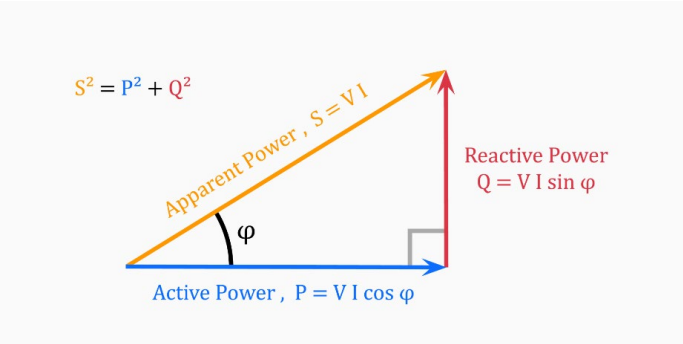


Figure 6.17: *Power triangle diagram*

$$S^2 = P^2 + Q^2$$

Power factor

The power factor (PF) is a measure of how effectively electrical power is being converted into useful work. It is the ratio of active power to apparent power.

$$PF = \frac{P}{S} = \cos\theta$$

Where:

- PF is the power factor (dimensionless, ranges from 0 to 1).
- P is the active power (W).
- S is the apparent power (VA).
- θ is the phase angle between the supply voltage and the total current of the circuit.

Interpretation

- PF = 1 (unity power factor): Occurs in purely resistive circuits or at resonance in RLC circuits. Voltage and current are in phase, and all apparent power is active power. This is the most efficient use of power.
- PF < 1 (lagging power factor): Occurs in inductive circuits (current lags voltage). Common in motors, transformers, and fluorescent lighting.
- PF < 1 (leading power factor): Occurs in capacitive circuits (current leads voltage). Less common as primary load type, but capacitors are often used for power factor correction.
- PF = 0: Occurs in purely inductive or purely capacitive circuits. No active power is consumed; all power is reactive.

Importance

A low power factor means that more current is required to deliver the same amount of active power. This leads to:

- Increased losses in transmission lines (due to I^2R heating).
- Larger conductor sizes required.

- Reduced capacity of power generation and distribution equipment.
- Higher electricity bills for industrial consumers (often penalised for low power factor).

Power Factor Correction

Capacitors are often connected in parallel with inductive loads to improve the power factor by providing leading reactive power that cancels out the lagging reactive power.

Learning Tasks

1. Build R-C, R-L, and R-L-C series circuits using real or virtual tools, then measure and record current, voltage across components, and phase differences using multimeters or simulations.
2. Write and compare equations for current in pure resistive, inductive, and capacitive AC circuits, identifying how phase shifts arise and what they mean.
3. Sketch and label voltage and current waveforms for R, L, and C circuits, showing and explaining the phase relationships between them.
4. Calculate reactance and impedance in R-C, R-L, and R-L-C series circuits using provided values for frequency, resistance, capacitance, and inductance.
5. Investigate resonance in an R-L-C circuit by adjusting frequency, observe the conditions for resonance, and calculate the resonant frequency using the appropriate formula.

Pedagogical Exemplars

Talk for Learning

Guide learners to write down and compare the governing equations for pure resistive (V=IR), pure capacitive ($I = I_o \sin(\omega t + \frac{\pi}{2})$, and pure inductive ($I = I_o \sin(\omega t - \frac{\pi}{2})$ a.c. circuits. Provide step-by-step scaffolding so they can see how the phase shift terms $\pm\frac{\pi}{2}$ arise from the component's behaviour.

Ask learners to sketch voltage and current vs. time graphs for each pure circuit type, clearly marking phase relationships (in phase for resistors, current leading voltage for capacitors, and current lagging voltage for inductors). Have them annotate where peaks and zero crossings occur and explain briefly what these features mean physically.

Provide learners with an exemplar calculation or measurement data for current at a known frequency in simple capacitor and inductor circuits. Guide them to generalise from that example and derive the standard expressions $X_L = 2\pi fL$ and $X_c = \frac{1}{2\pi fC}$, reinforcing the inverse and direct frequency dependencies respectively.

Using guided steps, let learners draw phasor diagrams for R, R-L, and R-C series circuits. Then lead them through the derivation of the impedance formula:

$Z = \sqrt{(R^2 + X_C^2)}$, for R-C

$Z = \sqrt{(R^2 + X_L^2)}$ for R-L

$Z = \sqrt{R^2 + (X_C - X_L)^2}$ for R-L-C

Provide values for apparent power (S), true power (P), and reactive power (Q). Guide learners to construct the power triangle and calculate the power factor using $cos\phi = \frac{P}{S}$. Link this to phasor diagrams and triangle resolution.

Problem-Based Learning

Provide learners with a worksheet containing R-L and R-C series circuits where resistance, inductance or capacitance, and frequency are provided. Guide them to calculate the inductive reactance using $X_L = 2\pi fL$ and the capacitive reactance using $X_c = \frac{1}{2\pi fC}$, helping them observe how reactance varies with frequency.

Model a solved example of finding impedance in an R-C, R-L or R-L-C series circuit step by step, then give learners a worksheet to calculate reactance and impedance for varied values, offering support as they work through each problem.

Experiential Learning

Provide learners with resistors, capacitors, inductors, and AC power sources. In small groups, guide them to build R-C, R-L, and R-L-C series circuits. Using multimeters and oscilloscopes, let learners measure current, voltage across each component, and phase relationships. Discuss how each component affects current and phase.Let learners build R-C and R-L series circuits using virtual lab tools like PhET or real circuit kits containing resistors, capacitors, inductors, and power sources. Guide them to connect the components correctly, measure the voltage across each component using a multimeter or simulation tool, and record the total current flowing in the circuit.

Project-Based Learning

Present learners with a case study: poor power factor in an industrial setup. Ask them to recommend how capacitors could be used to improve the power factor and reduce energy loss. Link to savings on electricity bills.

Key Assessment: Practice Paper 1

Question 1

Write an essay describing the behaviour of a resistor, an inductor, and capacitor in an AC series circuit. Include descriptions of the functions of each component.

10 marks

Question 2

A series RLC circuit is connected to an AC power supply with a rms voltage of 120 V and a frequency of 60 Hz. The circuit contains a resistor of 100 Ω, an inductor of 0.2 H, and a capacitor of 80 μF.

a. Calculate the inductive reactance, capacitive reactance, and the total impedance Z of the circuit.

6 marks

b. Determine the current flowing in the circuit.

4 marks

c. Calculate the phase angle θ between the current and the voltage.

4 marks

d. Explain whether the circuit is predominantly inductive or capacitive and justify the conclusion based on the values calculated.

2 marks

HINT

*Conduct **Practice Paper 1**. It should cover the contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section. Learners' papers should be marked immediately and scores entered into the SAP.*

TABLE OF SPECIFICATION
Multiple choice

Sub strand	Indicators	Type	1	2	3	4	Total
Introduction to Physics	1.1.1.LI.1 Identify careers that are related to physics in various sectors of the economy.	MCQs	1				1
		Essay					
		Practical					
	1.1.1.LI.2 Use basic mathematical concepts to solve problems – trigonometric ratios, Pythagoras's theorem, sine and cosine rule, indices.	MCQs					
		Essay			1		1
		Practical					
	1.1.1.LI.1 Identify the basic units in physics	MCQs	2				2
		Essay					
		Practical					
	1.1.1.LI.2 Determine the dimensions of physical quantities (velocity, acceleration, mass, length, time, weight, energy, force)	MCQs					
		Essay			1		1
		Practical					

	1.1.1.LI.3 Identify the errors in the use of meter rule, protractor, electronic balance, vernier calliper and the micrometer screw gauge.	MCQs					
		Essay					
		Practical					
	1.1.1.LI.4 Explain the types of errors – systematic, random and parallax	MCQs	1				1
		Essay					
		Practical					
	1.1.1.LI.5 Explain scientific notation and their unit multipliers.	MCQs		1			1
		Essay					
		Practical					
	1.1.1.LI.6 Distinguish scalars from vectors (qualitative treatment)	MCQs		2			2
		Essay					
		Practical					
Basic Physics	**2.1.1.LI.1** Explain density	MCQs					
		Essay					
		Practical					
	2.1.1.LI.2 State Archimedes' principle	MCQs		1			1
		Essay					
		Practical					
	2.1.1.LI.3 State principle of flotation	MCQs					

		Essay					
		Practical					
	2.1.1.LI.4 Apply Archimedes' principle and principle of flotation to solve problems	MCQs					
		Essay					
		Practical					
	2.1.1.LI.1 Check validity of equations	MCQs					
		Essay					
		Practical					
	2.1.1.LI.2 Establish the relationship between quantities	MCQs					
		Essay					
		Practical					
	2.1.1.LI.1 Resolve vectors into their components	MCQs					
		Essay					
		Practical					
	2.1.1.LI.2 Determine the resultant of two vectors	MCQs					
		Essay					
		Practical					
	3.1.1.LI.1 Explain moments	MCQs		1			1
		Essay					
		Practical					
	3.1.1.LI.2 State the principle of moments	MCQs					
		Essay					
		Practical					

	3.1.1.LI.3 State the conditions necessary for a body to be in equilibrium	MCQs	2				2
		Essay					
		Practical					
	3.1.1.LI.4 Calculate the reactions at supports	MCQs					
		Essay			1		1
		Practical					
	3.1.1.LI.1 State Newton's law of universal gravitation	MCQs		1			1
		Essay					
		Practical					
	3.1.1.LI.2 Deduce the relationship between acceleration due to gravity, g and universal gravitation constant, G	MCQs					
		Essay					
		Practical					
	3.1.1.LI.3 Deduce the period of rotation of a satellite moving in circular orbit	MCQs					
		Essay					
		Practical					
	3.1.1.LI.4 Explain weightlessness	MCQs					
		Essay					
		Practical					
	3.1.1.LI.1 Explain the universe and its composition as applied to astronomy and cosmology	MCQs		1			1
		Essay					

		Practical					
	3.1.1.LI.2 Explain how our indigenous culture benefits from and applies to astronomy and cosmology.	MCQs					
		Essay					
		Practical					
	3.1.1.LI.3 Explain the formation of the sun, planets and stars	MCQs					
		Essay					
		Practical					
	3.1.1.LI.4 Describe galaxies and their various types - elliptical, spiral, irregular, quasars, blazers, Lenticular, active, seyfert.	MCQs					
		Essay					
		Practical					
Matter	**1.1.2.LI.1** Identify the various states of matter	MCQs	1	1			2
		Essay					
		Practical					
	1.1.2.LI.2 Distinguish between molecular arrangement of the various states	MCQs					
		Essay					
		Practical					
	2.1.2.LI.1 Distinguish elastic deformation from plastic deformation	MCQs		1			1

		Essay			1		1
		Practical					
	2.1.2.LI.2 State Hooke's law	MCQs					
		Essay					
		Practical					
	2.1.2.LI.3 Calculate the energy stored in in an elastic material	MCQs					
		Essay					
		Practical					
	2.1.2.LI.4 Calculate Young's modulus	MCQs					
		Essay					
		Practical					
Kinematics	**1.1.3.LI.1** Describe the various types of motion i.e. circular, oscillatory, rectilinear, spin and random	MCQs		1			1
		Essay					
		Practical					
	1.1.3.LI.2 Establish equations of uniformly accelerated motion and its application in everyday life	MCQs					
		Essay					
		Practical					
	1.1.3.LI.3 Represent the motion of objects graphically i.e. distance-time, displacement-time and velocity-time as well as deducing equations that can be made from it	MCQs					

		Essay					
		Practical					
	2.1.3.Ll.1 Identify some games and sports where projectiles are seen of circular motion	MCQs	1				1
		Essay	1				1
		Practical					
	2.1.3.Ll.2 Determine the time taken by a projectile to reach maximum height and the maximum height	MCQs					
		Essay					
		Practical					
	2.1.3.Ll.3 Determine the range of a projectile	MCQs					
		Essay					
		Practical					
	2.1.3.Ll.1 Explain circular motion and give some examples of circular motion	MCQs					
		Essay					
		Practical					
	2.1.3.Ll.2 Explain and calculate centripetal force	MCQs		1			1
		Essay					
		Practical					
	2.1.3.Ll.3 Explain banking and skidding	MCQs					
		Essay					

		Practical					
	2.1.3.LI.4 Calculate maximum and minimum tension in a string	MCQs					
		Essay					
		Practical					
	3.1.2.LI.1 Explain simple harmonic motion and give some examples of such type of motion	MCQs	1				1
		Essay					
		Practical			1	1	2
	3.1.2.LI.2 Determine the velocity, acceleration and kinetic energy of a body performing SHM	MCQs					
		Essay					
		Practical					
	3.1.2.LI.3 Explain the variation of potential and kinetic energy of a body performing SHM	MCQs					
		Essay					
		Practical					
	3.1.2.LI.4 Determine the energy stored in a system performing SHM	MCQs					
		Essay					
		Practical					
Dynamics	**1.1.4.LI.1** State Newton's laws of motion	MCQs					
		Essay					

	1.1.4.LI.2 Apply Newton's second law to establish the relationship between force, mass and acceleration	MCQs		1			1
		Essay					
		Practical					
	1.1.4.LI.3 Identify daily applications of Newton's laws of motion	MCQs					
		Essay					
		Practical					
	1.1.4.LI.1 Explain how pressure changes with depth in a fluid.	MCQs					
		Essay					
		Practical					
	1.1.4.LI.1 Explain the operation of brake systems in vehicles and the operation of the hydraulic press	MCQs					
		Essay					
		Practical					
	1.1.4.LI.1 State Pascal's principle.	MCQs	2				2
		Essay	1				1
		Practical					
	2.1.4.LI.1 Identify some effects and applications of friction	MCQs					
		Essay		1			1
		Practical					

	2.1.4.LI.2 Determine the coefficient of friction	MCQs					
		Essay					
		Practical					
	3.1.3.LI.1 Distinguish between elastic and inelastic collisions	MCQs					
		Essay					
		Practical					
	3.1.3.LI.2 Use momentum change to establish impulse and hence deduce Newton's second law of motion	MCQs					
		Essay					
		Practical					
	3.1.3.LI.3 Verify Newton's third law of motion from momentum change	MCQs					
		Essay					
		Practical					
Heat	**1.2.1.LI.1** Discuss the thermometric substances and properties and their associated characteristics	MCQs					
		Essay					
		Practical					
	1.2.1.LI.2 Describe the features and uses of different types of thermometers	MCQs					
		Essay					
		Practical					

	1.2.1.LI.3 Describe the various temperature scales and the construction of their corresponding thermometers	MCQs					
		Essay		1			1
		Practical					
	1.2.1.LI.4 Derive the relationship between the Celsius, Fahrenheit and the Kelvin scales.	MCQs					
		Essay					
		Practical					
	2.2.1.LI.1 Explain the specific heat capacity and classify substances into good and bad conductors of heat	MCQs					
		Essay					
		Practical					
	2.2.1.LI.2 Calculate the specific heat capacities of substances	MCQs					
		Essay					
		Practical					
	2.2.1.LI.3 Describe how to determine the specific heat capacity of a solid using a liquid of a known specific heat capacity	MCQs					
		Essay					
		Practical					

	2.2.1.LI.4 Explain latent heat of fusion and vaporisation and specific latent heat of fusion and vaporisation	MCQs					
		Essay					
		Practical					
	3.2.1.LI.1 Explain linear, area and volume expansivities	MCQs					
		Essay					
		Practical					
	3.2.1.LI.2 Calculate the linear, area and volume expansivities of metals	MCQs					
		Essay			1		1
		Practical					
	3.2.1.LI.3 Group metals in increasing order of expansion property using their linear expansivities	MCQs					
		Essay					
		Practical					
Wave	**1.2.2.LI.1** Describe the process involved in image formation in plane mirrors and their characteristics	MCQs	2				
		Essay	1				1
		Practical					
	1.2.2.LI.2 Deduce the laws of reflection	MCQs					
		Essay					

		Practical					
	1.2.2.LI.3 Determine the number of images formed by inclined mirrors	MCQs					
		Essay					
		Practical					
	1.2.2.LI.1 Explain terminologies associated with spherical mirrors	MCQs					
		Essay					
		Practical					
	1.2.2.LI.2 Describe the processes involved in image formation in spherical mirrors and their characteristics using ray tracing	MCQs					
		Essay					
		Practical		1		1	2
	1.2.2.LI.3 Determine the position and characteristics of images formed by spherical mirrors with mirror formula and magnification formula	MCQs					
		Essay			1		1
		Practical					
	1.2.2.LI.1 Explain refraction and state the laws of refraction	MCQs					
		Essay					
		Practical					

	1.2.2.LI.2 Determine refractive index of a medium	MCQs					
		Essay					
		Practical					
	1.2.2.LI.3 Explain total internal reflection	MCQs					
		Essay					
		Practical					
	1.2.2.LI.4 Establish the relationship between the real depth, apparent depth and the refractive index.	MCQs					
		Essay					
		Practical					
	2.2.2.LI.1 Identify types of waves with properties	MCQs					
		Essay					
		Practical					
	2.2.2.LI.2 Classify waves under longitudinal, transverse, electromagnetic, mechanical, progressive and stationary	MCQs					
		Essay		1			1
		Practical					
	2.2.2.LI.3 Determine the amplitude, velocity, frequency, period, wavelength from a sinusoidal wave signal	MCQs					
		Essay					

		Practical					
	2.2.2.LI.4 Given the amplitude, velocity, frequency, period, wavelength of a wave, deduce the wave equation	MCQs					
		Essay					
		Practical					
	2.2.2.LI.1 Explain the production, nature and transmission of sound	MCQs					
		Essay					
		Practical					
	2.2.2.LI.2 Classify sound into infrasonic, audio-sonic and ultrasonic	MCQs	2				2
		Essay	1				1
		Practical					
	2.2.2.LI.3 Explain how an echo comes about and apply the phenomenon in the determination of the depth of rivers.	MCQs					
		Essay					
		Practical					
	2.2.2.LI.4 Apply the concept of resonance in the determination of speed of sound in air.	MCQs					
		Essay					
		Practical					
	3.2.2.LI.1 Identify the types and features of lenses	MCQs					

		Essay					
		Practical					
	3.2.2.LI.2 Describe how images are formed by lenses	MCQs					
		Essay					
		Practical					
	3.2.2.LI.3 Calculate the image distance and magnification using the lens formula	MCQs		1			1
		Essay					
		Practical					
	3.2.2.LI.1 Identify features of laser configuration	MCQs					
		Essay					
		Practical					
	3.2.2.LI.2 Describe the production of laser beam	MCQs					
		Essay					
		Practical					
	3.2.2.LI.3 Identify the properties of lasers	MCQs	1				1
		Essay					
Electrostatics	**1.3.1.LI.1** Explain how the gold leaf electroscope can be used to detect the charge carried by a body	MCQs					
		Essay					
		Practical					

	1.3.1.LI.2 Identify electrons as mobile charge carriers	MCQs					
		Essay					
		Practical					
	1.3.1.LI.3 Explain how charge carriers in conductors, semiconductors and insulators behave.	MCQs					
		Essay					
		Practical					
	1.3.1.LI.4 Explain the distribution of charges on surfaces; spherical, pear-shaped and sharp point	MCQs					
		Essay					
		Practical					
	1.3.1.LI.1 Define charge as a fundamental property of matter(like mass)	MCQs	1				1
		Essay					
		Practical					
	1.3.1.LI.2 Explain the conservation of charge and its behaviour	MCQs					
		Essay					
		Practical					
	1.3.1.LI.3 Differentiate between two charges (positive and negative)	MCQs					
		Practical					

	2.3.1.LI.1 Explain and show how an electric field is represented and their characteristics	MCQs					
		Essay					
		Practical					
	2.3.1.LI.2 State Coulomb's law of electrostatics and calculate electrostatic force acting on the charges	MCQs					
		Essay					
		Practical			1		1
	2.3.1.LI.3 Determine the electric field/ intensity at a point due to a point charge	MCQs		1			1
		Essay					
		Practical					
	1.3.1.LI.4 Define and calculate potential difference	MCQs					
		Essay					
		Practical					
	2.3.1.LI.1 Describe the structure and operation of capacitors	MCQs					
		Essay					
		Practical					
	2.3.1.LI.2 Determine the effective capacitance of a number of capacitors arranged in : **(i)** series **(ii)** parallel	MCQs					
		Essay			1		1

		Practical					
	2.3.1.LI.3 Determine the capacitance of a parallel plate capacitors	MCQs					
		Essay					
		Practical					
	2.3.1.LI.4 Describe the behaviour of a capacitor in DC and AC circuits	MCQs					
		Essay					
		Practical					
	2.3.1.LI.5 Calculate the energy stored in a capacitor	MCQs					
		Essay					
		Practical					
Direct current	**3.3.1.LI.1** Explain the key terminologies of circuitry and how they are related to one another	MCQs					
		Essay					
		Practical					
	3.3.1.LI.2 Express Ohm's law and its relationship to electrical resistance; ohmic and non-ohmic conductors	MCQs		1			1
		Essay			1		1
		Practical				1	1
	3.3.1.LI.1 Describe and demonstrate the structure and working principle of resistors and their arrangements in circuits	MCQs		1			1
		Essay			1		1

		Practical		1			1
	3.3.1.LI.2 Describe and demonstrate the types of variable resistors i.e. potentiometers and rheostats and their working principles.	MCQs					
		Essay					
		Practical					
	3.3.1.LI.1 State Kirchhoff's laws of electrical networks	MCQs		1			1
		Essay					
		Practical					
	3.3.1.LI.2 Determine the current flowing through a branch in electrical networks	MCQs					
		Essay					
		Practical					
	3.3.1.LI.3 Discuss how a galvanometer can be adapted as an ammeter and a voltmeter	MCQs					
		Essay					
		Practical					
Magnetostatics	1.3.2.LI.1 Distinguish between magnets, magnetic and non-magnetic materials.	MCQs	2				2
		Essay	1				1
		Practical					
	1.3.2.LI.2 Describe the magnetic field	MCQs	1				1

		Essay					
		Practical					
	1.3.2.LI.3 Describe the processes involved in magnetisation and demagnetisation	MCQs					
		Essay					
		Practical					
Electromagnetism	**2.3.2.LI.1** Describe the force exerted on a current-carrying conductor in a magnetic field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.2 Discuss the factors that affect the magnitude of the magnetic force on a current-carrying conductor in a magnetic field	MCQs	1				1
		Essay					
		Practical					
	2.3.2.LI.3 Fleming's left-hand rule	MCQs					
		Essay					
		Practical					
	2.3.2.LI.1 Explain the forces acting between parallel conductors carrying current in a magnetic field	MCQs					
		Essay					
		Practical					

	2.3.2.LI.2 Explain the torque on a rectangular current-carrying coil in a magnetic field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.3 Describe and analyse the structure and working principle of the motor and moving coil galvanometer	MCQs					
		Essay					
		Practical					
	2.3.2.LI.1 Calculate force on a charged particle in a magnetic field.	MCQs					
		Essay					
		Practical					
	2.3.2.LI.2 Describe a force on a moving charged particle in an electric field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.2 Calculate a force on a moving charged particle in a crossed field (Lorentz force)	MCQs					
		Essay					
		Practical					
Alternating current	**3.3.2.LI.1** Discuss the characteristics of alternating current/voltage	MCQs					
		Essay					
		Practical					

	3.3.2.LI.2 Distinguish between the types of AC waveforms	MCQs					
		Essay					
		Practical					
	3.3.2.LI.3 Using mathematical relationships to define alternating current and alternating voltage	MCQs					
		Essay					
		Practical					
	3.3.2.LI.1 Describe a.c. circuit connections using resistors, inductors, capacitors in series	MCQs					
		Essay					
		Practical					
	3.3.2.LI.2 Describe and distinguish between resistance and impedance	MCQs					
		Essay					
		Practical					
	3.3.2.LI.3 Describe the power triangle and explain the power factor using mathematical concepts	MCQs					
		Essay					
		Practical					
Analogue Electronics	**1.3.3.LI.1** Describe the formation of the two types of conductors; n-type and p-type	MCQs					
		Essay		1			1

		Practical					
	1.3.3.LI.2 Describe the basic structure and application of the PN junction diode in reverse and forward-biased circuits	MCQs					
		Essay					
		Practical					
	1.3.3.LI.3 Analyse the benefits of using LEDs and I-V characteristics of Zener diodes and applications	MCQs					
		Essay					
		Practical					
	1.3.3.LI.1 Explain the terminologies "input" and "output" of a transducer with examples	MCQs		1			1
		Essay					
		Practical					
	1.3.3.LI.2 Explain the effect of temperature changes on resistance using a thermistor, light dependent resistor (LDR), infra-red diode and the microphone to analyse the characteristic graphs of thermistors and LDRs	MCQs					
		Essay					
		Practical					

	1.3.3.LI.3 Describe the processes involved in the operation of the following transducers; microphone, loudspeaker, buzzer, low voltage DC motor, electromagnetic relays and infra-red diode	MCQs	1				1
		Essay					
		Practical					
	1.3.3.LI.1 Describe the construction and action of the bipolar junction transistor	MCQs					
		Essay					
		Practical					
	1.3.3.LI.2 Describe transistor biasing	MCQs					
		Essay					
		Practical					
	1.3.3.LI.3 Describe various transistor configurations and the use of an N-P-N transistor as a small signal amplifier.	MCQs					
		Essay					
		Practical					
Digital Electronics	**2.3.3.LI.1** Describe analogue and digital signals	MCQs	1				1
		Essay					
		Practical					

	2.3.3.LI.2 Distinguish between pull-up and pull-down resistors	MCQs					
		Essay					
		Practical					
	2.3.3.LI.3 Describe and use the 7-segment display module	MCQs					
		Essay					
		Practical					
	2.3.3.LI.1 Distinguish between analogue and digital signals and describe their functions	MCQs	2				2
		Essay	1				1
		Practical					
	2.3.3.LI.2 Describe the characteristics of basic logic and universal gates	MCQs					
		Essay					
		Practical					
	2.3.3.LI.3 Describe and explain sum of product (Boolean expression)	MCQs					
		Essay					
		Practical					
	2.3.3.LI.4 Describe combinational logic applications and microcontroller.	MCQs					
		Essay					
		Practical					

	2.3.3.LI.1 Describe simple integrated circuits	MCQs					
		Essay					
		Practical					
	2.3.3.LI.2 Design and describe the fabrication of a simple integrated circuit	MCQs					
		Essay					
		Practical					
Electromagnetic induction and application	**3.3.3.LI.1** Explain electromagnetic induction	MCQs					
		Essay					
		Practical					
	3.3.3.LI.2 Using experimentation, verify the laws of electromagnetic induction	MCQs					
		Essay					
		Practical					
	3.3.3.LI.3 Describe the factors that affect induced emf and explain direction of induced current using mnemonics and Fleming's Right Hand Rule	MCQs					
		Essay					
		Practical					

	3.3.3.LI.1 Explain inductance and obtain a mathematical expression for the relationship	MCQs					
		Essay					
		Practical					
	3.3.3.LI.2 Discuss the behaviour of the inductor in a.c and d.c. circuits	MCQs					
		Essay					
		Practical					
	3.3.3.LI.3 Explain how energy is stored in an inductor.	MCQs					
		Essay					
		Practical					
	3.3.3.LI.1 Discuss the structure, uses and principle of operation of a transformer	MCQs					
		Essay					
		Practical					
	3.3.3.LI.2 Discuss the factors that affect the transmission of power and efficiency of a transformer and ways of improving its efficiency	MCQs					
		Essay					
		Practical					
	3.3.3.LI.3 Explain Eddy current, effects and applications	MCQs					
		Essay					
		Practical					

Application of electronics	**3.3.4.LI.1** Design a half wave rectifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.2 Design a full wave rectifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.3 Design a smoother/filter circuit using a capacitor	MCQs					
		Essay					
		Practical					
	3.3.4.LI.1 Design a PNP amplifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.2 Design an NPN amplifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.1 Design a darkness detector	MCQs					
		Essay					
		Practical					
	3.3.4.LI.2 Design a battery charger	MCQs					
		Essay					
		Practical					
Atomic Physics	**1.4.1.LI.1** Explain various atomic models and their limitations	MCQs	1				1
		Essay					
		Practical					

	1.4.1.LI.2 Calculate the energy of a photon during a transition	MCQs		1			1
		Essay					
		Practical					
	2.4.1.LI.1 Explain photoelectric effect and wave-particle duality	MCQs	1				1
		Essay					
		Practical					
	2.4.1.LI.2 State the laws of photoelectric effect	MCQs					
		Essay					
		Practical					
	2.4.1.LI.3 Identify areas of application of photoelectric effect and how they are applied	MCQs					
		Essay					
		Practical					
	3.4.1.LI.1 Describe how x-rays are produced	MCQs	1				1
		Essay		1			1
		Practical					
	3.4.1.LI.2 Distinguish between hard x-rays and soft x-rays	MCQs					
		Essay					
		Practical					
	3.4.1.LI.3 Calculate the energy, frequency and wavelength of x-rays	MCQs					
		Essay					

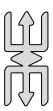
		Practical					
	3.4.1.LI.4 Identify sectors where x-rays are applied and how they are applied	MCQs					
		Essay					
		Practical					
Nuclear Physics	**1.4.2.LI.1** Describe the structure of the nucleus of the atom	MCQs		1			1
		Essay					
		Practical					
	1.4.2.LI.2 Explain radioactivity	MCQs					
		Essay	1				1
		Practical					
	1.4.2.LI.3 Balanced basic nuclear reactions	MCQs	1				1
		Essay					
		Practical					
	2.4.2.LI.1 State the radioactive decay law	MCQs					
		Essay					
		Practical					
	2.4.2.LI.2 Calculate the half-life of a radioactive sample	MCQs					
		Essay			1		1
		Practical					
	2.4.2.LI.3 Calculate the age of a bone specimen	MCQs					
		Essay					
		Practical					

	3.4.2.LI.1 Calculate the energy released in a nuclear reaction	MCQs		1			1
		Essay		1			1
		Practical					
	3.4.2.LI.2 Distinguish between fission and fusion	MCQs					
		Essay		1			1
		Practical					
	3.4.2.LI.3 Describe the process of power generation using a nuclear reactor	MCQs					
		Essay					
		Practical					
	Total		36	30	12	3	81

PLC Session 12

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



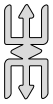
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   a. The key assessment for the week is ***Practice Paper 1***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through the problem individually for 3–4 minutes
   c. the group then works through it together the problem, step by step
   d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 6 Review

This section has focused on two key areas within the strand of Electricity and Magnetism: Fundamentals of Alternating Current (AC) and AC Circuits with Resistors, Inductors, and Capacitors. Over the two-week period, attention has been given to understanding how alternating current behaves, the mathematical representation of AC signals, and the interaction of electrical components within AC circuits.

In the first week, the focus was on the fundamental characteristics of alternating current and voltage. Learners should have explored how AC differs from DC, identifying key features such as amplitude, frequency, period, instantaneous value, and direction reversal. Various AC waveform types—sinusoidal, square, and triangular—were examined, highlighting their uses and distinguishing features. Using mathematical relationships, the concepts of peak and RMS values were introduced, enabling accurate calculation and representation of AC quantities. Learners should also have interpreted graphical waveforms and used the standard AC equations to model current and voltage changes over time.

During the second week, attention shifted to the behaviour of electrical components in AC series circuits. Learners should have examined the individual responses of resistors, inductors, and capacitors to alternating current, especially their distinct phase relationships and energy-handling properties. The concepts of inductive and capacitive reactance were introduced, along with their dependence on frequency. Learners should have calculated total impedance in series R-L, R-C, and R-L-C circuits and interpreted phasor diagrams to understand the vector nature of voltage and current relationships. The section concluded with the analysis of the power triangle, differentiating between real, reactive, and apparent power, and explaining the significance of power factor and its correction in electrical systems.

By the end of this section, learners should have developed a strong conceptual and analytical foundation in AC theory and circuits. They should be able to model and calculate quantities in AC systems, interpret circuit behaviour using diagrams and formulas, and appreciate the importance of power efficiency and power factor in practical electrical applications.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 11

Question 1

Component	Mark Level	What to Look For
Sine Wave Description *[2 marks]*	*2 marks*	• *Accurately describes smooth, curved shape* • *Mentions it's the natural waveform for AC generation* • *Provides specific applications (standard electricity, audio signals)* • *Mentions mathematical properties (uniform rate of change, etc.)* • *May include formula $y = A \sin(\omega t)$*
	1 mark	• *Basic description of sine wave shape* • *Limited information on applications* • *Some technical details*
Square Wave Description *[2 marks]*	*2 marks*	• *Accurately describes rapid switching between fixed values* • *Mentions abrupt transitions between positive and negative* • *Provides specific applications (digital signals, switching circuits)* • *Describes how they're generated* • *May mention harmonics or frequency components*
	1 mark	• *Basic description of square wave shape* • *Limited information on applications* • *Some technical details*
Triangular Wave Description *[2 marks]*	*2 marks*	• *Accurately describes linear rise and fall pattern* • *Mentions constant rate of change (ramp up, ramp down)* • *Provides specific applications (audio synthesis, testing)* • *Describes how they're generated* • *May mention relationship to integration of square waves*
	1 mark	• *Basic description of triangular wave shape* • *Limited information on applications* • *Some technical details*
Visual Representations *[2 marks]*	*2 marks*	• *Includes clear diagrams/images of all three waveforms* • *Diagrams are labelled with key features* • *Visual comparison makes differences obvious* • *May include oscilloscope screenshots or well-drawn illustrations* • *Visuals support explanations*

	1 mark	*• Basic visuals of waveforms included* *• Some labelling or explanation* *• Visuals somewhat support text*
Comparative Analysis *[2 marks]*	*2 marks*	*• Direct comparisons between all three waveforms* *• Identifies key differences in characteristics: – Energy content/efficiency – Harmonic content – Rise/fall times – Suitability for different applications* *• Analytical rather than just descriptive* *• May include comparison table*
	1 mark	*• Some comparison between waveforms* *• Limited analysis of differences* *• Mostly descriptive rather than analytical*

Indicative content

Sine Wave

- Smooth, continuous curve that rises and falls gradually
- Natural waveform produced by generators and alternators
- Used in main power supply (household electricity)
- Has no abrupt changes or corners
- Most energy-efficient for transmission
- Common in audio and radio signals

Square Wave

- Instant jumps between positive and negative values (looks like rectangles)
- Stays at fixed values before switching
- Used in digital electronics and switching circuits
- Contains many frequencies (harmonics)
- Good for on/off control signals
- Found in computer circuits, pulse generators

Triangular Wave

- Straight lines going up and down at constant rates
- Forms perfect triangles or sawtooth pattern
- Used in audio synthesis (electronic music)
- Signal testing and calibration
- Contains fewer harmonics than square waves
- Used in some timing circuits

WEEK 12

Question 1

Component	Mark Level	What to Look For
Basic Component Descriptions *[2 marks]*	*2 marks*	*• Correctly describes all three components: – Resistor (opposes current flow) – Inductor (coil that stores energy in magnetic field) – Capacitor (stores energy in electric field between plates)* *• Mentions basic physical construction of each* *• Shows understanding of fundamental properties*
	1 mark	*• Basic descriptions of components*
Resistor in AC *[2 marks]*	*2 marks*	*• Explains that resistors behave the same in AC as in DC* *• States that current and voltage are in phase (rise and fall together)* *• Mentions that resistance value remains constant regardless of frequency* *• May mention that resistors convert electrical energy to heat*
	1 mark	*• Basic explanation of resistor behaviour* *• Some understanding of resistance concept* *• Limited explanation of phase relationship*
Inductor in AC *[2 marks]*	*2 marks*	*• Explains that inductors oppose changes in current* *• States that current lags behind voltage by 90° (quarter cycle)* *• Mentions that opposition (reactance) increases with frequency* *• May use terms like "inductive reactance" correctly*
	1 mark	*• Basic explanation of inductor behaviour* *• Some understanding of opposition to current changes* *• Limited explanation of frequency effects*
Capacitor in AC *[2 marks]*	*2 marks*	*• Explains that capacitors pass AC but block DC* *• States that current leads voltage by 90° (quarter cycle)* *• Mentions that opposition (reactance) decreases with frequency* *• May use terms like "capacitive reactance" correctly*
	1 mark	*• Basic explanation of capacitor behaviour* *• Some understanding of charging/discharging* *• Limited explanation of frequency effects*
Essay Structure & Quality *[2 marks]*	*2 marks*	*• Well-organised with clear introduction and conclusion* *• Logical progression from basic concepts to complex relationships* *• Appropriate use of technical vocabulary* *• Clear explanations accessible to non-specialists* *• May include diagrams or examples to illustrate concepts*

	1 mark	• *Basic organisation with some structure* • *Some logical progression of ideas* • *Limited use of technical vocabulary*

Resistor basics

- Resistors simply oppose current flow in any circuit
- In AC circuits, current and voltage rise and fall together (in phase)
- Resistance stays the same regardless of frequency
- They convert electrical energy to heat

Inductor basics

- Inductors (coils of wire) resist changes in current
- In AC circuits, current "lags behind" voltage (when voltage is maximum, current is increasing)
- They oppose current flow more at higher frequencies
- They store energy in magnetic fields

Capacitor basics

- Capacitors (two plates separated by insulator) store electric charge
- In AC circuits, current "leads" voltage (when voltage is increasing, current is maximum)
- They oppose current flow more at lower frequencies
- They store energy in electric fields

Question 2

(a) Calculate inductive reactance X_L, capacitive reactance X_c, and impedance Z

- Correct formula for $X_L = 2\pi fL$
- Correct value of $X_L = 2\pi \times 60 \times 0.2 = 75.4\ \Omega$
- Correct formula for $X_c = \frac{1}{2\pi fC}$
- Correct value of $X_c = \frac{1}{2\pi \times 80 \times 10^{-6}} = 33.2\ \Omega$
- Correct use of $Z = \sqrt{R^2 + (X_C - X_L)^2}$
- Correct value of $Z = \sqrt{100^2 + (75.4 - 33.2)^2} = 108.45\ \Omega$

6 marks

(b) Determine the current in the circuit

- Correct formula $I = \frac{V}{Z}$
- Correct substitution $I = \frac{120}{108.45}$
- Correct final value $I = 1.107\ A$ **(RMS)**
- Unit seen

4 marks

(c) Calculate the phase angle θ

- Correct formula $\tan\theta = \frac{X_L - X_C}{R}$

- Correct substitution $\tan\theta = \frac{75.4-33.2}{100}$
- Correct use of calculator or function to find angle:

$$\theta = tan^{-1}(0.422)$$

- Correct value $\theta = 22.9\,°$

4 marks

(d) Explain if the circuit is inductive or capacitive

- Identifies that $X_L > X_C$
- Correct conclusion: Circuit is inductive

2 marks

SECTION 7: BEHAVIOUR OF LIGHT IN LENSES AND LASER SYSTEMS

STRAND: ENERGY

Sub-Strand: Wave

Week 13

Content Standard: *Demonstrate knowledge and understanding of lenses.*

Learning Outcome: *Use the working principles of lenses to explain the operation of some optical instruments.*

Week 14

Content Standard: *Demonstrate knowledge and understanding of lasers.*

Learning Outcome: *Explain the production and working principles of lasers.*

INTRODUCTION AND SECTION SUMMARY

Section 7 focuses on two major topics within the study of energy and wave phenomena: **lenses** and **lasers**. It provides a comprehensive overview of the fundamental principles governing the behaviour of light as it interacts with lenses and the operational mechanisms of laser systems. The section is structured to progressively build understanding through explanation, graphical representation, and application.

The first part of the section deals with **lenses**, categorising them into **converging (convex)** and **diverging (concave)** types based on their shapes and how they refract light. Essential optical terms such as focal length, principal axis, optical centre, and centre of curvature are clearly defined. The method of **ray tracing** is introduced as a tool for determining image formation, describing how images vary in size, orientation, and position depending on the object's location relative to the lens.

Mathematical treatment follows through the use of the **lens formula** and **magnification equation**, supported by guidance on sign conventions to ensure accurate calculations. The practical importance of lenses is emphasised by examining their use in various devices and instruments, including magnifying glasses, cameras, projectors, microscopes, telescopes, and corrective eyewear. Learners will identify link between the behaviour of light through lenses with the behaviour of light reflecting in curved mirrors from **Year 1, week 12**.

The second part of the section covers **lasers**, beginning with an explanation of the term "LASER" and distinguishing laser light from ordinary light through its key properties: **monochromaticity**, **coherence**, **directionality**, and **high intensity**. The process of laser generation is explained using the principles of **stimulated emission**, **population inversion**, and **optical pumping**, along with the

structural components of a typical laser system—**active medium**, **pumping source**, and **optical resonator**.

The section categorises **types of lasers** into solid-state, gas, semiconductor, and dye lasers, highlighting the materials used, methods of excitation, and typical applications. Lasers are shown to have widespread use in fields such as medicine, industry, communication, scientific research, consumer electronics, and defence. Attention is also given to **laser hazards**, particularly the risks to eye and skin safety, and outlines standard **precautionary measures** for safe usage.

The weeks and the indicators covered by the section are:

- ***Week 13***

Identify the types and features of lenses.

Describe how images are formed by lenses.

Calculate the image distance and the magnification using the lens formula.

- ***Week 14***

Identify features of laser configuration.

Describe the production of a laser beam.

Identify the properties of lasers.

Year 1	**Week 12** Determine the position and characteristics of images formed by spherical mirrors with mirror formula and magnification formula. 2. Explain refraction and state the laws of refraction.

SUMMARY OF PEDAGOGICAL EXEMPLARS

This section presents a variety of activities aimed at developing understanding of lenses and lasers through observation, experimentation, and research. For lenses, tasks involve classifying types, drawing ray diagrams, and calculating image properties using the lens formula. Practical experiments help determine focal length, while simulations and structured exercises reinforce image formation principles.

Laser-related activities include researching key concepts like stimulated emission and population inversion, using simulations to explore beam properties, and linking laser characteristics to real-life applications. Group projects and presentations are used to investigate laser types and safety practices. Overall, the activities combine practical, visual, and theoretical approaches to deepen understanding of optical systems.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Identify the types and features of lenses. Describe how images are formed by lenses. Calculate the image distance and the magnification using the lens formula.	Level 3	Test of practical knowledge Case study
Identify features of laser configuration. Describe the production of a laser beam. Identify the properties of lasers.	Level 2	

WEEK 13

Learning Indicators

1. *Identify the types and features of lenses*
2. *Describe how images are formed by lenses*
3. *Calculate the image distance and the magnification using the lens formula*

FOCAL AREA: LENSES

Lenses

A lens is a transparent optical device that focuses or disperses light rays by means of refraction. Lenses are essential components in a vast array of optical instruments, from eyeglasses and cameras to microscopes and telescopes. Their ability to manipulate light allows for the formation of images, magnification of objects, and correction of vision.

Types of lenses

Lenses are primarily categorised into two main types based on their shape and how they affect parallel light rays: Converging (Convex) Lenses and Diverging (Concave) Lenses.

1. Converging (Convex) Lenses

These lenses are thicker in the middle and thinner at the edges. When parallel rays of light pass through a converging lens, they are refracted inward and converge to a single point. They cause parallel light rays to converge to a real focal point on the opposite side of the lens. They are used in magnifying glasses, cameras, and the human eye.

Types of Convex Lenses

a. Bi-convex (convex on both sides)

b. Plano-convex (one side flat, one side convex)

c. Concavo-convex (one side concave, one side convex, but overall converging)



Figure 7.1 Types of convex lens

2. **Diverging (Concave) Lenses**

These lenses are thinner in the middle and thicker at the edges. When parallel rays of light pass through a diverging lens, they are refracted outward and spread apart. They cause parallel light rays to diverge as if originating from a virtual focal point on the same side of the lens as the incident light. They are used in eyeglasses for shortsightedness and some optical instruments.

Types of Concave Lenses

a. Bi-concave (concave on both sides)

b. Plano-concave (one side flat, one side concave)

c. Convexo-concave (one side convex, one side concave, but overall diverging)

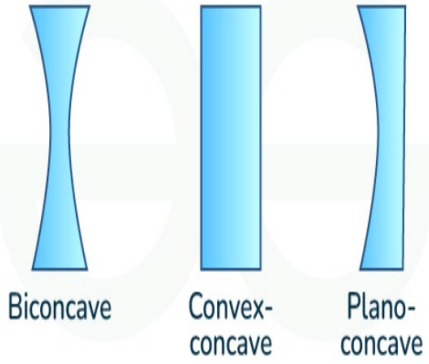


Figure 7.2: *Types of concave lens*

Features of Lenses

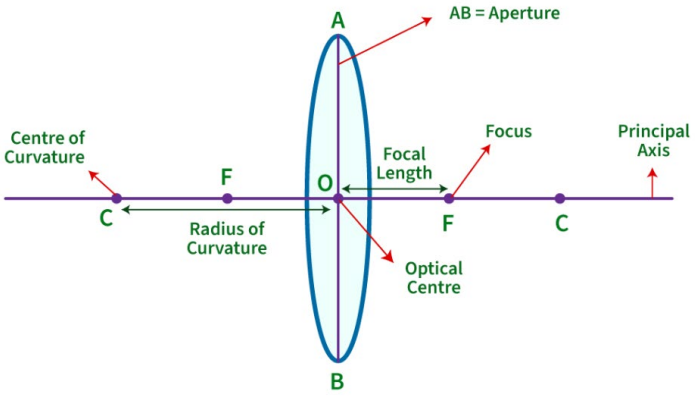


Figure 7.3: *Features of a lens*

a. **Principal Axis:** An imaginary straight line passing through the centre of the lens and perpendicular to its surfaces.

b. **Optical Centre (O):** The midpoint of the lens where light passes straight without deviation.

c. **Principal Focus (F)**

   i. For a converging lens, this is the point on the principal axis where parallel rays of light converge after passing through the lens. There are two principal foci, one on each side of the lens, equidistant from the optical centre. It is a real focus.

   ii. For a diverging lens, this is the point on the principal axis from which parallel rays of light appear to diverge after passing through the lens. It is a virtual focus.

d. **Focal Length (f):** Distance from the optical centre to the focal point. Positive for convex lenses, negative for concave lenses.

e. **Centre of Curvature (2F or C):** A point on the principal axis at a distance equal to twice the focal length from the optical centre. It is the centre of the sphere from which the lens surface is a part.

Power of a lens

The power of a lens is its ability to converge or diverge incident rays of light. The formula for the power of a lens is given by

$$\therefore P = \frac{1}{f}$$

and its unit is Dioptre (D). To calculate the power of a lens in dioptres, the focal length must first be expressed in metres

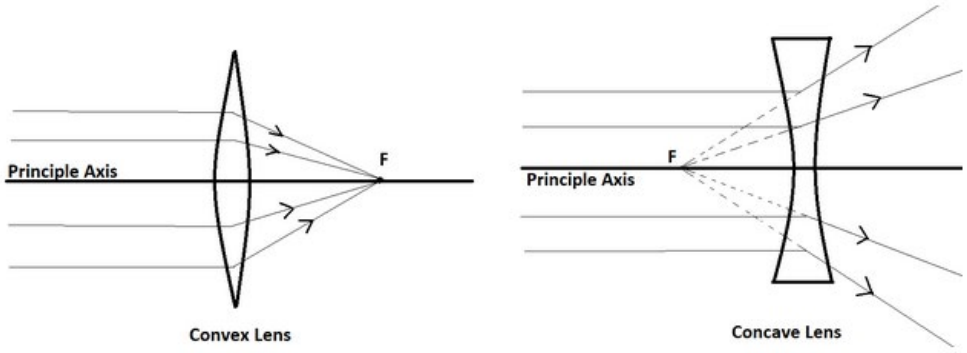


Figure 7.4: *Parallel rays refracted by convex lens and concave lens*

Images Formed by Lenses (Ray Tracing)

Ray tracing is a graphical method used to determine the characteristics (position, nature, size) of an image formed by a lens. It involves drawing at least two principal rays from the top of an object and observing where they intersect after passing through the lens.

Principal Ray Rules (for both types of lenses)

1. A ray parallel to the principal axis passes through (converging) or appears to diverge from (diverging) the principal focus (F) after refraction.
2. A ray passing through the optical centre (O) goes undeviated.
3. A ray passing through (converging) or directed towards (diverging) the principal focus (F) emerges parallel to the principal axis after refraction.

Images Formed by Converging (Convex) Lenses

The nature and position of the image depend on the object's position relative to F and 2F.

Case 1: Object at Infinity

Image is: Real, inverted, highly diminished, formed at F.

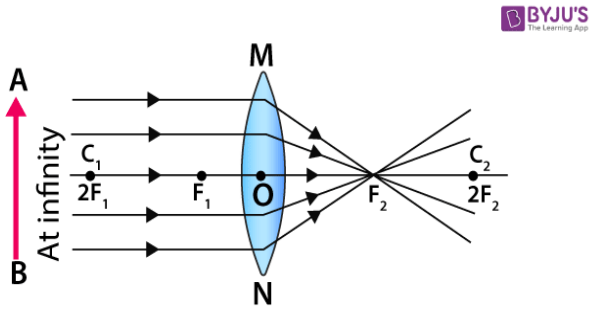


Figure 7.5: *Ray diagram showing the formation of image by a convex lens for an object at infinity*

Case 2: Object Beyond 2F

Image is: Real, inverted, diminished, formed between F and 2F on the opposite side.

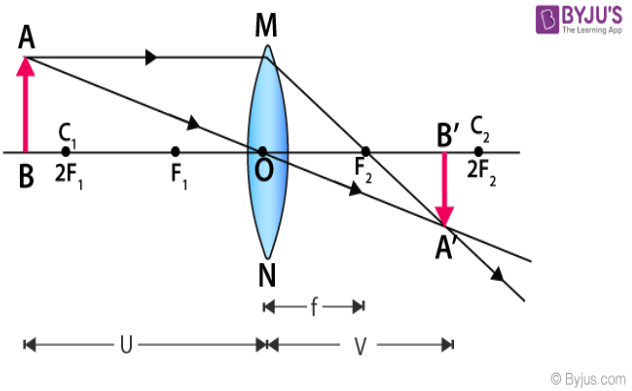


Figure 7.6: *Ray diagram showing the formation of image by a convex lens for an object beyond 2F*

Case 3: Object at 2F

Image is: Real, inverted, same size as object, formed at 2F on the opposite side.

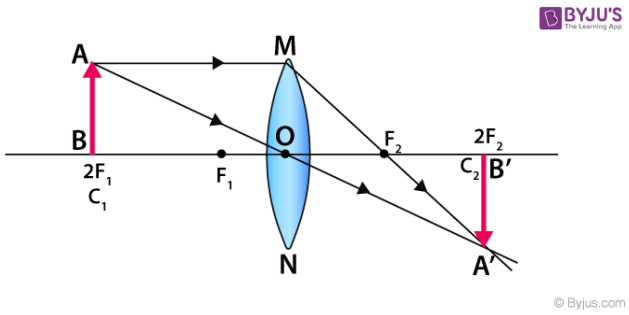


Figure 7.7: *Ray diagram showing the formation of image by a convex lens for an object at 2F"*

Case 4: Object Between F and 2F

Image is: Real, inverted, magnified, formed beyond 2F on the opposite side.

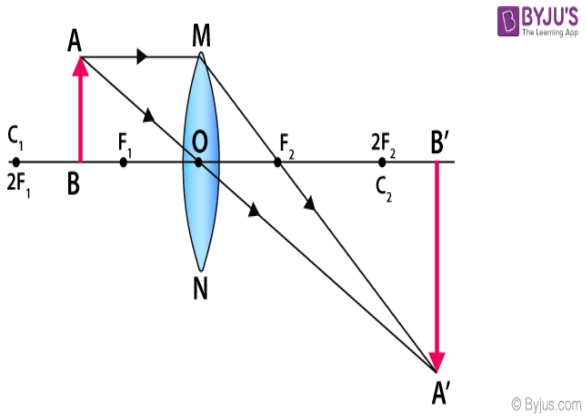
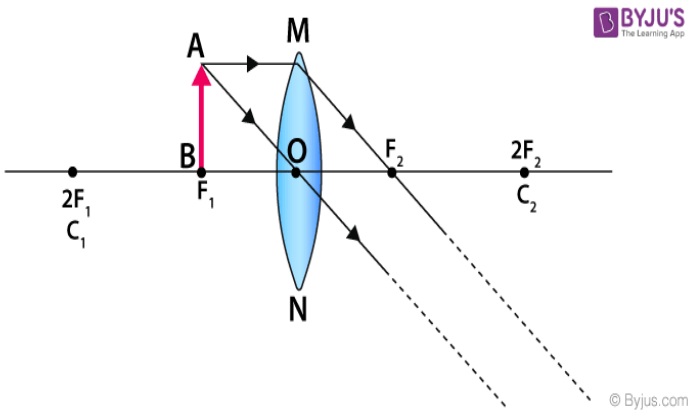


Figure 7.8: *Ray diagram showing the formation of image by a convex lens for an object between F and 2F"*

Case 5: Object at F

Image is: Formed at infinity (rays emerge parallel).



F

Figure 7.9: *Ray diagram showing the formation of image by a convex lens for an object at F*

Case 6: Object Between F and Optical Centre (O)

Image is: Virtual, upright, magnified, formed on the same side as the object. (This is how a magnifying glass works).

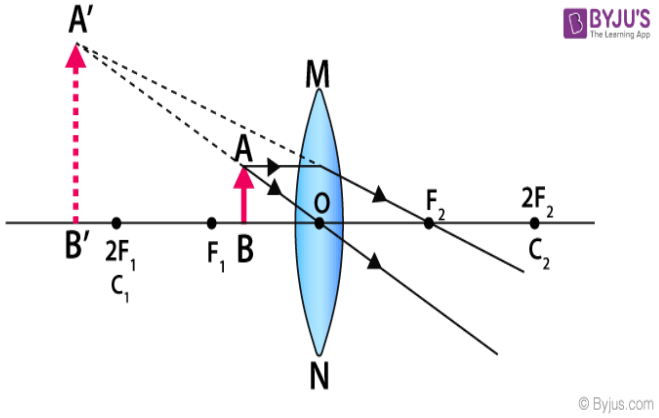


Figure 7.10: *Ray diagram showing the formation of image by a convex lens for an object between F and optical centre"*

Summary Table for Image formation in Convex Lens

Position of Object	Position of Image	Size of Image	Nature of Image
At infinity	At the focus	Diminished	Real and Inverted
Beyond 2F	Between the focus and centre of curvature 2F	Diminished	Real and Inverted
At 2F	At the centre of curvature 2F	Same size	Real and Inverted
Between F and 2F	Beyond the centre of curvature 2F	Enlarged	Real and Inverted
At the focus F	At infinity	Enlarged	Real and Inverted
Between the focus and optical centre	Behind the object	Enlarged	Virtual and erect

Images Formed by Diverging (Concave) Lenses

Image is: Virtual, erect, diminished and formed on the same side of the lens as the object.

Diverging lenses always form images as described above, regardless of object position.

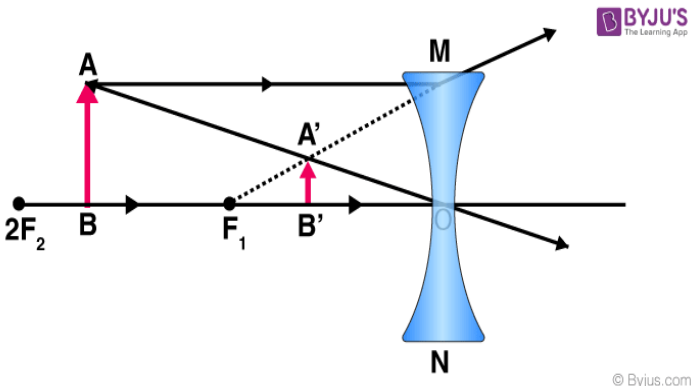


Figure 7.11: *Ray diagram showing the formation of image by a concave lens*

Determination of Image Distance and Magnification Using Lens Formula

While ray tracing provides a visual understanding, the lens formula and magnification formula offer precise mathematical calculations for image characteristics.

The **lens formula** is a fundamental equation in optics that relates the **object distance** (u), **image distance** (v), and the **focal length** (f) of a thin lens. It is applicable to both **convex (converging)** and **concave (diverging)** lenses and helps predict where an image will form and its size relative to the object.

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Where:

- f= focal length of the lens (positive for convex, negative for concave)
- v = image distance from the lens
- u = object distance from the lens

Magnification (m) is a measure of how much larger or smaller the image formed by a lens is compared to the actual object. It describes the ratio of the image height to the object height. Its formula is expressed as

$$m = \frac{h_i}{h_o} = \frac{v}{u}$$

Where:

- m = magnification
- h_i = height of the image
- h_o = height of the object
- v = image distance from the lens

- u = object distance from the lens

To use the lens formula correctly, one of the following sign conventions must be applied consistently throughout the calculation. The "real is positive" convention and the "new Cartesian rule". The real-is-positive convention defines distances to the right of the pole (or optical centre) as positive and to the left as negative, while the new Cartesian rule assigns positive signs to distances measured in the direction of the incident light and negative signs for distances measured against it.

Real-is-Positive Convention

- Distances of real objects and images are positive, while those of virtual objects and images are negative.
- Concave mirrors have a real principal focus and thus a positive focal length, while convex mirrors have a virtual principal focus and a negative focal length.

New Cartesian Rule

- All distances are measured from the mirror's pole or the lens's optical centre.
- Distances measured in the same direction as the incident light are positive.
- Distances measured against the direction of the incident light are negative.

Application of Convex and Concave Lenses

Lenses are ubiquitous in modern technology and daily life, serving a wide array of purposes due to their ability to manipulate light.

Applications of Converging (Convex) Lenses

Convex lenses are used in applications where light needs to be focused, magnified, or projected.

1. Magnifying Glasses: A single convex lens is used to produce a magnified, upright, and virtual image of an object when the object is placed within its focal length (as shown in Case 6 of image formation).
2. Cameras: The primary lens in most cameras is a convex lens (or a combination of lenses that acts as a convex lens) to focus light from the scene onto the film or digital sensor, forming a real, inverted, and diminished image.
3. Projectors (Slide Projectors, Movie Projectors): Convex lenses are used to form a real, inverted, and highly magnified image of a small slide or film frame onto a large screen. The slide is placed just beyond the focal length to achieve this.
4. Microscopes (Compound Microscopes): Both the objective lens (closer to the specimen) and the eyepiece lens are convex lenses. The objective forms a real, magnified image, which is then further magnified by the eyepiece to produce a large virtual image.
5. Telescopes (Refracting Telescopes): The objective lens of a refracting telescope is a large convex lens that collects light from distant objects and forms a real, inverted, and diminished image. The eyepiece (also convex) then magnifies this image.
6. Correcting Hyperopia (longsightedness): People with hyperopia have difficulty seeing nearby objects because their eye lens focuses light behind the retina. A convex lens converges the incoming light rays before they enter the eye, ensuring they focus correctly on the retina.

7. Burning Glass: A convex lens can focus sunlight to a small, intense spot, generating enough heat to burn paper or other materials.

Applications of Diverging (Concave) Lenses

Concave lenses are primarily used to spread out light or correct vision problems where light focuses too quickly.

1. Correcting Myopia (Shortsightedness): People with myopia have difficulty seeing distant objects because their eye lens focuses light in front of the retina. A concave lens diverges the incoming light rays before they enter the eye, pushing the focal point back onto the retina for clear vision.
2. Peepholes in Doors (Door Viewers): These often contain a concave lens, which provides a wide field of view, allowing a person to see a broader area outside the door. The image formed is virtual, upright, and diminished.
3. Flashlights and Street Lights: While the main reflector is often parabolic, concave lenses (or lens elements within a complex system) can be used to spread out the light beam to illuminate a wider area.
4. Laser Beam Expanders: In laser systems, a concave lens is often used in combination with a convex lens to expand the diameter of a laser beam.
5. Galilean Telescopes: Unlike refracting telescopes which use a convex eyepiece, a Galilean telescope uses a concave lens as its eyepiece to produce an upright (erect) final image, though with a narrower field of view.

Learning Tasks

1. Research and define key lens-related terms such as convex lens, concave lens, focal length, and optical centre using textbooks or the internet.
2. Use real or virtual lenses, ray boxes, and screens to identify focal length and classify lenses based on how they bend light.
3. Draw ray diagrams for convex and concave lenses at different object positions and describe the image formed in terms of size, orientation, and type.
4. Perform a lens experiment by focusing a distant object with a convex lens to find its focal length and relate the result to the lens formula.
5. Work in groups to research how lenses function in devices like the human eye, cameras, and telescopes, then present with labelled diagrams and explanations.

Pedagogical Exemplars

Enquiry-Based Learning

Reinforce the concept of light bending through a lens by revisiting Year 1 work on Snell's Law. Guide learners to explain how light refracts when passing through curved surfaces, relating it to the change in speed and direction.Let learners use the internet or reference books to research the meanings of terms such as convex lens, concave lens, pole, principal focus, principal axis, focal length, and optical centre.

Experiential Learning

Provide converging and diverging lenses, white screens, and ray boxes or candles. Guide learners to identify features such as optical centre, principal axis, principal focus, and focal length. Let learners classify the lenses into convex and concave based on how they refract light.Let learners perform a practical activity using a convex lens and a distant object (like a window or tree). Ask them to find the sharpest image on a screen and measure the distance from the lens to the screen. Guide them to identify this as the focal length and relate it to the lens formula.Using ray boxes and convex lenses, let learners observe and sketch image formation for different object positions (e.g., beyond 2F, at 2F, between F and 2F, at F, and between lens and F). Repeat using concave lenses and guide learners to record characteristics of images formed.Use simulations (e.g., PhET "Geometric Optics") to allow learners to manipulate object distance and lens type. Let them record changes in image location, size, and nature, reinforcing the use of the lens formula and ray diagram interpretation.

Talk for Learning

Link the concept of lenses to Year 1 work on spherical mirrors by comparing terminology such as principal axis, focal point, and image nature. Help learners see that many ray construction rules are similar, though image behaviour differs. Use visuals and examples to highlight these connections.

Problem-Based Learning

Provide learners with structured ray diagram exercises showing different object positions relative to a convex or concave lens (e.g., closer than, at, and beyond the focal point). Let them sketch and label ray diagrams and describe the image properties (real/virtual, upright/inverted, magnified/reduced).Using worked examples, guide learners to apply the lens formula and magnification formula to calculate image distance, height, and characteristics. Emphasise the use of any of the conventions and interpretation of results, such as identifying whether the image is real or virtual. Ensure the examples include cases where the object is placed at various positions relative to the lens. Assign a worksheet with problems of increasing difficulty for practice.

Collaborative Learning

Assign a research-based group activity where learners investigate and present how lenses are used in the human eye, cameras, microscopes, and telescopes. Let each group draw simple labelled diagrams and explain the function of the lens in each application.

Key Assessment: Level 3: Test of Practical

Question 1Construct a ray diagram for a convex lens with object at 2F and explain the image characteristics.

(12 marks)

Question 2 - Test of practical knowledge

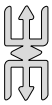
During an experiment, a learner places an object in front of a convex lens and observes that the image is upside down and appears on a screen. Later, the learner moves the object closer, and the image becomes upright and can no longer be projected. Explain why the image characteristics changed as the object moved. Based on the lens behaviour, recommend the best object position if the learner wants a magnified, upright image. Justify your answer.

(10 marks)

PLC Session 13

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



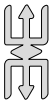
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***test of practical***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*

- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 14

Learning Indicators

1. *Identify features of laser configuration*
2. *Describe the production of a laser beam*
3. *Identify the properties of lasers*

FOCAL AREA: LASERS



Figure 7.12: *Laser Light*

The term "LASER" is an acronym for **Light Amplification by Stimulated Emission of Radiation**. Unlike conventional light sources (like incandescent bulbs or fluorescent lamps) which produce incoherent light, lasers generate a highly specialised form of light. The theoretical foundation for stimulated emission was laid by Albert Einstein in 1917, but the first working laser was built by Theodore Maiman in 1960. The development of lasers revolutionised numerous fields, from medicine and manufacturing to communications and scientific research.

Properties of Lasers

What distinguishes laser light from ordinary light (like that from a flashlight)? Lasers possess four unique properties that make them incredibly powerful and versatile tools:

1. **Monochromaticity**: Laser light is highly monochromatic; whilst ordinary light sources emit a wide spectrum of wavelengths, a laser emits light within a very narrow spectral range. This purity of colour is crucial for applications like spectroscopy and optical data storage.
2. **Coherence**: This is perhaps the most defining characteristic. Laser light is highly coherent, meaning its light waves are in phase with each other, both in space and time.
    a. Temporal Coherence: All photons in the laser beam maintain a constant phase relationship over a significant distance along the beam's direction. This allows for applications like holography and interferometry.
    b. Spatial Coherence: All photons across the beam's cross-section maintain a constant phase relationship. This allows the laser beam to be focused to a very small spot.
3. **Directionality (Low Divergence):** Laser light is highly directional, meaning it travels in a very narrow, collimated beam with minimal spreading (divergence) over long distances. Unlike a flashlight beam that spreads out rapidly, a laser beam can travel miles with little dispersion. This property is vital for applications like laser ranging and optical fibre communication.

4. **High Intensity/Brightness**: Due to its low divergence and coherence, laser light can be concentrated into a very small area, resulting in extremely high-power density or brightness. Even low power lasers can be dangerous to the eye because their energy is focused onto a tiny spot on the retina.

Laser Production (The Mechanism)

The production of laser light relies on a quantum mechanical process called **stimulated emission** and requires specific conditions within a laser device.

1. **Atomic Energy Levels:** Atoms (or molecules/ions) have discrete energy levels. Electrons in an atom can exist in a ground state (lowest energy) or various excited states (higher energy).
2. **Spontaneous Emission:** An electron in an excited state can spontaneously drop to a lower energy level, emitting a photon of a specific energy (and thus wavelength). This process is random, leading to incoherent light.
3. **Stimulated Emission:** If an excited atom is struck by a photon whose energy exactly matches the energy difference between its excited state and a lower energy state, it can be "stimulated" to emit an identical photon. This emitted photon is in phase, has the same direction, polarisation, and wavelength as the incident photon. This is the core of "Light *Amplification* by *Stimulated Emission* of *Radiation*."
4. **Population Inversion:** For stimulated emission to dominate and create a laser beam, there must be more atoms in an excited state than in a lower energy state. This non-equilibrium condition is called **population inversion**. It's counter-intuitive, as atoms naturally prefer lower energy states.
5. **Optical Pumping:** Energy must be supplied to the active medium to raise electrons to excited states and achieve population inversion. This process is called **pumping**. Common pumping methods include:
    a. Optical Pumping: Using intense light from flash lamps or other lasers.
    b. Electrical Pumping: Passing an electric current through a gas or semiconductor.
    c. Chemical Pumping: Using chemical reactions.
6. **Active Medium (Gain Medium):** This is the material (solid, gas, liquid, or semiconductor) whose atoms are excited and undergo stimulated emission. It determines the laser's wavelength and other characteristics.
7. **Optical Resonator (Resonator Cavity):** This consists of two mirrors precisely aligned at either end of the active medium.
    a. One mirror is fully reflective (100% reflection).
    b. The other is partially transmissive (e.g., 95-99% reflective), known as the output coupler.
    c. Photons generated by stimulated emission bounce back and forth between these mirrors. As they travel through the active medium, they stimulate more excited atoms to emit identical photons, leading to an exponential amplification of light.
8. **Laser Beam Output:** When the amplified light beam becomes sufficiently intense, a portion of it passes through the partially transmissive mirror, forming the collimated laser beam.

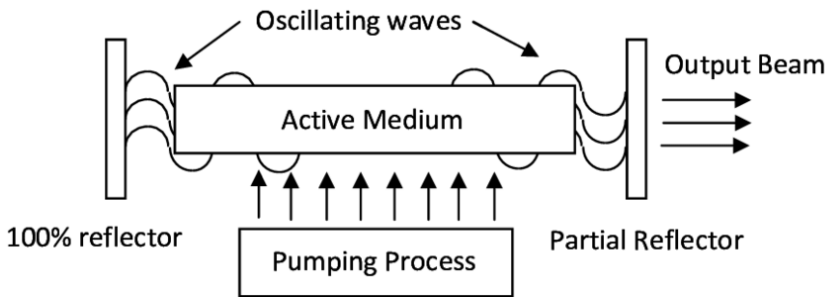


Figure 7.13: *Scheme showing basic components of a laser system*

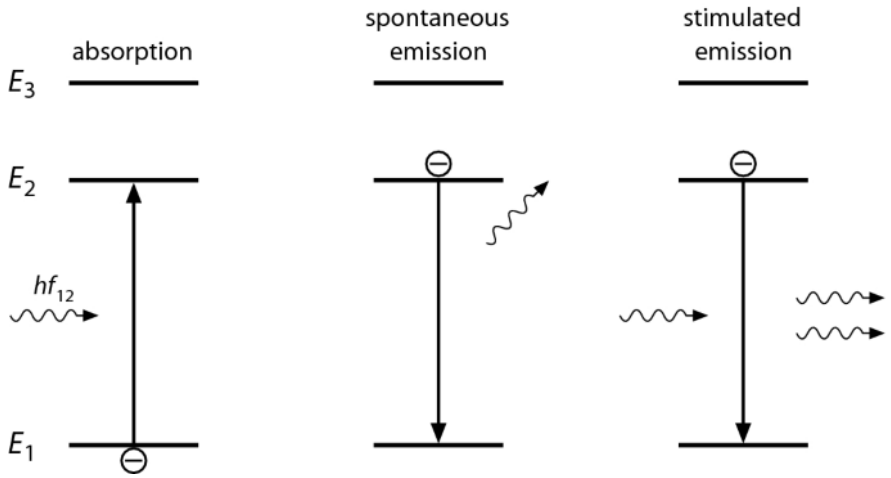


Figure 7.14: *Absorption, Spontaneous emission and Stimulated emission*

Features of Laser Configuration

A typical laser system includes three essential components:

1. **Active Medium (Gain Medium)**

   As discussed, this is the core material that amplifies light. Its choice dictates the laser's wavelength and power characteristics. Examples include ruby crystals (solid), Helium-Neon gas mixtures (gas), organic dyes (liquid), or semiconductor junctions (diode lasers).

2. **Energy Source (Pump)**

   Provides the energy to excite the active medium's atoms. This can be electrical discharge (for gas lasers), flash lamps (for solid-state lasers), or even other lasers (for dye lasers or some solid-state lasers).

3. **Optical Resonator (Cavity)**Formed by two highly reflective mirrors. Their precise alignment and distance determine the specific wavelengths that are amplified and resonate within the cavity. The length of the cavity also dictates the separation between different modes (allowed wavelengths) of the laser.

Types of Lasers

1. **Solid-State Lasers**

   a. **Active Medium:** Ions doped into a crystalline or glass host material (e.g., Neodymium-doped Yttrium Aluminium Garnet - Nd:YAG; Ruby - Chromium-doped Alumina).

   b. **Pumping:** Typically, optically pumped by flash lamps or laser diodes.

   c. **Characteristics:** Can produce very high peak powers in pulsed operation. Widely used in industry (cutting, welding) and medicine (surgery, tattoo removal).

2. **Gas Lasers**
    a. **Active Medium:** A gas or mixture of gases (e.g., Helium-Neon (He-Ne), Carbon Dioxide (CO2), Argon-ion).
    b. **Pumping:** Usually by electrical discharge.
    c. **Characteristics:** Often produce continuous wave (CW) beams. He-Ne lasers are common for alignment and barcode scanners (red light). CO2 lasers are very powerful and used extensively in industrial cutting and welding. Argon-ion lasers produce blue-green light, used in medical applications and printing.
3. **Semiconductor Lasers (Diode Lasers)**
    a. **Active Medium:** A p-n junction in a semiconductor material (e.g., Gallium Arsenide (GaAs), Gallium Nitride (GaN)).
    b. **Pumping:** Directly by electric current.
    c. **Characteristics:** Most common type of laser. Compact, efficient, and inexpensive. Found in CD/DVD/Blu-ray players, laser pointers, fibre optic communication, laser printers, and barcode scanners.
4. **Liquid Lasers (Dye Lasers)**
    a. **Active Medium:** Organic dye molecules dissolved in a solvent.
    b. **Pumping:** Typically, optically pumped by other lasers or flash lamps.
    c. **Characteristics:** Unique for their **tunability**, meaning their wavelength can be adjusted over a broad range. Used extensively in scientific research, especially spectroscopy.

Applications of Lasers

The unique properties of lasers have led to their widespread adoption across almost every scientific and industrial sector:

1. **Medicine**
    a. **Surgery:** Precision cutting and cauterising (e.g., in ophthalmology for LASIK eye surgery, general surgery for precise tissue removal, dermatology for skin treatments).
    b. **Diagnostics:** Flow cytometry, blood analysis, endoscopies.
    c. **Therapeutic Uses:** Photodynamic therapy for cancer, pain relief.
2. **Industry and Manufacturing**
    a. **Cutting, Welding, Drilling:** High-power lasers precisely cut and weld metals, plastics, and other materials with minimal waste.
    b. **Engraving and Marking:** Used for permanent marking on various surfaces (e.g., serial numbers, logos).
    c. **3D Printing (Additive Manufacturing):** Lasers are used to fuse powdered materials (Selective Laser Sintering/Melting) or cure liquid resins (Stereolithography) layer by layer to build 3D objects.
    d. **Metrology and Alignment:** Precision measurement of distances, alignment of machinery, surveying.

3. **Communication**
    a. **Fiber Optics:** Lasers transmit vast amounts of data at high speeds over long distances through optical fibres, forming the backbone of the internet and telecommunications.
    b. **Free-Space Optical Communication:** Used for line-of-sight communication where fibre optics are impractical (e.g., satellite communication).
4. **Information Technology & Consumer Electronics**
    a. **Barcode Scanners:** Read barcodes in retail and logistics.
    b. **Optical Storage:** Read and write data on CDs, DVDs, and Blu-ray discs.
    c. **Laser Printers:** Use a laser beam to create images on a photosensitive drum, which then attracts toner.
    d. **Optical Mice:** Use a laser to track movement across surfaces.
5. **Research and Science**
    a. **Spectroscopy:** Precise analysis of material composition and structure.
    b. **Interferometry:** Highly sensitive measurements of displacement, vibration, or refractive index changes.
    c. **Holography:** Creation of 3D images.
    d. **Fusion Research:** High-power lasers are used to initiate nuclear fusion reactions in experimental reactors.
    e. **Atomic Clocks:** Laser cooling and trapping of atoms for ultra-precise timekeeping.
6. **Military and Defence**
    a. **Ranging and Targeting:** Determining distances to targets, guiding precision munitions.
    b. **LIDAR (Light Detection and Ranging):** Remote sensing for mapping and environmental monitoring.
    c. **Directed Energy Weapons (in development):** Potential for anti-drone or missile defence.
7. **Entertainment:** Laser light shows for concerts and events.

Dangers Associated with Laser

Despite their many benefits, lasers can pose significant hazards if not handled properly. Due to their high intensity, coherence, and directionality, even relatively low-power lasers can cause permanent damage, primarily to the eyes. Higher-power lasers also present skin and fire hazards.

1. **Eye Hazards (Primary Concern):** This is the most common and severe risk associated with lasers. The human eye is highly efficient at focusing parallel light rays onto the retina. Because laser beams are highly collimated (low divergence), the eye can focus all the laser energy from a beam, even from a distance, onto a tiny spot on the retina. This can lead to:
    a. Thermal Burns: High-power lasers can cause immediate and irreversible burns to the retina, leading to blind spots.
    b. Photochemical Damage: Lower power lasers, especially in the blue/UV spectrum, can cause chemical changes in the retina over time, leading to damage.
    c. Corneal/Lens Damage: Lasers in the UV or far-infrared spectrum may be absorbed by the cornea or lens, causing cataracts or corneal burns.

d. Permanent Blindness: Severe retinal damage can result in permanent loss of vision.

e. Wavelength Dependence: The specific type and severity of eye damage depend heavily on the laser's wavelength. For example, visible and near-infrared lasers (400-1400 nm) are particularly dangerous because they pass through the eye's lens and focus on the retina. Far-infrared lasers are absorbed by the cornea, causing surface burns.

2. **Skin Hazards**: High-power lasers can cause burns to the skin, ranging from mild reddening to severe blistering and tissue damage. The severity depends on the laser's power, wavelength, exposure time, and skin pigmentation**.**

Precautions for Laser Safety

To mitigate these dangers, strict safety protocols and engineering controls are essential.

1. **Never look directly into a laser beam or its specular reflection**. This is the golden rule of laser safety.
2. **Use appropriate Laser Safety Eyewear (LSE)**: Goggles or spectacles must be worn for specific laser wavelengths and have an adequate Optical Density (OD) rating to provide sufficient attenuation.
3. **Control Beam Paths**: Keep the laser beam path enclosed or at a height that prevents accidental eye exposure.
4. **Use Interlocks and Warning Signs**: Employ interlocks on laser enclosures and clearly display warning signs (like the standard laser hazard symbol) in laser areas.
5. **Designated Laser Controlled Areas**: Establish specific areas where lasers are operated, with controlled access.
6. **Proper Training**: All personnel working with lasers must receive comprehensive safety training.
7. **Avoid Reflective Surfaces**: Remove unnecessary reflective objects from the laser working area.
8. **Emergency Procedures:** Have clear procedures for laser-related emergencies.

Learning Tasks

1. Research and define key laser production terms—pumping, population inversion, active medium, metastable state, and stimulated emission—and illustrate them with energy level diagrams.
2. Observe a video comparing laser light and flashlight beams, then identify and explain the unique properties of laser light such as coherence and directionality.
3. Complete a table linking laser applications in various fields to the specific properties of laser light that make them effective (e.g., precision surgery → collimation).
4. Use a simulation to explore how changing variables in a laser cavity (e.g., mirror reflectivity) affects the laser's output and stability.
5. In groups, research and present on different types of lasers (e.g., gas, solid-state) based on their active medium, typical wavelengths, and real-life uses.

Pedagogical Exemplars

Enquiry-Based Learning

Using the internet or reference books, learners research key terms related to laser production—**pumping, population inversion, active medium, metastable state, and stimulated emission**. Each learner records definitions in their notebook, followed by a short class discussion where volunteers define and illustrate each concept on the board using energy level diagrams.Guide learners in identifying and explaining key properties of laser light such as coherence, monochromaticity, directionality, and high intensity. Let them observe demonstrations or simulations (e.g., comparing a laser beam with a flashlight) and explain what makes the laser unique.

Let learners observe a short, focused video on the applications of lasers in medicine, industry, communication, and security. After viewing, guide a class discussion where learners identify each application shown and match it with the laser property that enables it (e.g., precision cutting in surgery due to collimation). Learners then complete a table summarising the application, corresponding laser property, and its advantage in that context.

Talk for Learning

Use a short video or simulation to introduce how lasers work, focusing on their essential components—energy source, gain medium, and optical cavity. Guide learners to identify and label these parts in a schematic diagram. Follow up with a class discussion where learners describe how stimulated emission leads to coherent light production.

Experiential Learning

Use an interactive simulation (such as PhET or Open Source Physics) to let learners model how a laser cavity works. Allow them to manipulate variables such as mirror reflectivity or gain medium and observe the impact on laser intensity and stability.

Under strict supervision and using Class 1 or Class 2 laser pointers, let learners explore reflection and beam properties by shining the laser on mirrors and different surfaces. Learners record observations on intensity, beam spread, and reflection, linking them to laser properties like directionality and coherence.

Collaborative Learning

Introduce different types of lasers (e.g., gas, solid-state, semiconductor, dye lasers) using a presentation or reference material. Then, let learners work in small groups to classify various lasers based on their active medium, wavelength range, and application. Each group presents a summary chart to the class.

Problem-Based Learning

Introduce learners to laser safety classifications and potential hazards (e.g., eye and skin damage). Discuss real-world safety practices in labs and workplaces. Then, have learners create safety posters or infographics showing proper handling procedures and personal protective measures when using lasers.

Project-Based Learning

Assign learners to research specific applications of lasers in fields like medicine (e.g., eye surgery), industry (e.g., cutting/welding), communication, and science (e.g., spectroscopy). Learners present their findings through posters, slideshows, or brief oral presentations.

Assign a research project titled in small groups. Provide a research guide with the following structure:

a. Define and explain laser production terms.

b. Draw an annotated diagram showing laser operation.

c. Describe the four key properties of lasers.

d. Identify and explain at least two real-world applications of lasers using those properties.Let each group prepares a mini-report and oral presentation. Provide a rubric with clear criteria: accuracy of content, quality of visuals, teamwork, and clarity of explanation.

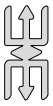
Key Assessment Level 2: Case study

A student observes that a laser pointer produces a very narrow, intense beam of light, while a regular LED flashlight produces a wide, diffused beam. Explain why the internal configuration of a laser must include: (a) A gain medium (b) Two mirrors (one fully reflective, one partially reflective) (c) An external energy source (pumping mechanism.

PLC Session 14

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

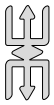
4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***case study***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the case study (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 7 Review

This section focuses on two important topics within the strand of Energy and Wave Phenomena: **Lenses** and **Lasers**. Over the course of two weeks, the section develops key concepts in geometrical optics and modern optical technology, guiding the understanding of how lenses form images and how lasers operate based on quantum and electromagnetic principles.

In week 13, the focus is on the **types, features, and applications of lenses**. Lenses are categorised as converging (convex) or diverging (concave), based on how they refract light.

Important features such as the principal axis, optical centre, focal point, and focal length are introduced. Using ray diagrams, the image formed by lenses is analysed in terms of size, orientation, and nature, depending on the position of the object. The lens formula and magnification equation are used to calculate image distance and size. Sign conventions are also introduced to ensure consistent and accurate results. Practical applications of lenses are explored across devices such as magnifying glasses, cameras, microscopes, telescopes, and corrective lenses for vision.

In week 14, attention shifts to **laser technology**, beginning with an explanation of the term LASER—Light Amplification by Stimulated Emission of Radiation. The properties that make laser light unique—monochromaticity, coherence, directionality, and high intensity—are described and illustrated. The production of laser light is explained through the processes of spontaneous and stimulated emission, population inversion, and optical pumping. Key components of a laser system such as the active medium, pumping source, and optical resonator are discussed. Different types of lasers—solid-state, gas, semiconductor, and dye lasers—are introduced with examples of their materials, methods of excitation, and applications. The section also examines the wide range of laser uses in medicine, communication, industry, research, and entertainment. Finally, the safety risks associated with laser use—particularly to the eyes and skin—are outlined, along with standard safety measures for safe handling.

By the end of the section, essential principles governing image formation by lenses and the operation of laser systems are established. The knowledge gained sets the foundation for further exploration of optical devices and their applications in everyday life and advanced technologies.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 13

Question 1

What should be in a correct diagram

1. A horizontal line (optical axis) with a convex lens drawn in the centre
2. Focal points (F) marked on both sides of the lens at equal distances
3. Points marked at 2F (twice the focal distance) on both sides
4. An upright arrow (object) placed at the 2F point on one side
5. Three rays drawn from the top of the object:
    - One parallel to the axis, then bending through F
    - One through F on the near side, then parallel
    - One through the centre of the lens, continuing straight
6. These rays should meet at a point on the opposite side at 2F
7. A downward-pointing arrow (image) drawn where rays meet

The correct image characteristics

- Same size as the object
- Inverted (upside down)
- Real (rays actually pass through image point)
- Located at 2F on the opposite side

Component	Mark Level	What to Look For
Diagram Setup [2 marks]	*2 marks*	*• Draws optical axis (horizontal line through centre of lens)* *• Draws convex lens symbol (double-curved lines) in centre* *• Clearly marks focal points (F) on both sides of lens* *• Marks 2F points at twice the distance from lens as F* *• Places object at 2F on one side of lens*
	1 mark	*• Basic setup with some elements missing* *• F and 2F placed in approximately the correct places* *• Lens drawn but missing proper shape* *• Object placed approximately at 2F*
Ray 1: Parallel Ray [2 marks]	*2 marks*	*• Draws ray from top of object parallel to optical axis* *• Shows ray bending through focal point on opposite side* *• Ray drawn with ruler (straight lines)* *• Clear arrow showing direction*

	1 mark	*• Ray starts parallel but may bend* *• Ray approximately drawn from object* *• Some understanding shown but with errors*
Ray 2: Focal Ray *[2 marks]*	*2 marks*	*• Draws ray from top of object through focal point on same side* *• Shows ray emerging parallel to optical axis after lens* *• Ray drawn with ruler (straight lines)* *• Clear arrow showing direction*
	1 mark	*• Ray attempts to pass through F but with errors* *• Basic understanding shown but with mistakes*
Ray 3: Central Ray *[2 marks]*	*2 marks*	*• Draws ray from top of object through centre of lens* *• Shows ray continuing straight through lens (no deviation)* *• Ray drawn with ruler (straight line)* *• Clear arrow showing direction*
	1 mark	*• Ray passes through centre but with slight bend* *• Basic understanding shown but with errors*
Image Location *[2 marks]*	*2 marks*	*• Shows image forming where all three rays intersect* *• Places image at 2F on opposite side of lens* *• Draws image as an arrow pointing downward* *• May label image position clearly*
	1 mark	*• Image shown but not precisely at intersection of all rays* *• Position close to but not exactly at 2F* *• Image drawn but not clearly labelled*
Image Characteristics *[2 marks]*	*2 marks*	*• Correctly states image is at 2F on opposite side* *• States image is inverted (upside down)* *• States image is the same size as object* *• States image is real (can be projected on screen)* *• May mention image is focused/sharp*
	1 mark	*• Some characteristics correctly identified* *• Basic understanding demonstrated*

Question 2The key points a good answer should include:

1. **Initial setup**
   - The inverted image on a screen means it was a real image
   - Real, inverted images occur when objects are placed beyond the focal point of a convex lens
   - The object was likely placed somewhere beyond the focal point (at or beyond 2F)

2. **What changed**
   - When the object moved closer, it crossed inside the focal point
   - When objects are inside the focal point (between lens and F), the image becomes:
     - o Virtual (cannot be projected on a screen)
     - o Upright (not inverted)
     - o Magnified (larger than object)
3. **Recommendation**
   - For a magnified, upright image, the object should be placed inside the focal point
   - This is exactly how a magnifying glass works
   - The closer to (but still inside) the focal point, the greater the magnification

Component	Mark Level	What to Look For
Initial Image Analysis *[2 marks]*	*2 marks*	*• Correctly identifies the initial image as real (appears on screen)* *• Explains that real images are formed when object is beyond focal point* *• States that inverted images form when object is beyond focal point* *• May mention the object was likely between F and 2F or beyond 2F*
	1 mark	*• Identifies image as real OR inverted but with limited explanation* *• Some understanding of initial object position* *• Limited connection between position and image type*
Image Change Explanation *[3 marks]*	*3 marks*	*• Explains that moving object closer changed its position relative to focal point* *• Clearly states that object moved to inside the focal point* *• Explains that objects inside focal point produce virtual images* *• Explains that virtual images are upright* *• Explains why virtual images cannot be projected on a screen*
	2 marks	*• Basic explanation of position change* *• Some understanding of virtual image formation* *• Limited explanation of why image became upright* *• Some connection between position and projection ability*
	1 mark	*• Limited explanation of position change* *• Some/limited understanding of image formation*
Light Ray Behaviour *[2 marks]*	*2 marks*	*• Explains how light rays behave differently when object is in different positions* *• Describes how rays converge to form real images* *• Describes how rays appear to diverge (don't actually meet) for virtual images* *• May reference how the lens bends light rays* *• May mention ray diagrams or specific ray paths*

	1 mark	*• Basic explanation of ray behaviour* *• Limited discussion of ray convergence/divergence* *• Some understanding demonstrated*
Recommendation for Magnified, Upright Image *[2 marks]*	*2 marks*	*• Clearly recommends placing object inside the focal point* *• Explains this produces a virtual, upright, magnified image* *• States that the closer to focal point (but still inside), the greater the magnification* *• Explains why this position achieves the desired characteristics*
	1 mark	*• Recommends correct position with limited explanation* *• Some understanding of how to achieve desired image* *• Limited explanation of magnification*
Justification Quality *[1 mark]*	*1 mark*	*• Provides clear, logical reasoning for recommendation* *• Connects position to the requested image characteristics* *• May mention practical applications (e.g., magnifying glass)* *• Shows understanding of lens behaviour and image formation*

WEEK 14

Expected/Model Answer

(a) Gain Medium [4 marks]

The gain medium is a special material (such as ruby crystal, helium-neon gas, or semiconductor material) that contains atoms or molecules capable of being excited to higher energy levels. When these excited atoms return to lower energy states, they emit photons of light. The gain medium is essential because it provides the amplification needed for laser operation through a process called stimulated emission. When a photon of the correct energy passes through the excited gain medium, it stimulates other excited atoms to emit identical photons, creating an avalanche effect that amplifies the light beam.

(b) Two Mirrors [4 marks]

The laser requires two mirrors positioned at opposite ends of the gain medium to create an optical cavity or resonator. The fully reflective mirror (100% reflective) ensures that all light hitting it bounces back into the gain medium. The partially reflective mirror (typically 95-99% reflective) allows most light to bounce back but permits a small percentage to escape as the laser beam. This mirror arrangement causes light to bounce back and forth through the gain medium many times, with each pass causing further amplification through stimulated emission. This repeated amplification creates the intense, narrow, and coherent beam characteristic of lasers.

(c) External Energy Source (Pumping) [4 marks]

An external energy source (called a pump) is necessary to continuously excite the atoms in the gain medium to higher energy levels. This creates a condition called “population inversion” where more atoms exist in excited states than in ground states - a situation that doesn’t occur naturally. The pumping mechanism can be electrical current, intense light, or chemical reactions. Without continuous pumping, the excited atoms would quickly return to their ground states, and stimulated emission would cease, stopping laser operation.

Component	Mark Level	What to Look For
Gain Medium Description [2 marks]	*2 marks*	*• Correctly identifies gain medium as material containing excitable atoms/molecules• Explains that atoms get excited and emit light energy• Mentions amplification or stimulated emission process• Shows understanding of energy level transitions*
	1 mark	*• Basic description of gain medium as light-producing material• Some understanding of excitation concept• Limited explanation of amplification process*
Gain Medium Function[2 marks]	*2 marks*	*• Clearly explains how stimulated emission creates amplification• Mentions avalanche effect or chain reaction of photon emission• Links to production of intense, coherent light• May reference specific gain medium materials*
	1 mark	*• Basic explanation of light amplification• Some understanding of photon emission• Limited connection to laser properties*
Mirror Configuration [2 marks]	*2 marks*	*• Correctly identifies one fully reflective and one partially reflective mirror• Explains positioning at opposite ends of gain medium• Describes optical cavity/resonator concept• Shows understanding of mirror percentages (100% vs 95-99%)*
	1 mark	*• Basic description of two-mirror setup• Some understanding of reflection concept• Limited explanation of mirror differences*
Mirror Function [2 marks]	*2 marks*	*• Explains repeated bouncing of light through gain medium• Describes how multiple passes increase amplification• Links to narrow, intense beam formation• Explains how partially reflective mirror allows beam output*
	1 mark	*• Basic explanation of light bouncing• Some understanding of amplification through multiple passes• Limited connection to beam characteristics*
External Energy Source[2 marks]	*2 marks*	*• Identifies need for continuous excitation of gain medium• Explains population inversion concept• Mentions specific pumping methods (electrical, optical, chemical)• Shows understanding of energy input requirements*
	1 mark	*• Basic explanation of energy input need• Some understanding of excitation process• Limited explanation of pumping mechanisms*
Energy Source Function[2 marks]	*2 marks*	*• Explains why continuous energy is needed for sustained operation• Links to maintaining excited state population• Describes what happens without pumping (laser stops)• May mention energy efficiency considerations*
	1 mark	*• Basic understanding of continuous operation need• Some explanation of sustained excitation• Limited connection to laser functionality*

SECTION 8: PRINCIPLES AND APPLICATIONS OF ELECTROMAGNETIC INDUCTION

STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Sub-Strand: Electromagnetic Induction & Applications

Week 15

Content Standard: *Demonstrate knowledge and understanding of electromagnetic induction.*

Learning Outcome: *Use the concept of electromagnetic induction to explain how electricity can be generated.*

Week 16

Content Standard: *Demonstrate knowledge and understanding of induction.*

Learning Outcome: *Explain the working principles of inductors and their applications.*

Week 17

Content Standard: *Demonstrate knowledge and understanding of the principles of operation of transformers.*

Learning Outcome: *Describe the structure, principle of operation and applications of a transformer.*

INTRODUCTION AND SECTION SUMMARY

This section explores the principles and applications of electromagnetic induction. It begins with the discovery and explanation of how a changing magnetic field can induce an electromotive force (EMF) and current in a conductor, described by Faraday's and Lenz's laws. The direction of induced current is determined using Fleming's Right-Hand Rule, and key factors affecting the strength of the induced EMF—such as magnet strength, coil turns, and speed of motion—are identified.

The section then examines inductors as components that store energy in magnetic fields. Their structure, function in AC and DC circuits, and the concept of inductance are discussed, including the energy stored and the distinction between self-inductance and mutual inductance. This leads to the operation of transformers, which rely on mutual induction to step voltages up or down. Transformer structure, efficiency, and real-world applications are explained, along with the energy losses due to eddy currents, hysteresis, and resistance.

Finally, the section covers eddy currents—their causes, effects, and how they are managed. Though often a source of energy loss, eddy currents also have useful applications such as in induction heating and electromagnetic braking. The section links all these principles to practical devices like generators, dynamos, and transformers, reinforcing their relevance in everyday electrical systems.

The weeks and the indicators covered by the section are:

- ***Week 15***

  Explain electromagnetic induction.

  Using experimentation, verify the laws of electromagnetic induction.

  Describe the factors that affect induced emf and explain direction of induced current using mnemonics of the Fleming's Right Hand Rule.

- ***Week 16***

  Explain inductance and obtain a mathematical expression for the relationship.

  Discuss the behaviour of the inductor in AC and DC circuits.

  Explain how energy is stored in an inductor.

- ***Week 17***

  Discuss the structure, uses and principle of operation of a transformer.

  Discuss the factors that affect the transmission of power and efficiency of a transformer and ways of improving its efficiency.

  Explain Eddy current, effects and applications

Year 2	**Week 17:** Describe the force exerted on a current-carrying conductor in a magnetic field. Discuss the factors that affect the magnitude of the magnetic force on a current-carrying conductor in a magnetic field. Discuss Fleming's left-hand rule.

SUMMARY OF PEDAGOGICAL EXEMPLARS

The section outlines a variety of activities designed to build understanding of electromagnetic induction and its applications through observation, experimentation, and problem-solving. Simulations and demonstrations are used to show how moving magnets or coils generate current, with Fleming's Right-Hand Rule applied to determine the direction of the induced current. Factors such as the number of coil turns, magnet strength, and motion speed are explored to see their effect on induced electromotive force.

Activities also cover the role of inductors in circuits, including their behaviour in both AC and DC conditions, and the calculation of stored energy using relevant formulas. Real-life devices such as dynamos, transformers, and induction cookers are investigated to illustrate core principles like mutual inductance and electromagnetic energy conversion. Practical design tasks involve creating simple generators or transformers using local materials, along with calculations involving turns ratios and efficiency. These exemplars support both conceptual understanding and real-world application of key electromagnetic principles.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/ or Mode
Explain electromagnetic induction. Using experimentation, verify the laws of electromagnetic induction. Describe the factors that affect induced emf and explain direction of induced current using mnemonics of the Fleming's Right Hand Rule.	Level 3	Demonstration
Explain inductance and obtain a mathematical expression for the relationship. Discuss the behaviour of the inductor in a.c and d.c circuits. Explain how energy is stored in an inductor.	Level 4	Class exercise, Project
Discuss the structure, uses and principle of operation of a transformer. Discuss the factors that affect the transmission of power and efficiency of a transformer and ways of improving its efficiency. Explain Eddy current, effects and applications	Level 4	Homework, Project

WEEK 15

Learning Indicators

1. *Explain electromagnetic induction*
2. *Using experimentation, verify the laws of electromagnetic induction*
3. *Describe the factors that affect induced emf and explain direction of induced current using mnemonics of the Fleming's Right Hand Rule*

FOCAL AREA: ELECTROMAGNETIC INDUCTION AND ITS LAWS

Electromagnetic Induction

Electromagnetic induction is a fundamental phenomenon in physics where a changing magnetic field induces an electromotive force (EMF) and, consequently, an electric current in a conductor. This principle forms the basis for the operation of many electrical devices, including generators, transformers, and induction cooktops.

The phenomenon was discovered independently by Michael Faraday in 1831 and Joseph Henry in 1832. Faraday's detailed experimental work led to the formulation of the laws governing this effect.

The essence of electromagnetic induction is that relative motion between a conductor and a magnetic field, or a changing magnetic field through a stationary conductor, will generate an electric current. This is a conversion of mechanical energy (or energy from the changing magnetic field) into electrical energy.

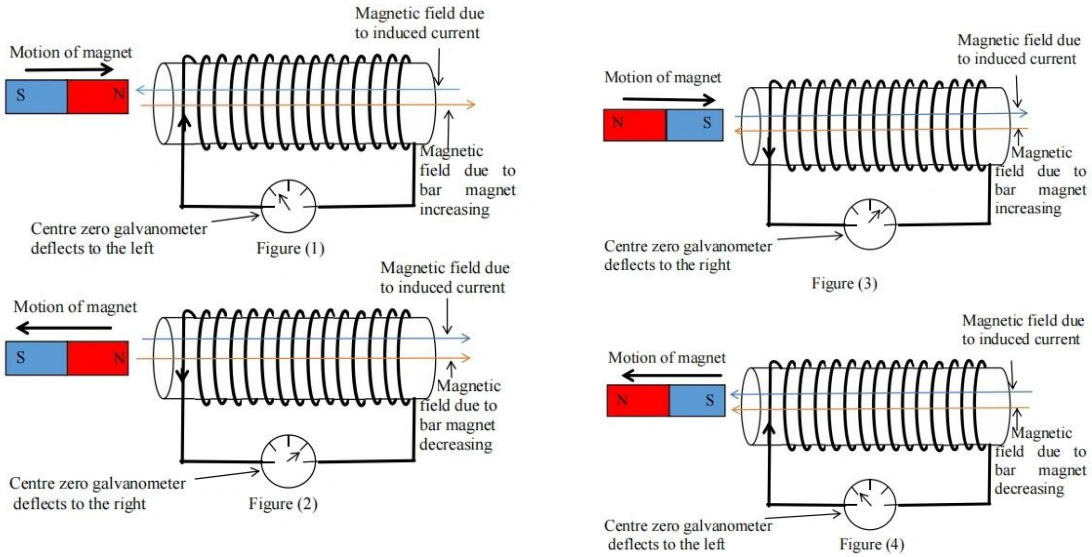


Figure 8.1: *Induced Current in a Coil due to Relative Motion of a Bar Magnet (Lenz's Law Demonstration)*

In Figure 8.1 (1), when a magnetic north pole approaches the coil, the magnetic field to the right intensifies. The induced electromotive force(e.m.f.) in the coil generates a current that opposes this field, thereby establishing a magnetic field to the left. Suppose that the galvanometer shows a deflection to the left.

In Figure 8.1 (2), as a magnetic north pole moves away from the coil, the magnetic field to the right weakens. The induced e.m.f. in the coil produces a current opposing this change, resulting in a magnetic field to the right. The galvanometer deflects to the right.

Figure 8.1 (3) illustrates that when a magnetic south pole approaches the coil, the magnetic field to the left strengthens. The induced e.m.f. in the coil induces a current opposing this change, causing a magnetic field to form to the right. Consequently, the galvanometer deflects to the right.

In Figure 8.1 (4), when a magnetic south pole moves away from the coil, the magnetic field to the left diminishes. The induced e.m.f. generates a current opposing this decrease, resulting in a magnetic field to the left. The galvanometer reflects this opposition, displaying a deflection to the left.

If the magnet is held at rest, galvanometer will not deflect as there is no change in the magnetic flux through the coil.

Deflection in the galvanometer increases, when (i)the magnet is moved faster (ii) a more powerful magnet is used (iii) more turns in the coil (iv) the cross-sectional area of the coil is larger.

Laws of Electromagnetic Induction

The phenomenon of electromagnetic induction is governed by two primary laws: Faraday's Law and Lenz's Law.

Faraday's Law of Electromagnetic Induction

Faraday's Law states that whenever there is a change in the magnetic flux linking a circuit, an emf is induced and its magnitude is directly proportional to the time rate of change of magnetic flux linking the circuit.

$$E \propto \frac{d\emptyset}{dt} \Longrightarrow E = -N\frac{d\emptyset}{dt}$$

E is the induced EMF in Volts (V).

N is the number of turns in the coil.

dΦ is the change in magnetic flux (Wb).

dt is the time interval over which the change occurs (s).

The negative sign is included to incorporate Lenz's Law, indicating the direction of the induced EMF.

This law quantifies the induced EMF. A faster change in magnetic flux (either by moving the magnet faster, using a stronger magnet, or changing the area/orientation more rapidly) results in a larger induced EMF.

Magnetic Flux (Φ): Magnetic flux is a measure of the total number of magnetic field lines passing through a given area. It is calculated as:

$$\emptyset = B\,A\cos\theta$$

Where:

- B is the magnetic field strength (magnetic flux density) in Tesla (T).
- A is the area through which the magnetic field lines pass, in square meters (m^2).
- θ is the angle between the magnetic field lines and the normal to the area.
- The unit of magnetic flux is the Weber (Wb).

Magnetic Flux Linkage (NΦ): When a coil has N turns, the total magnetic flux linking the coil is NΦ.

Lenz's Law

Lenz's Law states that the direction of the induced current (or induced EMF) is always such that it opposes the change in magnetic flux that produced it.

This law is a direct consequence of the principle of conservation of energy. If the induced current were to aid the change in flux, it would lead to a runaway process generating energy indefinitely, which violates the conservation of energy. Instead, the induced current creates a magnetic field that opposes the change in the external magnetic flux.

Examples of Opposition

- If a magnet is moved towards a coil, the induced current will create a magnetic pole that repels the incoming magnet.
- If a magnet is moved away from a coil, the induced current will create a magnetic pole that attracts the receding magnet.
- In both cases, external work must be done to overcome this opposition, and this work is converted into electrical energy.

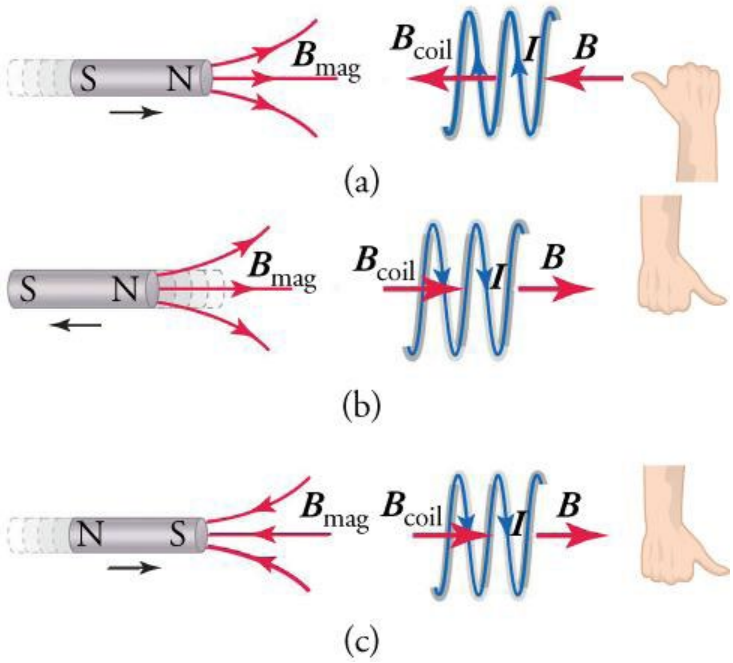


Figure 8.2: *Lenz's law is shown in panels (a)–(c) for various magnet orientations and velocities. The right hands at right show how to apply the right-hand rule to find in which direction the induced current flows around the coil*

Factors Affecting the Magnitude of the Induced EMF

Based on Faraday's Law, several factors directly influence the magnitude of the induced EMF:

1. **Rate of Change of Magnetic Flux ($\Delta\Phi/\Delta t$):** This is the most critical factor. The faster the magnetic flux linking the conductor changes, the larger the induced EMF. This change can occur due to:
    a. Speed of Relative Motion: Moving the conductor faster through the magnetic field or moving the magnet faster relative to the coil.
    b. Rate of Change of Magnetic Field Strength (B): If the magnetic field itself is changing in strength over time (e.g., using an electromagnet whose current is varied).
    c. Rate of Change of Area (A): If the area of the coil exposed to the magnetic field is changing (e.g., a loop expanding or contracting in a magnetic field).

d. Rate of Change of Orientation (θ): If the angle between the magnetic field and the normal to the coil's area is changing (e.g., rotating a coil in a magnetic field, as in a generator).

2. **Strength of the Magnetic Field (B):** A stronger magnetic field will result in a greater induced EMF for the same rate of change of area, relative motion or change of orientation.
3. **Number of Turns in the Coil (N):** For a coil, the induced EMF is directly proportional to the number of turns. More turns mean more conductors cutting through the magnetic field lines, leading to a larger total induced EMF.
4. **Length of the Conductor (L) (for a straight conductor moving in a field):** For a straight conductor moving perpendicular to a magnetic field, the induced EMF is given by $E = BLv$, where L is the length of the conductor in the field and v is its velocity. A longer conductor will experience a larger induced EMF.

Fleming's Right-Hand Rule

Fleming's Right-Hand Rule is a mnemonic used to determine the direction of the induced current (or induced EMF) when a conductor moves in a magnetic field. It is particularly useful for generators

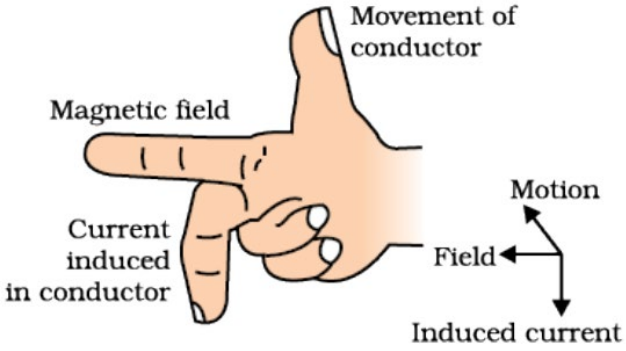


Figure 8.3: *Fleming's right hand rule*

Fleming's right hand rule states that if the first two fingers and the thumb of the right hand are held at right angles to each other with the fore finger in the direction of the field and the thumb in the direction of motion, then the second finger points in the direction of the induced current.

Distinction from Fleming's Left-Hand Rule: Emphasise that the Right-Hand Rule is for induced current (generators), while the Left-Hand Rule is for force on a current-carrying conductor in a magnetic field (motors).

Learning Tasks

1. Observe a demo or simulation of a magnet and coil, then draw the setup and explain how moving the magnet causes current.
2. Use an online simulation to test how speed, coil turns, and magnet strength affect the induced current, and record your findings.
3. Move a magnet through a coil and observe the galvanometer; try different speeds and directions and describe what happens.
4. Use Fleming's Right Hand Rule to find the direction of current in different examples, then complete a worksheet using the rule.
5. Research a real-life device (like a generator or dynamo) that uses electromagnetic induction and explain how it works.

Pedagogical Exemplars

Enquiry-Based Learning

Let learners observe a demonstration or simulation showing how moving a magnet through a coil or moving a coil through a magnetic field induces a current. Prompt them to explain what they observe and guide them to identify the basic principle of electromagnetic induction. Learners sketch and label the setup and describe the direction of current flow.

Talk for Learning

Introduce Fleming's Right Hand Rule using a mnemonic such as "FBI" (F = Force/motion, B = magnetic field, I = current). Use diagrams and hand gestures to help learners align their right hands properly.

Problem-Based Learning

Give worksheet-based practice where learners determine the direction of induced current in different scenarios using the rule.

Experiential Learning

Using an online simulation like PhET's "Faraday's Electromagnetic Lab," let learners manipulate the speed of magnet motion, number of coil turns, and magnetic strength. Let learners record the induced emf values and draw conclusions on how each factor affects the emf, relating it to Faraday's law.

Provide learners with simple materials (a bar magnet, coil of wire, and galvanometer) to explore how moving the magnet faster or reversing its direction affects the galvanometer's deflection. Allow them to investigate and draw conclusions about the relationship between motion and induced emf.

Project-Based Learning & Collaborative Learning

Assign learners to small groups to research and present real-life devices that work on electromagnetic induction (e.g., electric generators, induction cookers, bicycle dynamos). Each group explains how Faraday's law applies to their device and identifies the changing magnetic field and resulting current.

Key Assessment Level 3: Demonstration

1. Using locally available materials such as insulated copper wire, a magnet, and a galvanometer (or any simple current-detecting device), design and demonstrate an experiment to verify **Faraday's law** and **Lenz's law** of electromagnetic induction. Clearly explain how your setup proves each law and suggest one real-life application of each law in Ghanaian society.

   (10 marks)

2. An engineering student is designing three different electricity generators for a remote village project:

   Generator A: A bicycle-powered generator with a coil rotating in a strong permanent magnet field
   Generator B: A hand-crank generator with a magnet moving in and out of a stationary coil

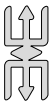
   Generator C: A wind-powered generator with multiple coils and variable-strength electromagnetsWith reference to **Faraday's** and **Lenz's laws**, and in as much detail as you can, explain which of the generators would likely produce the highest emf and why a continuous input of mechanical energy is required. Finally, suggest an improved design for the village's generator, justifying your reasoning.

   (10 marks)

PLC Session 15

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



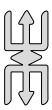
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***demonstration***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the homework (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 16

Learning Indicators

1. *Explain inductance and obtain a mathematical expression for the relationship*
2. *Discuss the behaviour of the inductor in AC and DC circuits*
3. *Explain how energy is stored in an inductor*

FOCAL AREA: PRINCIPLES AND APPLICATIONS OF INDUCTANCE AND ELECTROMAGNETIC INDUCTION

Inductor

An inductor is a passive electrical component that stores energy in a magnetic field when electric current flows through it. It typically consists of a coil of wire.

Structure of an Inductor

The basic structure of an inductor consists of three main parts: the coil (wire), the core, and the terminals.

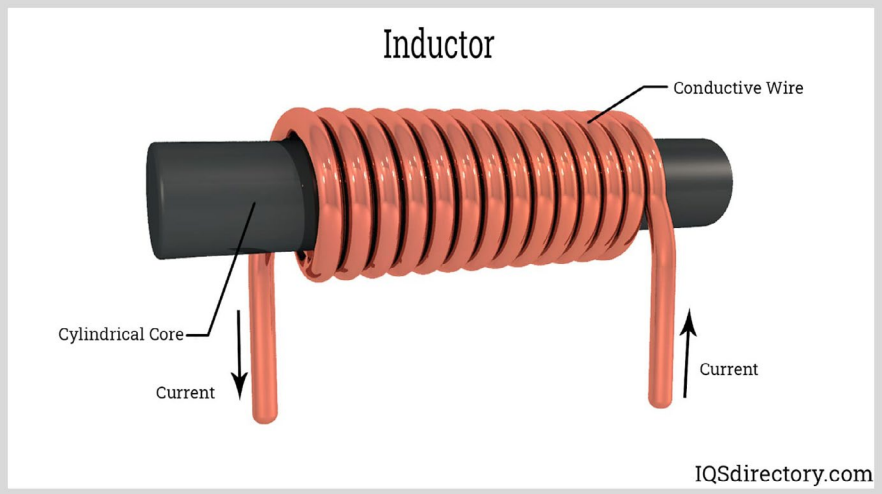


Figure 8.4: *Structure of an inductor*

The **coil** is made of a conductive material, most commonly copper, due to its excellent electrical conductivity. This wire is wound into a helical shape, and the inductance of the inductor depends on several factors related to this coil. These include the number of turns in the coil, the diameter of the coil, and the spacing between the turns. A greater number of turns or a larger diameter generally leads to higher inductance, while the spacing affects the magnetic coupling between turns.

Inside the coil lies the **core**, which can be made of different materials depending on the desired application. In an **air-core inductor**, there is no magnetic material inside the coil — only air. This type is typically used in low-inductance applications or in high-frequency circuits, where magnetic cores may cause energy losses due to eddy currents or hysteresis. In contrast, an **inductor with a ferromagnetic core** uses materials such as iron, ferrite, or powdered iron. These materials significantly enhance the magnetic field generated by the coil, thereby increasing the inductance. The core works by concentrating the magnetic field lines, making such inductors suitable for applications requiring higher inductance values.

The **terminals** are simply the two ends of the coil wire, which provide points of electrical connection to a circuit. When connected, the inductor can influence the current and voltage behaviour within the system, often resisting changes in current and causing phase shifts in alternating current (AC) circuits.

In circuit diagrams, an inductor is represented by a symbol that resembles a series of coiled loops. If the inductor includes a magnetic core, the symbol often includes a solid line or lines parallel to the coil to indicate this feature.

Behaviour of the Inductor in AC and DC Circuits

The behaviour of an inductor is fundamentally different in DC (direct current) and AC (alternating current) circuits due to its property of opposing changes in current.

In DC Circuits

1. **At Switch On (Transient State):** When a DC voltage is first applied to an inductor, the current tries to rise rapidly. The inductor opposes this change by inducing a large back-EMF that temporarily limits the current. This causes the current to rise gradually from zero to its steady-state value. The inductor acts like a temporary open circuit.
2. **Steady State (After a long time):** Once the current reaches a constant, steady value (i.e., the rate of change of current is zero), the inductor no longer induces a back-EMF. In this state, a pure inductor behaves like a short circuit (a wire with zero resistance). The only opposition to current flow comes from the DC resistance of the wire itself (which is usually very small).
3. **At Switch Off (Transient State):** When the DC supply is removed, the current tries to drop rapidly to zero. The inductor again opposes this change by inducing a large back-EMF (in the opposite direction), trying to maintain the current flow. This can cause a high voltage spike across the inductor, which can be damaging to other components if not suppressed.

In AC Circuits

1. **Continuous Opposition**: In an AC circuit, the current is constantly changing in both magnitude and direction. This continuous change means the inductor is always inducing a back-EMF, which continuously opposes the change in current.
2. **Inductive Reactance ():** This opposition to AC current is quantified by inductive reactance (). As discussed in section 6, increases with frequency.
3. **Phase Shift:** The back-EMF induced in the inductor causes the voltage across the inductor to lead the current through it by 90°. This means the voltage waveform reaches its peak a quarter cycle before the current waveform reaches its peak.
4. **Energy Exchange:** The inductor continuously stores energy in its magnetic field during one part of the AC cycle and releases it back to the circuit during another part. It does not dissipate energy as heat (in an ideal inductor).

Inductance (L) and its Mathematical Expression

Inductance (L) is a measure of an inductor's ability to oppose changes in current. It quantifies how much magnetic flux is produced per unit of current. The higher the inductance, the greater the opposition to current changes. The SI unit of inductance is the **Henry (H)**, named after Joseph Henry.

Inductance is defined as the ratio of the magnetic flux linkage ($N\Phi$) to the current (I) producing it:

$$L = \frac{N\emptyset}{I}$$

Where:

- L is inductance (H).
- N is the number of turns in the coil.
- Φ is the magnetic flux (Wb).
- I is the current (A).

Mathematical Expression for a Solenoid (Ideal Inductor): For a long solenoid (a common model for an inductor), its inductance can be calculated based on its physical dimensions and the properties of its core material:

$$L = \frac{\mu N^2 A}{I}$$

Where:

- L is inductance (H).
- μ is the magnetic permeability of the core material (H/m). $\mu = \mu_o \mu_r$, where μ_r is the relative permeability of the core (dimensionless) and μ_o is the permeability of free space (4π x 10 H/m).
- N is the number of turns in the coil.
- A is the cross-sectional area of the coil (m²).
- l is the length of the coil (m).

Factors Affecting Inductance: This formula clearly shows that inductance increases with:

1. More turns (N).
2. Larger cross-sectional area (A).
3. Shorter length (l).

Higher permeability of the core material (μ).

Self-Inductance and Mutual Inductance

Self-Inductance: This is the property of a single coil to induce an EMF within itself due to a change in the current flowing through it. When the current in a coil changes, the magnetic flux produced by that current also changes. According to Faraday's Law, this changing flux induces an EMF in the coil itself, which opposes the change in current. The inductance 'L' discussed above is typically referred to as self-inductance. The induced self-EMF (ε_L) is given by: $\varepsilon_L = -L\frac{dI}{dt}$ Where dI/dt is the rate of change of current.

This self-induced EMF is often called a "back-EMF" because, by Lenz's Law, its direction always opposes the change in current that created it. If the current is increasing, the self-induced EMF acts to reduce it; if the current is decreasing, it acts to maintain it. This property is crucial for the operation of many electronic circuits, including chokes (which block AC while allowing DC), filters, and energy storage devices.

Mutual Inductance (M): This is the property where a change in current in one coil induces an EMF in a neighbouring coil. If two coils are placed close to each other, the magnetic field produced by one

coil can link with the other coil. When the current in the first coil changes, the magnetic flux linking the second coil also changes, inducing an EMF in the second coil.

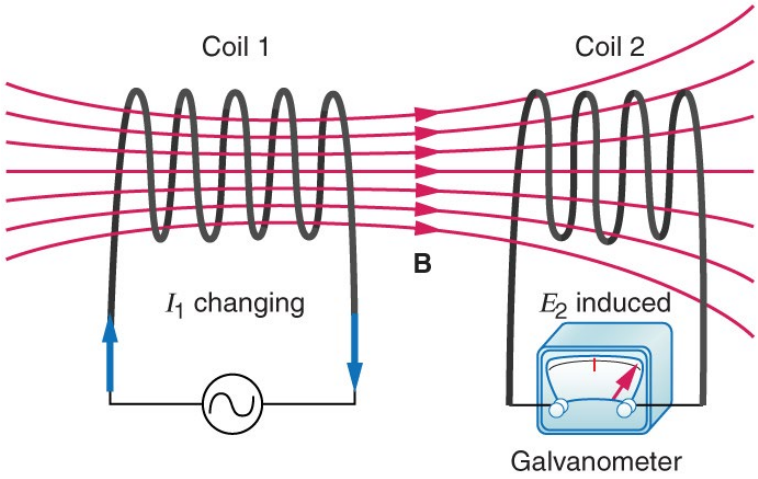


Figure 8.5: *Two coils induce emfs in one another like an inefficient transformer. Their mutual inductance M indicates the effectiveness of the coupling between them. Here a change in current in coil 1 is seen to induce an emf in coil 2*

The mutual inductance 'M' between two coils (coil 1 and coil 2) is defined as:

$$\mathrm{M} = \frac{N_2 \emptyset_{12}}{I_1}$$

Where

- N_2 is the number of turns in coil 2.
- $\emptyset_{12}$ is the magnetic flux from coil 1 that links with coil 2.
- I_1 is the current in coil 1.

The induced EMF (ε_2) in coil 2 due to a changing current in coil 1 is**:**

$$\varepsilon_2 = -M\frac{dI_1}{dt}$$

Mutual inductance describes the magnetic coupling between two or more coils. The closer the coils are, the more turns they have, and the higher the permeability of the core material they share, the greater the mutual inductance.

Coefficient of Coupling (k): This dimensionless quantity (ranging from 0 to 1) describes the degree of magnetic coupling between two coils. $k = \frac{M}{\sqrt{L_1 L_2}}$ Where L_1 and L_2 are the self-inductances of the individual coils. A value of k=1 indicates perfect coupling (all flux from one coil links the other), while k=0 indicates no coupling.

Mutual inductance is the fundamental principle behind transformers, where electrical energy is efficiently transferred from one circuit to another via a changing magnetic field. It's also used in induction heating, wireless power transfer, and various sensor applications.

Energy Stored in an Inductor

An ideal inductor does not dissipate energy as heat (like a resistor). Instead, it stores energy in its magnetic field when current flows through it. This stored energy can then be returned to the circuit when the current decreases.

When current flows through the coil, it creates a magnetic field around the inductor. The energy required to establish this magnetic field is stored within the field itself.

The energy (E) stored in an inductor is given by:

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

Where:

- E is the energy stored (Joules, J).
- L is the inductance (H).
- I is the current flowing through the inductor (A).

The energy stored is proportional to the square of the current. This stored energy is responsible for the inductor's ability to oppose changes in current and for the voltage spikes observed when current is rapidly interrupted (e.g., when a switch is opened in an inductive DC circuit). In AC circuits, energy is continuously stored and released, leading to reactive power.

Application of Electromagnetic Induction

Operation of dynamo and generators

Generators (also known as alternators) and dynamos are devices that convert mechanical energy into electrical energy based on the principle of electromagnetic induction. This is achieved by creating relative motion between a conductor and a magnetic field, thereby inducing an electromotive force (EMF) and current.

Both types of machines operate on Faraday's Law of Electromagnetic Induction, which states that an EMF is induced in a conductor when it cuts magnetic flux lines. The direction of the induced current is given by Fleming's Right-Hand Rule.

Common Components

1. **Armature (Rotor Coil):** A coil of wire that rotates within a magnetic field. This is where the EMF is induced.
2. **Magnetic Field (Stator Magnets):** Provided by permanent magnets or electromagnets, creating the magnetic flux that the armature coil cuts.
3. **Brushes:** Stationary carbon blocks that make electrical contact with the rotating slip rings or commutator, allowing current to be drawn from the armature.

AC Generator (Alternator)

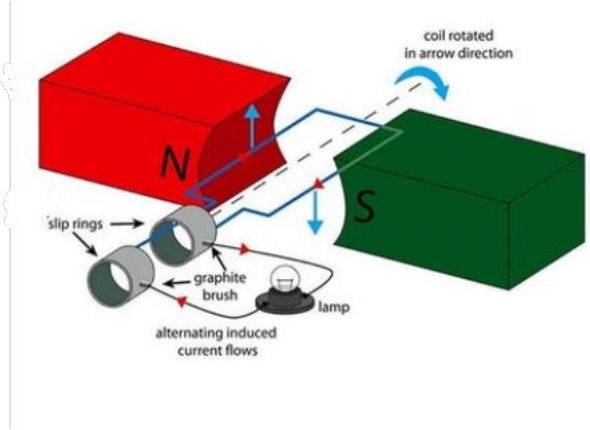


Figure 8.6: *Structure of an AC Generator*

Output: Produces alternating current (AC).

Mechanism: The ends of the armature coil are connected to two separate slip rings. As the coil rotates in the magnetic field, the induced EMF and current continuously change direction, resulting in an AC output. The slip rings maintain continuous contact with the stationary brushes, transferring the alternating current to the external circuit.

DC Generator (Dynamo)

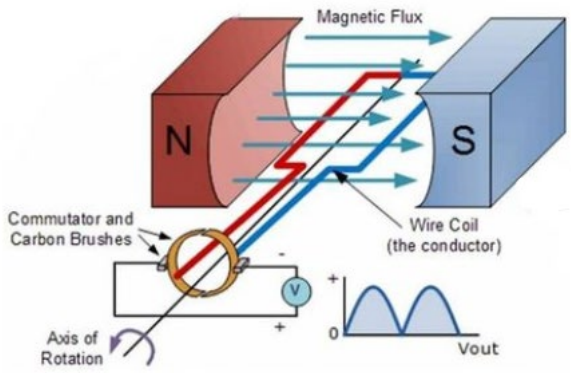


Figure 8.7: *Structure of an DC Generator*

Output: Produces direct current (DC).

Mechanism: Instead of slip rings, the ends of the armature coil are connected to a single commutator. The commutator is a split ring that reverses the connection of the coil to the external circuit every half rotation. This ensures that the current flowing out to the external circuit always flows in the same direction, resulting in a pulsating DC output.

Modification from AC Generator: A DC generator is essentially an AC generator with a crucial modification: the replacement of slip rings with a commutator. In an AC generator, the slip rings maintain continuous contact with the rotating coil, allowing the alternating current to be drawn directly. In contrast, the commutator in a DC generator acts as a mechanical rectifier. As the coil rotates, the commutator segments switch contact with the brushes at the precise moment the current in the coil reverses direction. This continuous switching ensures that the current delivered to the external circuit always flows in the same direction, thus producing a pulsating DC output rather than a continuously alternating one.

Learning Tasks

1. Draw and label an inductor after studying its structure from a video or diagram, then explain how the coil and core affect inductance.
2. Observe a video of a bicycle dynamo and describe how turning the wheel generates electricity using electromagnetic induction.
3. Compare AC and DC generators using diagrams, then label key parts and explain how AC can be changed to DC.
4. Build or simulate an RL circuit and observe how current rises slowly due to back emf, then sketch a current vs. time graph.
5. Use a simulation to see how changing coil turns or core material affects inductance, and record your findings.

Pedagogical Exemplars

Talk for Learning: Using videos or diagrams from textbooks, guide learners to study the internal structure of an inductor, including the coil, core (air or iron), and wire winding. Let learners draw and label the structure in their notebooks, followed by a class discussion on how the physical design affects inductance.

a. Let learners observe a video or animation of a bicycle dynamo in action. Guide them to describe how mechanical rotation is converted to electrical energy using electromagnetic induction, and relate this to Faraday's law.

b. Using diagrams or models, guide learners to compare the structure of an AC generator and a DC generator. Emphasise the role of the slip rings and commutator and let learners annotate diagrams showing the modification needed to convert an AC generator into a DC generator.

Experiential Learning: Allow learners to explore the behaviour of an inductor in a DC circuit by building or simulating a simple RL circuit. Let them observe how the current does not rise instantly when the switch is closed and takes time to reach its maximum, due to back emf. Let Learners sketch and interpret current vs time graphs.

a. Use a hands-on activity or simulation of a simple AC generator to demonstrate how mechanical rotation of a coil in a magnetic field induces current. Guide learners to sketch how the current varies with time and identify components such as coil, slip rings, and brushes.

Enquiry-Based Learning

a. Guide learners to explore the behaviour of an inductor in an AC circuit using an interactive simulation. Learners should observe how the current lags the voltage and sketch the phase relationship between them. Conclude with a summary discussion on inductive reactance.

b. Let learners use simulation tools (e.g., PhET) to change the number of coil turns or the core material in an inductor and observe the effect on inductance. Guide them to record their observations and deduce the relationship between inductance and coil design.

c. Use a simulation or video to demonstrate mutual inductance between two coils. Let learners record their observations and discuss how changing current in one coil induces emf in the second coil, leading to transformer action.

Problem-Based Learning

Introduce learners to the energy stored in an inductor with the formula $E = \frac{1}{2}LI^2$. Use worked examples to show how to calculate the energy stored for given values of inductance and current, and let learners solve simple problems using the formula.

Give learners a worksheet with a mix of conceptual and calculation questions on inductance, behaviour in AC/DC circuits, and energy storage. Provide worked examples first and offer guided support as learners complete the worksheet in pairs or small groups.

Project-Based Learning

Assign a research task where learners investigate real-life devices that use inductors (e.g., transformers, radio tuning circuits, power supplies). Let each group present how inductors function in their chosen device.

Collaborative Learning

Engage learners in a group research task where they explore the concept of self-inductance. Each group presents how a changing current in a coil induces emf in the same coil, with examples like inductors and transformers.

Key Assessment Level 4: Project

1. Your school needs a backup power system for emergency lighting during power cuts. You have inductors with L = 0.5 H that can safely carry 4 A, and the emergency lights need exactly 8 J of stored energy. Design an inductor-based energy storage system by determining how many inductors you need and whether to connect them in series or parallel. Calculate the energy storage capacity of your design and justify why your chosen arrangement is better than the alternative arrangement for this school emergency application.

   (10 marks)

2. Design and construct a simple **DC generator** or **AC generator** using locally available materials such as nails, copper wire, plastic bottles, cardboard, magnets, and bicycle parts. Your task must include:

   a. A labelled diagram of your design showing the coil, magnet, shaft (or crank), and terminals.

   b. A brief explanation of how the generator works, applying **Faraday's Law** and **Fleming's Right Hand Rule**.

   c. A discussion of the type of current (AC or DC) produced and how your design supports that.

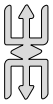
   d. One way your generator could help solve a real-world problem in your school or community (e.g., lighting a bulb, charging phones, powering a radio).

   (10 marks)

PLC Session 16

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

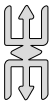
- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*

- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 17

Learning Indicators

1. *Discuss the structure, uses and principle of operation of a transformer*
2. *Discuss the factors that affect the transmission of power and efficiency of a transformer and ways of improving its efficiency*
3. *Explain Eddy current, effects and applications*

FOCAL AREA: ELECTROMAGNETIC INDUCTION–EDDY CURRENTS AND TRANSFORMER OPERATION

Eddy Currents

Eddy currents are loops of electric current induced within conductors by a changing magnetic field in the conductor. They are a consequence of Faraday's Law of Electromagnetic Induction.

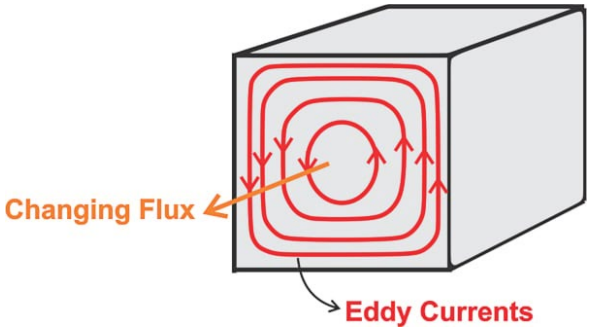


Figure 8.8: *A changing magnetic field produces eddy currents in an electrically conductive core*

How they form: When a conductor (especially a bulk piece of metal, not just a wire) is exposed to a changing magnetic flux (either because the magnetic field itself is changing, or the conductor is moving through a static magnetic field), circulating currents are induced within the body of the conductor. These currents flow in closed loops, resembling eddies in water, hence the name.

Lenz's Law in Action: According to Lenz's Law, these induced eddy currents create their own magnetic fields that oppose the change in the original magnetic flux that produced them. This opposition leads to a resistive force that opposes the motion or the change in flux.

Dangers/Disadvantages of Eddy Currents

1. **Energy Loss (Heat Generation):** As eddy currents flow through the resistance of the conductor, they dissipate energy in the form of heat (I^2R losses). This is often an undesirable effect, leading to reduced efficiency in devices like transformers, motors, and generators.
2. **Damping Force:** The opposing magnetic field created by eddy currents can exert a braking or damping force on moving parts, which can be undesirable in some applications (e.g., in rotating machinery where it causes mechanical resistance).
3. **Heating in Electrical Devices:** Excessive eddy currents can lead to overheating of components, potentially causing damage or reducing the lifespan of electrical machinery.

How to Minimise Eddy Currents

Minimising eddy currents is crucial in many electrical devices to reduce energy losses and prevent overheating.

1. **Lamination of Cores**: This is the most common and effective method. Instead of using a solid block of ferromagnetic material for transformer cores or motor armatures, the core is built up from thin sheets (laminations) of electrically insulated material (e.g., silicon steel), stacked together. The insulation between the laminations breaks the continuous paths for eddy currents, forcing them to flow in much smaller loops within each individual lamination. Since the resistance of these smaller loops is much higher (and the area enclosed is smaller), the magnitude of the eddy currents and thus the heat generated is significantly reduced.

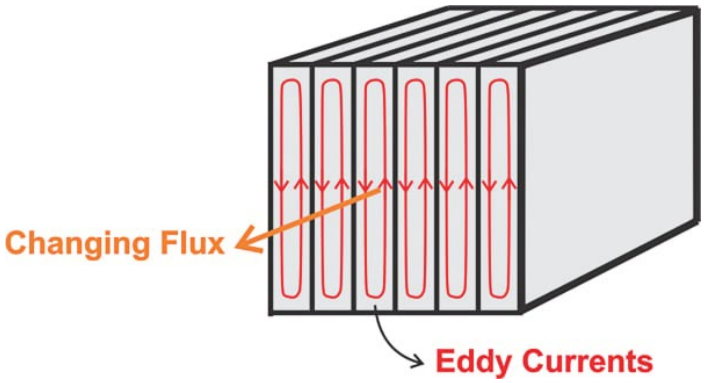


Figure 8.9: *Eddy currents in a laminated core*

2. **Using High Resistivity Materials:** While not always practical for core materials (which need to be good magnetic conductors), using materials with higher electrical resistivity can help reduce eddy currents, as $I = V/R$.
3. **Reducing the Frequency of Changing Flux:** In some applications, if feasible, reducing the frequency of the alternating magnetic field can decrease the rate of change of flux, thereby reducing the induced EMF and eddy currents.

Applications of Eddy Currents

While often seen as undesirable, eddy currents have several beneficial applications where their heating or damping effects are harnessed.

1. **Induction Furnace**

   Principle: A high-frequency alternating current is passed through a coil, producing a rapidly changing magnetic field. A metal to be melted (or heated) is placed within this changing magnetic field.

   Operation: The changing magnetic flux induces strong eddy currents within the metal workpiece. Due to the electrical resistance of the metal, these large eddy currents generate significant heat (I^2R heating), rapidly melting the metal.

   Advantages: Clean heating (no direct contact with fuel), precise temperature control, and rapid melting.

2. **Electromagnetic Damping (in Galvanometers/Analog Meters)**

   Principle: In sensitive measuring instruments like galvanometers, a coil rotates in a magnetic field. When the current through the coil changes, or the coil moves, eddy currents are induced in the metallic frame on which the coil is wound (or in a separate damping mechanism).

Operation: According to Lenz's Law, these induced eddy currents create a magnetic field that opposes the motion of the coil. This opposing force quickly brings the coil to rest without oscillation, allowing for a stable and quick reading.

Advantages: Provides smooth and rapid damping of oscillations, preventing needle fluctuations and allowing for accurate readings.

3. **Speedometers (Older Analog Types)**

   Principle: Relies on the interaction between a rotating magnet and a metallic drum.

   Operation: A rotating permanent magnet (connected to the vehicle's wheel via a cable) is placed near a non-magnetic aluminium drum. As the magnet rotates, it creates a changing magnetic field that induces eddy currents in the aluminium drum. By Lenz's Law, these eddy currents create an opposing magnetic field, causing the drum to experience a torque and try to follow the magnet's rotation.

   Measurement: The drum is connected to a spring and a pointer. The faster the magnet rotates (higher speed), the stronger the eddy currents and the greater the torque. The pointer deflects proportionally to the speed, indicating the vehicle's speed.

Transformers

A transformer is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. It is primarily used to step-up or step-down AC voltages and currents.

Structure of a Transformer

1. **Core:** Made of a soft iron core. The core provides a low-reluctance path for the magnetic flux, ensuring efficient coupling between the coils.

   Laminated Core: Consists of thin sheets of silicon steel insulated from each other. This significantly reduces eddy current losses.

   Types of Cores

   - **Shell Type:** Both primary and secondary windings are wound on the central limb of the core. Provides better magnetic shielding.
   - **Core Type:** Windings are placed on two separate limbs of the core.

2. **Primary Winding (Np):** The coil connected to the input AC voltage source (primary side).
3. **Secondary Winding (Ns):** The coil connected to the load (secondary side), where the induced voltage is obtained.
4. **Insulation**: Insulating materials are used between the windings and the core, and between the turns of the windings, to prevent short circuits.
5. **Tank/Cooling System:** Larger transformers are housed in a tank filled with insulating oil (which also acts as a coolant) and may have external radiators or fans for heat dissipation.

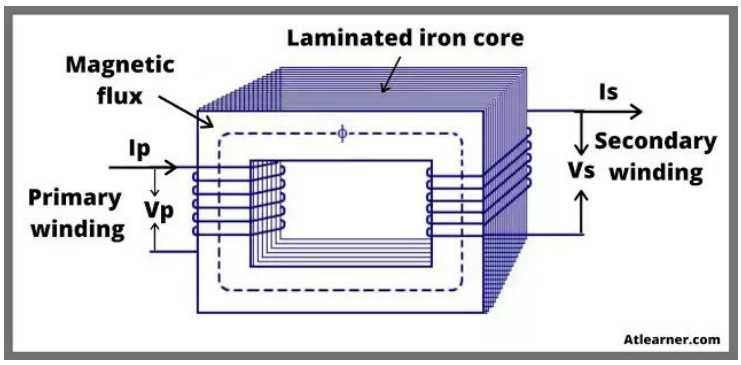


Figure 8.10: *Structure of a core-type transformer*

Uses of a Transformer

Transformers are indispensable in modern electrical power systems and countless electronic devices.

1. **Power Transmission and Distribution**
   a. Step-up Transformers: At power generation plants, they increase the generated voltage (e.g., from 11 kV to 400 kV) for efficient long-distance transmission. High voltage reduces current (P=VI), minimising I^2R losses in transmission lines.
   b. Step-down Transformers: Near consumption points (substations, homes), they decrease the voltage to safe and usable levels (e.g., from 400 kV to 11 kV, then to 240 V or 120 V)
2. **Electronic Devices**
   a. **Power Supplies:** Convert high AC mains voltage to lower AC voltages before rectification to DC for electronic circuits.
   b. **Matching Impedances:** Used in audio amplifiers to match the impedance of the amplifier output to the impedance of a speaker for maximum power transfer.
   c. **Isolation:** Provide electrical isolation between circuits, enhancing safety.
3. **Welding:** High-current, low-voltage transformers are used in arc welding.
4. **Medical Equipment:** For voltage regulation and isolation.

Mode of Operation of a Transformer

The operation of a transformer is based on the principle of mutual induction.

1. **AC Input to Primary:** When an alternating voltage (Vp) is applied across the primary winding, an alternating current (Ip) flows through it.
2. **Changing Magnetic Flux:** This alternating current produces a continuously changing magnetic flux (Φ) in the primary winding.
3. **Flux Linkage with Secondary:** Most of this changing magnetic flux is confined within the soft iron core and links with the secondary winding.
4. **Induced EMF in Secondary:** According to Faraday's Law of Electromagnetic Induction, this changing magnetic flux linking the secondary winding induces an alternating electromotive force (EMF) or voltage (Vs) across the secondary winding.
5. **Induced Current in Secondary:** If the secondary circuit is closed (connected to a load), the induced voltage causes an alternating current (Is) to flow through the load.

6. **Voltage and Turns Ratio:** The ratio of the voltage in the primary and secondary windings is directly proportional to the ratio of the number of turns in their respective coils:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

   a. **Step-up Transformer:** If $N_s > N_p$, then $V_s > V_p$ (voltage is increased).

   b. **Step-down Transformer:** If $N_s < N_p$, then $V_s < V_p$ (voltage is decreased).

7. **Current and Turns Ratio (for an ideal transformer):** For an ideal transformer (100% efficient), the power input equals the power output.

   ($P_p = P_s$). Since $P = VI$, we have: $V_p I_p = V_s I_s$.

   Rearranging and substituting the voltage ratio:

$$\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$$

   This shows that if voltage is stepped up, current is stepped down proportionally, and vice versa, conserving power.

Factors that Affect the Efficiency of a Transformer and Ways of Improving its Efficiency

No transformer is 100% efficient due to various energy losses. Efficiency (η) is defined as the ratio of output power to input power:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\ \%$$

Factors Affecting Efficiency (Losses)

1. **Copper Losses (I^2R Losses)**

   a. **Cause:** Due to the resistance of the primary and secondary windings. When current flows through the coils, heat is generated (I^2R).

   b. **Effect:** Reduces the amount of electrical energy transferred to the load.

   c. **Improvement**

   - Use thick copper wires for windings, especially for high-current windings (lower resistance).
   - Design windings to have fewer turns where possible (though this affects voltage ratio).

2. **Eddy Current Losses**

   a. **Cause**: Induced circulating currents within the transformer's core due to the changing magnetic flux. These currents dissipate energy as heat.

   b. **Effect**: Reduces efficiency and causes heating of the core.

   c. **Improvement**

   - Laminated Core: Construct the core from thin sheets of silicon steel, insulated from each other. This significantly increases the resistance to eddy currents, forcing them into smaller, higher-resistance paths.
   - Use core materials with high resistivity.

3. **Hysteresis Losses**
   a. **Cause:** Energy loss due to the repeated magnetisation and demagnetisation of the ferromagnetic core material as the alternating current reverses direction. Energy is required to re-align the magnetic domains in the core.
   b. **Effect:** Dissipated as heat in the core.
   c. **Improvement**
      - Use soft magnetic materials (like silicon steel) for the core, which have a narrow hysteresis loop (easy to magnetise and demagnetise).
4. **Flux Leakage (Leakage Flux)**
   a. **Cause**: Not all the magnetic flux produced by the primary winding links with the secondary winding. Some flux lines escape into the surrounding air.
   b. **Effect**: Reduces the efficiency of power transfer between primary and secondary.
   c. **Improvement**
      - Winding Arrangement: Wind the primary and secondary coils closely together, often one over the other (as in shell-type transformers), to maximise flux linkage.
      - Use a high-permeability core material to confine the flux.
5. **Humming Losses (Vibrational Losses)**
   a. **Cause:** The alternating magnetic field causes the core laminations to vibrate, producing audible humming sounds and dissipating a small amount of energy as sound.
   b. **Effect:** Minor energy loss.
   c. Improvement: Tight clamping of laminations, proper core design.

Overall Improvement Strategies

1. Use high-quality, low-loss core materials (e.g., grain-oriented silicon steel).
2. Optimise core design to minimise flux leakage.
3. Ensure effective cooling systems for high-power transformers.
4. Manufacture windings with high-purity copper and appropriate wire gauge.

Learning Tasks

1. Observe a video and explain how eddy currents cause energy loss.
2. Label parts of a transformer and explain how it works.
3. Drop a magnet through a metal tube and explain why it slows down.
4. Use a simulation to test eddy currents in different materials.
5. Draw a schematic diagram showing how electricity gets from power stations to homes in Ghana.

Pedagogical ExemplarsTalk for Learning

Let learners observe a video or simulation showing how eddy currents are produced when a conductor moves through a magnetic field. Use this to guide a discussion on how these circulating currents oppose motion and result in energy loss.

Use a labelled diagram of a transformer to teach its structure, including the primary coil, secondary coil, and iron core. Use targeted questioning to guide learners to explain the stages involved in the mode of operation of a transformer using Faraday's law and mutual induction principles.

Experiential Learning

Demonstrate how eddy current losses are minimised by using laminated iron cores in devices. Use an actual transformer core, a model or visual aids to show the laminated layers and explain how this reduces the loop area for eddy currents. Ensure to link this back to the formula relating resistance, resistivity, area and length of a conductor.

Let learners perform a simple classroom demonstration by dropping a magnet through a copper or aluminium tube and observing its slower fall due to eddy currents. Ask learners to think-pair-share and explain the phenomenon in terms of electromagnetic induction and Lenz's Law.

Enquiry-Based Learning

Set up a virtual lab simulation where learners can vary the material and shape of a conductor to observe how eddy currents change. Learners should record observations and suggest practical ways of reducing unwanted eddy current effects in electrical devices.

Let learners research to identify the factors affecting transformer efficiency (e.g., eddy current loss, copper loss, hysteresis loss, flux leakage). Ask for feedback in a class discussion, and where possible demonstrate the energy loss phenomena with simple experiments or demonstrations (e.g., showing heating due to resistance or magnetisation).

Project-Based Learning

Guide learners to explore the **structure of the power system in Ghana** (generation, transmission, and distribution) through maps, online videos, or infographics from the Ghana Grid Company (GRIDCo) and Electricity Company of Ghana (ECG). Let learners draw a flow diagram or schematic diagram showing the path of electricity from power stations (e.g., Akosombo Dam, Bui Dam, thermal plants) to homes and industries.

Problem-Based Learning

Use a step-by-step guided worksheet to help learners calculate voltage, current, and turns ratio in transformers. Include both step-up and step-down examples. Support learners in identifying where power losses occur and how these can be minimised.

Provide problem-solving practice where learners calculate the efficiency of a transformer using the formula

$$Efficiency = \frac{P_{out}}{P_{in}} \times 100\ \%$$

Guide them through strategies for improving efficiency, such as using low-resistance coils, soft iron cores, and proper insulation.

Key Assessment Level 4: Homework

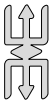
1. Design a simple step-down transformer that reduces a 240 V AC supply to 60 V AC. In your response, include a clearly labelled diagram of your transformer, formed from locally available materials such as soft iron rods, copper wire, plastic, or nails. Calculate the number of turns required on the secondary coil if the primary has 800 turns, identify one local material suitable for the core and explain why it is appropriate, and describe one way this transformer design could help solve a practical problem in your community.

(10 marks)

PLC Session 17

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

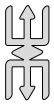
4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***homework***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the homework (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 8 Review

This section focuses on the topic of *Electromagnetic Induction and Applications*, a key component of the strand *Electric Fields, Magnetic Fields, and Electronics*. Over the past three weeks, the section has explored how electricity can be generated and controlled using magnetic fields, and how these principles are applied in devices such as inductors, generators, and transformers.

In week 15, the emphasis was on electromagnetic induction—the process by which a changing magnetic field induces an electromotive force (EMF) and current in a conductor.

Faraday's and Lenz's laws were introduced to explain the cause and direction of induced currents. The concept of magnetic flux, magnetic flux linkage, and their rate of change was discussed in detail. Visuals and practical activities demonstrated how moving a magnet through a coil or changing the magnetic field strength induces current. Factors that affect the magnitude of the induced EMF—such as the speed of motion, the strength of the magnetic field, and the number of turns in the coil—were examined. Fleming's Right-Hand Rule was also introduced to predict the direction of induced current in conductors.

In week 16, the focus shifted to inductance and the use of inductors in both AC and DC circuits. The structure of an inductor was explored, including how its core material, coil dimensions, and number of turns influence inductance. The behaviour of inductors in circuits was studied, showing how they resist changes in current and store energy in magnetic fields. Key differences between their response in AC and DC environments were outlined. Self-inductance and mutual inductance were explained, with mutual inductance serving as the foundation for transformer operation. The formula for the energy stored in an inductor was introduced, and its application in circuit analysis was demonstrated.

In week 17, attention turned to transformers and eddy currents. The structure and function of a transformer were explained using the principle of mutual induction. Step-up and step-down transformers were compared using voltage and current relationships derived from the turns ratio. Efficiency of transformers was discussed, including factors that affect it such as copper loss, hysteresis loss, eddy current loss, and flux leakage. Methods to minimise these losses—such as using laminated cores and soft magnetic materials—were also presented. Eddy currents were introduced as a result of changing magnetic fields in conductive materials, with both their drawbacks and practical applications discussed. Devices like induction furnaces, electromagnetic braking systems, and speedometers were used to demonstrate real-world uses of eddy currents.

By the end of this section, the key principles of electromagnetic induction, inductance, and transformer operation should be well established, alongside an appreciation of how these concepts are applied in energy generation, electronic devices, and power transmission systems.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 15

Question 1

What to look for in a successful demonstration

1. **Basic Setup**
   - A coil of insulated copper wire (multiple loops/turns)
   - Wire ends connected to a galvanometer or other current detector
   - A bar magnet or other strong magnet
2. **For Faraday's Law**
   - When magnet is moved near/through the coil, the detector should show current
   - When magnet is held still (even inside coil), no current should be detected
   - Faster movement should create stronger current reading
   - Student should explain that changing magnetic field creates electrical current
3. **For Lenz's Law**
   - When magnet is moved into coil, current flows in one direction
   - When magnet is pulled out of coil, current flows in opposite direction
   - If using north pole, then switching to south pole should reverse effects
   - Student should explain that the induced current creates a magnetic field that opposes the movement of the magnet

Component	Mark Level	What to Look For
Experimental Design *[2 marks]*	*2 marks*	*• Creates a functional setup using available materials* *• Coil is properly wound with insulated copper wire* *• Galvanometer/current detector is correctly connected to coil* *• Setup allows clear observation of results* *• Materials are thoughtfully arranged for demonstration*
	1 mark	*• Basic functional setup but with some issues* *• Coil construction has minor problems* *• Connections are working but not optimal* *• Setup allows demonstration but with limitations*
Faraday's Law Demonstration *[2 marks]*	*2 marks*	*• Clearly demonstrates that moving magnet near/through coil generates current* *• Shows that faster movement creates stronger current* *• Demonstrates that no movement means no current* *• Shows that more coil turns create stronger effect* *• Demonstrations are clear and visible to audience*

	1 mark	*• Basic demonstration of current generation* *• Limited demonstration of factors affecting strength* *• Some aspects unclear or difficult to observe* *• Partial demonstration of key principles*
Lenz's Law Demonstration [2 marks]	*2 marks*	*• Clearly demonstrates that changing direction of magnet movement reverses current direction* *• Shows opposite effects when moving magnet in vs. out of coil* *• May demonstrate physical resistance when moving magnet* *• Shows that north and south poles produce opposite effects* *• Clearly points out how this demonstrates opposition to change*
	1 mark	*• Basic demonstration of current reversal* *• Limited explanation of opposition principle* *• Some aspects unclear or difficult to observe* *• Partial demonstration of key principles*
Faraday's Law Explanation [1 mark]	*1 mark*	*• Clearly explains that changing magnetic field induces voltage/current* *• Explains that rate of change affects current strength* *• Shows understanding that magnetic flux change is key* *• Connects observations directly to law*
Lenz's Law Explanation [1 mark]	*1 mark*	*• Clearly explains that induced current opposes the change that caused it* *• Explains why current direction reverses with movement direction* *• Shows understanding of opposition principle* *• Connects observations directly to law*
Application of Faraday's Law in Ghana[1 mark]	*1 mark*	*• Suggests relevant, specific application in Ghanaian context, such as: - Electric generators for power production - Small-scale hydroelectric systems - Wind turbine electricity generation - Induction cooking technology - Microphones in local music/radio • Explains how the application relates to Faraday's law • Application is practical and realistic*
Application of Lenz's Law in Ghana [1 mark]	*1 mark*	*• Suggests relevant, specific application in Ghanaian context, such as: - Electromagnetic braking in transportation - Metal detectors for security or mining - Induction-based electricity meters - Eddy current testing of metal products - Shock absorbers in vehicles* *• Explains how the application relates to Lenz's law* *• Application is practical and realistic*

Question 2

Expected/Model Answer

(a) Prediction and Justification using Laws [5 marks]

Generator A (bicycle-powered with rotating coil) will likely produce the highest EMF. According to Faraday›s Law ($\varepsilon = -N\, d\Phi/dt$), the induced EMF depends on the rate of change of magnetic flux. A rotating coil in a magnetic field creates continuous, rapid flux changes as the coil orientation constantly changes relative to the field lines. This design typically allows for high rotational speeds and can incorporate many turns (high N value). Lenz's Law explains that the induced current will create a magnetic field opposing the change, which manifests as back-EMF that opposes the rotation, requiring continuous mechanical input to maintain operation.

(b) Evaluation of Design Factors [5 marks]

Rate of flux change ($d\Phi/dt$): Generator A has advantage with continuous rotation; Generator B depends on hand-crank speed; Generator C depends on wind consistency.

Number of turns (N): Generator A and C can incorporate multiple coils with many turns; Generator B limited by single coil design.

Magnetic field strength (B): Generator A uses permanent magnets (fixed B); Generator B uses permanent magnets; Generator C has advantage with variable electromagnets allowing field strength control. Generator C offers best overall design flexibility by combining multiple coils with controllable magnetic field strength.

(c) Recommendations for Improvement [5 marks]

Generator A: Increase number of coil turns, use stronger neodymium magnets, add gear system for higher rotation speeds, improve bearing system for reduced friction.

Generator B: Install stronger permanent magnets, design coil with more turns, add mechanical advantage system (lever arm), use ferromagnetic core to concentrate magnetic field.

Generator C: Optimise electromagnet current for maximum field strength, implement smart control system to vary field based on wind speed, use lightweight materials for faster turbine response, add energy storage system for consistent output during variable wind conditions.

Component	Mark Level	What to Look For
Prediction and Law Application [3 marks]	*3 marks*	*• Makes accurate prediction (Generator A most likely highest EMF)* *• Correctly applies Faraday's Law with equation $\varepsilon = -N\, d\Phi/dt$* *• Explains rate of flux change concept clearly* *• Links rotating coil design to continuous flux change* *• Shows understanding of factors: N (turns), $d\Phi/dt$ (flux rate)*
	2 marks	*• Makes reasonable prediction with some justification* *• Uses Faraday's Law concept (may not include equation)* *• Shows understanding of flux change importance* *• Some connection between design and EMF output*
	1 mark	*• Basic prediction made* *• Limited application of electromagnetic induction principles* *• Weak connection between theory and generator design*

Lenz's Law Application [2 marks]	*2 marks*	*• Correctly explains Lenz's Law (induced effects oppose change)* *• Applies law to generator operation (back-EMF opposes rotation)* *• Explains need for continuous mechanical input* *• Shows understanding of energy conservation principle*
	1 mark	*• Basic understanding of Lenz's Law* *• Some explanation of opposition concept* *• Limited application to generator context*
Factor Analysis – Rate of Change [2 marks]	*2 marks*	*• Correctly evaluates $d\Phi/dt$ for each generator design* *• Explains how rotation speed affects flux change rate* *• Compares continuous vs. intermittent motion effects* *• Links design features to flux change characteristics*
	1 mark	*• Basic understanding of flux change rate concept* *• Some evaluation of different generator motions* *• Limited comparison between designs*
Factor Analysis – Number of Turns [1 mark]	*1 mark*	*• Evaluates coil design possibilities for each generator* *• Explains how multiple coils increase N value* *• Recognises Generator C advantage with multiple coils*
Factor Analysis – Magnetic Field [2 marks]	*2 marks*	*• Correctly compares permanent magnets vs. Electromagnets* *• Explains advantages of variable field strength (Generator C)* *• Discusses field strength optimisation possibilities* *• Shows understanding of B value effects on EMF*
	1 mark	*• Basic comparison of magnetic field sources* *• Some understanding of field strength importance* *• Limited evaluation of design differences*
Improvement Recommendations [3 marks]	*3 marks*	*• Provides practical, scientifically-sound modifications for each generator* *• Clearly explains how each recommendation increases EMF* *• Shows creativity and engineering insight* *• Considers real-world implementation factors* *• Uses electromagnetic principles to justify suggestions*
	2 marks	*• Provides reasonable improvements with good explanations* *• Most recommendations scientifically sound* *• Good application of electromagnetic principles* *• Some consideration of practicality*
	1 mark	*• Basic improvement suggestions• Limited scientific reasoning• Some understanding of enhancement principles*

WEEK 16

Rubrics/Marking scheme

Question 1

Expected/Model Answer

Step 1: Basic Calculation Energy stored in one inductor:

$E = ½LI^2 = ½(0.5\ H)(4\ A)^2 = 4\ J$ Since we need 8 J and one inductor provides 4 J, we need at least 2 inductors.

Step 2: Design Options Series arrangement: Ltotal = 0.5 + 0.5 = 1.0 H, maximum current = 4 A Energy stored = $½(1.0)(4^2) = 8\ J$ ✓

Parallel arrangement: Ltotal = $(0.5 \times 0.5)/(0.5 + 0.5) = 0.25$ H, but total current can be 8 A (4 A through each) Energy stored = $½(0.25)(8^2) = 8\ J$ ✓

Step 3: Justification Parallel arrangement is better because: (1) If one inductor fails, the other continues working (reliability), (2) Current is distributed safely between inductors (4 A each), (3) Lower total inductance allows faster charging/discharging for emergency response.

Component	Mark Level	What to Look For
Basic Energy Calculation & Need Assessment [3 marks]	*3 marks*	*• Correctly calculates energy of one inductor: $E = ½LI^2 = 4\ J$* *• Determines that 2 inductors needed for 8 J requirement* *• Shows clear understanding of energy storage formula* *• Makes logical connection between single inductor capacity and total need*
	2 marks	*• Calculates energy correctly OR determines number needed correctly* *• Shows understanding of energy storage concept* *• Minor errors in calculation or reasoning*
	1 mark	*• Attempts energy calculation with some understanding* *• Shows basic grasp of energy storage principle* *• Significant errors but demonstrates some relevant knowledge*
System Design & Energy Calculations [3 marks]	*3 marks*	*• Correctly calculates energy for both series AND parallel arrangements* *• Series: Ltotal = 1.0 H, E = 8 J at 4 A* *• Parallel: Ltotal = 0.25 H, E = 8 J at 8 A total* *• Shows understanding of how inductance combines in each arrangement* *• Demonstrates both arrangements can meet 8 J requirement*
	2 marks	*• Correctly analyses one arrangement completely* *• Shows good understanding of inductance combination rules* *• Calculates energy correctly for chosen arrangement• Minor errors in second arrangement*

	1 mark	*• Basic understanding of series or parallel combinations* *• Attempts energy calculations with some success* *• Shows awareness that different arrangements are possible*
Design Justification & Critical Analysis [4 marks]	*4 marks*	*• Makes clear choice between arrangements with strong justification* *• Considers multiple factors: reliability, safety, practical implementation* *• Explains why chosen arrangement is better for school emergency system* *• Demonstrates extended critical thinking about real-world applications* *• May consider additional factors like cost, maintenance, response time*
	3 marks	*• Makes reasonable choice with good justification* *• Considers at least 2 relevant factors in comparison* *• Shows good critical thinking about practical applications* *• Reasoning is logical and well-explained*
	2 marks	*• Makes choice with basic justification* *• Considers at least 1 relevant factor* *• Shows some critical thinking about design trade-offs* *• Limited depth in reasoning*
	1 mark	*• Weak or no justification for design choice* *• Little evidence of critical thinking* *• Poor understanding of practical considerations* *• No meaningful comparison between arrangements*

Question 2

Verification Guide

Basic generator principles:

1. When a coil of wire moves through a magnetic field (or magnet moves near coil), electricity is generated
2. The electricity flows only during movement/change
3. The type of current depends on the design:
    - AC generator: Slip rings maintain same connection while coil rotates, creating alternating current
    - DC generator: Split-ring commutator reverses connections during rotation, creating direct current

What to look for in learner designs

For any generator

- A coil of copper wire (multiple turns)
- Magnets positioned near the coil
- Some way to rotate either the coil or magnets (crank, shaft, wheel)
- Terminals or wires to collect the generated electricity

For AC generator

- Simple continuous rings connecting to the coil
- No mechanism to reverse current direction

For DC generator

- Split-ring commutator (often made from copper strips)
- Brushes (wire or metal pieces touching the commutator)

Working demonstration

- When crank/shaft is turned, a small bulb should light, meter should move, or LED should glow
- Faster turning should produce stronger effect

Component	Mark Level	What to Look For
Design & Construction *[2 marks]*	*2 marks*	*• Functional generator that produces detectable current• Creative use of local materials• Sturdy construction that allows demonstration• Complete components: coil, magnet, turning mechanism, terminals • Evidence of careful craftsmanship*
	1 mark	*• Partially functional generator• Basic use of available materials• Some structural issues but generally stable• Most components present but may have deficiencies• Moderate level of craftsmanship*
Diagram Quality *[2 marks]*	*2 marks*	*• Clear, neat diagram with proper proportions • All components correctly labelled (coil, magnet, shaft/crank, terminals)• Shows internal and external components• Direction of movement indicated• Sufficient detail to understand design*
	1 mark	*• Basic diagram with most components labelled• Some proportion or clarity issues• Most major components shown• Limited details but generally understandable*
Working Principle Explanation *[2 marks]*	*2 marks*	*• Clearly explains Faraday's Law (changing magnetic field induces current)• Correctly applies Fleming's Right Hand Rule to explain current direction* *• Explains how motion creates changing field* *• Connects theory directly to specific parts of their generator* *• Uses appropriate terminology*
	1 mark	*• Basic explanation of principles* *• Some confusion about Faraday's Law or Fleming's Rule* *• Limited connection to specific generator design* *• Some appropriate terminology* *• Shows partial understanding*

Current Type Analysis *[2 marks]*	*2 marks*	*• Correctly identifies whether generator produces AC or DC* *• Explains why it produces that type (based on design features)* *• For AC: explains how current direction changes with rotation* *• For DC: explains how commutator/split ring reverses connections* *• May include how design could be modified to produce the other type*
	1 mark	*• Identifies current type with limited explanation* *• Some understanding of why design produces that type* *• Basic explanation of current flow* *• Some design features connected to current type* *• Some misconceptions present*
Real-World Application *[2 marks]*	*2 marks*	*• Proposes specific, realistic application for school/ community* *• Explains how generator could be scaled or adapted for this use* *• Discusses practical considerations (power output, usability)* *• Connects to local needs or challenges* *• Shows understanding of generator limitations and potential*
	1 mark	*• Proposes general application with limited specificity* *• Some discussion of adaptation needed* *• Limited discussion of practical considerations* *• Basic connection to local context* *• Limited understanding of capabilities*

WEEK 17

Question 1

Verification Guide

Basic transformer concepts

1. A transformer consists of two coils (primary and secondary) wound around a common core
2. The core should be made of a ferromagnetic material (usually soft iron)
3. Transformers only work with alternating current (AC), not direct current (DC)
4. The voltage ratio equals the turns ratio: Vp/Vs = Np/Ns

Calculation check

- For a step-down transformer from 240V to 60V with 800 primary turns:
- 240V/60V = 800 turns/Ns

- 4 = 800/Ns
- Ns = 800/4 = 200 turns
- So, the secondary coil should have 200 turns

Good core materials

- Soft iron rod or nails (not hardened steel)
- Transformer laminations (thin sheets of iron)
- Iron wire bundle
- These materials are good because they are ferromagnetic and concentrate the magnetic field

Common applications

- Powering devices that need lower voltage than mains supply
- Making electrical systems safer by reducing voltage
- Adapting imported 110V appliances to work with 240V supply
- Educational demonstrations of electromagnetic principles

Component	Mark Level	What to Look For
Transformer Design[2 marks]	*2 marks*	*• Design includes all essential components: primary coil, secondary coil, core* *• Arrangement shows correct configuration (coils wound around core)* *• Shows understanding of transformer structure* *• Materials selection is appropriate and realistic* *• Design is feasible to construct with local materials*
	1 mark	*• Design includes most essential components* *• Some issues with configuration* *• Basic understanding shown but with misconceptions* *• Some inappropriate material choices* *• Design partially feasible*
Diagram Quality [2 marks]	*2 marks*	*• Clear, neat diagram with proper proportions• All components correctly labelled (primary coil, secondary coil, core, input/output)• Shows number of turns on each coil (or indicates difference)• Input/output voltages marked• Well-presented and easy to understand*
	1 mark	*• Basic diagram with most components labelled• Some proportion or clarity issues• Limited labels or information• Some understanding demonstrated• Generally understandable but with flaws*
Turn Ratio Calculation[2 marks]	*2 marks*	*• Correctly calculates secondary turns as 200• Shows working using the turns ratio formula• Explains that turns ratio equals voltage ratio• Uses correct formula: Vp/Vs = Np/Ns• Substitutes values correctly: 240/60 = 800/Ns*
	1 mark	*• Calculation attempted with minor errors• Some understanding of turns ratio concept• Formula used but with application errors• Limited explanation of calculation • Partial working shown*

Core Material[2 marks]	*2 marks*	*• Identifies appropriate ferromagnetic material (soft iron, iron nails, etc.)• Explains why material is ferromagnetic* *• Explains that core concentrates magnetic field• Discusses how core improves transformer efficiency* *• Mentions that core should be laminated to reduce eddy currents if possible*
	1 mark	*• Identifies suitable material but with limited explanation• Some understanding of core purpose• Limited discussion of magnetic properties• Basic explanation of material choice*
Practical Application[2 marks]	*2 marks*	*• Describes specific, realistic application for community• Examples might include: – Powering electronics that require lower voltage – Making electrical systems safer – Adapting imported devices to local voltage – Educational demonstrations• Explains how transformer solves specific problem• Shows understanding of voltage reduction benefits• Application is culturally relevant to local context*
	1 mark	*• Describes general application with limited specificity• Basic understanding of transformer usage• Limited explanation of how it solves problems• Some connection to local context• Application somewhat realistic*

SECTION 9: SIMPLE HARMONIC MOTION AND COLLISIONS

STRAND: MECHANICS AND MATTER

Week 18 & 19

Sub-Strand: Kinematics

Content Standard: *Demonstrate knowledge and understanding of simple harmonic motion.*

Learning Outcome: *Use the concept of simple harmonic to determine acceleration due to gravity.*

Week 20

Sub-Strand: Dynamics

Content Standard: *Demonstrate knowledge and understanding of collisions.*

Learning Outcome: *Use the concept of momentum change to verify of Newton's second and third laws of motion.*

INTRODUCTION AND SECTION SUMMARY

This section covers two fundamental areas of physics: simple harmonic motion (SHM) and collisions. It begins with the principles of SHM, describing it as a type of periodic motion where the restoring force is directly proportional to displacement and acts in the opposite direction. Key conditions, mathematical equations, and examples such as the simple pendulum and spring-mass systems are discussed to illustrate SHM. The section also explains how displacement, velocity, and acceleration vary over time, and how energy shifts between kinetic and potential forms while the total mechanical energy remains constant.

The latter part of the section focuses on linear momentum, impulse, and collisions. It outlines the impulse-momentum relationship and connects it to Newton's second and third laws. Different types of collisions—elastic, inelastic, and perfectly inelastic—are defined and analysed using conservation of momentum and energy. Real-world examples help highlight the differences and applications of these concepts. Overall, the section provides a structured explanation of SHM and collisions, emphasising their physical principles, mathematical treatment, and relevance to everyday systems.

The weeks and the indicators covered by the section are:

- ***Week 18***

  Explain simple harmonic motion and give some examples of such type of motion.

  Determine the velocity, acceleration and kinetic energy of a body performing SHM.

- ***Week 19***

  Explain the variation of potential and kinetic energy of body performing SHM.

  Determine the energy stored in a system performing SHM.

- ***Week 20***

  Distinguish between elastic and inelastic collision.

  Use momentum change to establish impulse and hence deduce Newton's second law of motion.

  Verify Newton's third law of motion from momentum change.

Year 1	**Week 6** State Newton's laws of motion. Identify daily applications of Newton's laws of motion. Apply Newton's second law to establish the relationship between force, mass and acceleration.
Year 2	**Week 15:** Explain circular motion and give some examples of circular motion.

SUMMARY OF PEDAGOGICAL EXEMPLARS

This section presents a range of structured activities and exemplars aimed at deepening understanding of simple harmonic motion, energy transformation, and collisions. These include observational tasks using simulations and physical systems to identify key characteristics of motion, such as periodicity, restoring force, and equilibrium. Mathematical derivations are used to establish core equations, supported by graphical analysis of displacement, velocity, and acceleration over time.

Practical investigations involve pendulums and spring systems, where motion is measured, analysed, and used to calculate physical quantities. Energy concepts are explored through derivations and experiments that illustrate how kinetic and potential energy vary during oscillation while total energy remains constant.

In the context of collisions, real-world examples and demonstrations highlight momentum transfer, impulse, and energy conservation. Collisions are classified as elastic or inelastic through observation, measurement, and calculation. Simulations and hands-on experiments model these interactions, allowing for analysis of outcomes and verification of physical laws.

Throughout, a variety of approaches—including experimentation, problem-solving, and research—are used to reinforce conceptual understanding and connect abstract principles to physical systems and everyday applications.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Explain simple harmonic motion and give some examples of such type of motion. Determine the velocity, acceleration and kinetic energy of a body performing SHM.	Level 4	Test of practical knowledge, Homework
Explain the variation of potential and kinetic energy of body performing SHM. Determine the energy stored in a system performing SHM.	Level 3	
Distinguish between elastic and inelastic collision. Use momentum change to establish impulse and hence deduce Newton's second law of motion. Verify Newton's third law of motion from momentum change.	Level 3	Essay type

WEEK 18

Learning Indicators

1. *Explain simple harmonic motion and give some examples of such type of motion*
2. *Determine the velocity, acceleration and kinetic energy of a body performing SHM*

FOCAL AREA: SIMPLE HARMONIC MOTION: PRINCIPLES, EQUATIONS, AND APPLICATIONS

Key Terms

- **Equilibrium Position:** The position where the net force on the oscillating object is zero.
- **Displacement (x):** The distance of the oscillating object from its equilibrium position at any instant.
- **Amplitude (A):** The maximum displacement of the oscillating object from its equilibrium position.
- **Period (T):** The time taken for one complete oscillation (cycle), measured in seconds (s).
- **Frequency (f):** The number of complete oscillations per unit time, measured in Hertz (Hz). $f = 1/T$.
- **Angular Frequency (ω):** Related to frequency by $\omega = 2\pi f = 2\pi/T$.

Simple Harmonic Motion (SHM) is a special type of periodic motion where the restoring force (or torque) is directly proportional to the displacement from the equilibrium position and acts in the opposite direction to the displacement. This results in an oscillation where the acceleration of the oscillating object is directly proportional to its displacement from the equilibrium position and is always directed towards the equilibrium position.

Characteristics of SHM

1. Periodic: The motion repeats itself at regular intervals.
2. Oscillatory: The object moves back and forth about an equilibrium position.
3. Isochronous: The period (T) of oscillation is independent of the amplitude (for small amplitudes).
4. Sinusoidal Variation: Displacement, velocity, and acceleration all vary sinusoidally with time.

Key Conditions for SHM

1. Restoring Force: There must be a restoring force that always acts to bring the object back to its equilibrium position.
2. Proportionality to Displacement: The magnitude of this restoring force must be directly proportional to the magnitude of the displacement from the equilibrium position.
3. Direction: The restoring force must always be directed towards the equilibrium position (opposite to the displacement).
4. Inertia: The oscillating system must possess inertia (mass) so that it can overshoot the equilibrium position.

Mathematical Definition (Differential Equation)

The defining equation for SHM is:

$$a = -\omega^2 x$$

Where:

a is the acceleration of the oscillating body.

x is the displacement from the equilibrium position.

ω (omega) is the angular frequency (constant for a given SHM system), in radians per second (rad/s). The negative sign indicates that acceleration is always opposite to the displacement.

The derivation for this equation is given later.

Dynamics of Simple Harmonic Motion

The restoring force for small displacement x is given by $F = -k\,x$, where k is called the force constant of the system. Force constant is defined as the restoring force per unit displacement. Its SI unit is Nm^{-1}. If m is mass of the body and a is its acceleration, then for simple harmonic motion.

$$F = ma = -kx$$

$$m\frac{d^2x}{dt^2} + kx = 0$$

$$\frac{d^2x}{dt^2} + \frac{k}{m}x = 0$$

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

$$x + \omega^2 x = 0 \text{ where } x = \sqrt{\frac{k}{m}}$$

The general solution to this equation is

$x = a\sin(\omega t + \phi)$

Where,

x is the displacement from the equilibrium position

a is the amplitude,

$\omega t + \phi$ is the phase (also called as instantaneous phase),

ϕ is phase constant or initial phase angle (in radian) also called as epoch.

Consider a particle to execute SHM and assume that the path of the particle is on a straight line, then x is the displacement of particle from the mean position at that instant. The displacement of a particle executing SHM at time t is given by

$$x = a\sin(\omega t + \phi)$$

Note that this displacement from the mean position can also be derived by considering the vertical component of the motion of an object moving in a circle as shown in the image below. There are many parallels between SHM and circular motion.

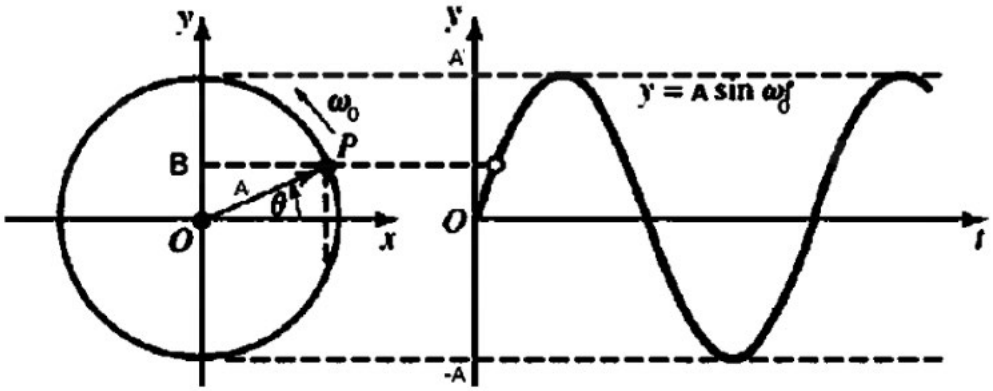


Figure 9.1: *Derivation of Simple Harmonic Motion from Uniform Circular Motion*

Velocity and Acceleration in Simple Harmonic Motion

Velocity And Acceleration In SHM: We can write the equation of motion of a particle performing SHM is

$$x = A\sin(\omega t + \phi) \quad \text{.....(i)}$$

Differentiating x with respect to t given velocity of the particle

$$v = \frac{dx}{dt} = A\omega\cos(\omega t + \phi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

From Eq. (i), we can write $\sin(\omega t + \phi) = \frac{x}{A}$

and we know that

$$\cos(\omega t + \phi) = \sqrt{1 - sin^2(\omega t + \phi)} = \sqrt{1 - \frac{x^2}{A^2}} = \frac{1}{A}\sqrt{A^2 - x^2}$$

Substituting the value of $\cos(\omega t + \phi)$ in Eq. (i), we get

$$v = A\omega\left(\frac{1}{A}\sqrt{A^2 - x^2}\right) = \omega\sqrt{A^2 - x^2} \quad \text{.....(iii)}$$

Differentiating Eq (ii) again with respect to time

Maximum Velocity (v_{max}):): The velocity is maximum when $\sin(\omega t + \phi) = \pm 1$.

$$v_{max} = A\omega$$

Location of Maximum Velocity: Maximum velocity occurs at the equilibrium position (x = 0).

Location of Zero Velocity: Velocity is zero at the extreme positions (x = ±A), where the body momentarily stops before reversing direction.

Maximum Acceleration (a_{max}): The acceleration is maximum when $\cos(\omega t + \phi) = \pm 1$.

$$a_{max} = A\omega^2$$

Location of Maximum Acceleration: Maximum acceleration occurs at the extreme positions (x = ±A), where the restoring force is strongest.

Location of Zero Acceleration: Acceleration is zero at the equilibrium position (x = 0), where the net restoring force is zero.

Systems or bodies that can be caused to perform simple harmonic motion

- A loaded spiral spring
- A loaded test tube floating in a liquid
- A cantilever
- The balance wheel of a clock or watch
- Simple pendulum
- Tuning fork
- Bifilar suspension, etc.

Simple Pendulum

A simple pendulum consists of a point mass (bob) suspended from a fixed support by a light, inextensible string.

When displaced from its equilibrium position (vertical) and released, gravity provides a restoring force that acts to bring the bob back. For small angular displacements (typically less than about 10-15 degrees), the restoring force component (-mg sinθ) is approximately proportional to the angular displacement θ (since sinθ ≈ θ for small angles).

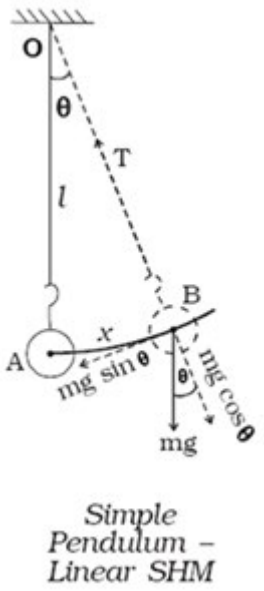


Figure 9.2: *Simple pendulum*

Suppose there is an angle between the string of length l and the vertical is θ. The bob's distance from the location of equilibrium A is AB. At B, weight mg acts downwards vertically. This force is divided into two components.

- The component mg cos θ is balanced against the fixed point O by the string's tension working along the length.
- mg sin θ, unbalanced, behaves perpendicular to the thread length of A. The bob continues to be returned to the mean position by this force. The path of the bob is a straight line if the oscillation amplitude is small,

$$F = -mg \sin\theta$$

If the angular displacement is small $\sin\theta \approx \theta$

$$F = -mg\,\theta$$

$$Sin\,\theta \approx \theta = \frac{x}{l}$$

Then

$$F = -mg\frac{x}{l}$$

Comparing this equation with Newton's second law (F = ma)

$$a = -g\frac{x}{l}$$

The negative sign means that the acceleration direction is opposite to the displacement. Thus, the simple pendulum's motion is SHM.

We know that $a = -\omega^2 x$

comparing this with $a = -g\frac{x}{l}$

$$\omega^2 = \frac{g}{l}$$

$$\omega = \sqrt{\frac{g}{l}}$$

Time period

$$T = \frac{2\pi}{\omega}$$

Then

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

Helical Spring

A mass attached to the end of a spiral spring, commonly a helical spring, which is wound into a helix. This system can oscillate horizontally (on a frictionless surface) or vertically.When the mass is displaced from its equilibrium position and released, the spring exerts a restoring force that is directly proportional to the displacement and acts opposite to the displacement. This is described by Hooke's Law: F = -kx, where k is the spring constant. This direct proportionality to displacement makes it a classic example of SHM.

When a mass is hung from a vertical helical spring, gravity causes the spring to stretch to a new equilibrium position. Oscillations occur around this new equilibrium. Importantly, the additional constant force of gravity only shifts the equilibrium position; it does not change the restoring force's proportionality to displacement from the new equilibrium, so the period remains the same as for a horizontal setup.

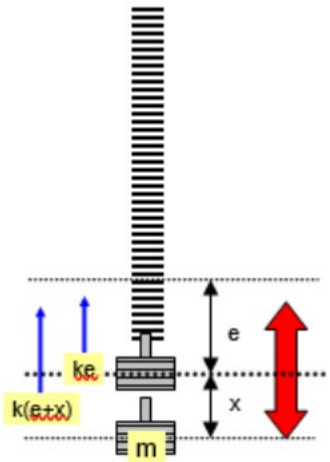


Figure 9.3: *Vertical oscillation of a mass-spring system showing restoring force and equilibrium extension*

From Hooke's law

$$F = ke$$

where k is the spring's constant and e is the extension

$$\Longrightarrow mg = ke$$

The mass is then pulled down a small distance x and released. The mass will oscillate due to both the effect of the gravitational attraction (mg) and the varying force in the spring (k(e + x)).
At any point distance x from the midpoint:
restoring force $F = -[k(e + x) - mg] = ma$

$$-ke - kx + mg = ma$$

but $mg = ke$

$$-ke - kx + ke = ma$$

$$-kx = ma$$

$$a = \frac{-k}{m}x = -\omega^2 x$$

This equation shows that the motion is simple harmonic

$$\omega = \sqrt{\frac{k}{m}}$$

$$T = \frac{2\pi}{\sqrt{\frac{k}{m}}}$$

$$T = 2\pi\sqrt{\frac{m}{k}}$$

but $mg = ke$,

$$\frac{m}{k} = \frac{e}{g}$$

$$T = 2\pi\sqrt{\frac{e}{g}}$$

Learning Tasks

1. Observe videos or simulations of SHM examples and define SHM based on observed features.
2. Derive and sketch graphs for SHM velocity and acceleration from $x = A\sin(\omega t)$
3. Measure spring oscillations to calculate period, velocity, and acceleration.
4. Perform a pendulum activity by timing oscillations for different lengths, and plotting graph to find the relationship.
5. Classify motions (e.g., ball bounce, circular motion) as SHM or not with reasons.

Pedagogical Exemplars

Enquiry-Based Learning

Let learners observe videos or simulations of a pendulum, mass-spring system, and tuning fork. Guide learners to identify characteristics of SHM such as oscillation about an equilibrium position, restoring force proportional to displacement, and sinusoidal motion. Ask learners to describe what is common across all these examples and define SHM based on observations.

Provide examples of periodic motion (e.g., a bouncing ball, circular motion, blinking light) and let learners decide which ones are SHM. Let them justify their reasoning based on criteria like linear restoring force and sinusoidal displacement.

Provide learners with pendulum and mass-spring systems in simulations (e.g., PhET) and guide them to observe and record the motion over time. Let them plot displacement-time, velocity-time, and acceleration-time graphs to identify sinusoidal patterns and discuss phase differences between these quantities.

Talk for Learning

Guide learners through the mathematical derivation of velocity and acceleration in SHM using the displacement equation $x = A\sin(\omega t)$

- Derive velocity $v = \frac{dx}{dt} = A\omega\cos(\omega t)$:
- Derive acceleration $a = \frac{dv}{dt} = -A\omega^2\sin\omega t = -\omega^2 x$:

  Use graphs to illustrate how displacement, velocity, and acceleration vary with time. Let learners sketch and interpret these graphs.

Collaborative Learning

Organise a scaffolded, peer-led activity where learners derive expressions for velocity $v = \omega\sqrt{A^2 - x^2}$ and $a = -\omega^2 x$ and acceleration $a = -\omega^2 x$ from the displacement equation.

Experiential Learning

Let learners conduct a simple lab using a mass suspended on a spring. They measure displacement, time for oscillations, and calculate period T, angular frequency $\omega = \frac{2\pi}{T}$, and use formulas to determine velocity and acceleration at various points. Provide a worksheet where learners compute values for different displacements using $v = \omega\sqrt{A^2 - x^2}$ and $a = -\omega^2 x$.

Let learners use a stopwatch and a string with a small bob to determine the period of a simple pendulum for different lengths. Guide them to record time for multiple oscillations and calculate the period using $T = \frac{t}{n}$. Let them plot a graph of T^2 against length l, showing a linear relationship based on $T = 2\pi\sqrt{\frac{l}{g}}$.

Problem-Based Learning

Provide a tiered worksheet with SHM problems ranging from basic (e.g., using $T = 2\pi\sqrt{\frac{l}{g}}$ and $T = 2\pi\sqrt{\frac{m}{k}}$) to more complex ones (e.g., calculating velocity using $v = \omega\sqrt{A^2 - x^2}$ or acceleration using $a = -\omega^2 x$). Encourage peer support or allow flexible grouping for learners to work through differentiated examples with teacher guidance where necessary.

Project-Based Learning

Assign learners to research and present everyday examples of SHM and its applications (e.g., oscillating springs in vehicle suspensions, quartz crystals in watches). Let them explain the restoring force and conditions that make the motion simple harmonic in each case.

Key Assessment: Practice Paper 2

1. Using a retort stand, string, and pendulum bob, set up a simple pendulum and investigate how the period of oscillation depends on the length of the pendulum. Measure the time for 20 complete oscillations for at least three different lengths, calculate the period and T² for each, and plot a graph of T² against length. From the slope of the graph, determine the acceleration due to gravity (g). Conclude by stating two sources of error, one assumption made during the experiment, and explain why small angular displacements are necessary

   (12 marks)

2. A child on a playground swing moves gently back and forth, which resembles simple harmonic motion (SHM). Assuming the motion of the swing can be modelled as SHM, explain how knowledge of velocity and acceleration in SHM can help improve the child's comfort and safety. Support your explanation with the SHM equations v_max = Aω, a_max = Aω² and T = 2π√(L/g), and justify how limiting the maximum velocity or acceleration could influence decisions about the design of playground swings.

   (10 marks)

3. A platform in a packaging machine moves with simple harmonic motion to shift items between conveyor belts. The platform has an amplitude of 0.2 m and completes 5 full oscillations every 10 seconds.

   a. Calculate the angular frequency, maximum velocity, and maximum acceleration of the platform.

   b. Determine the velocity and acceleration of the platform when it is 0.12 m from the equilibrium position.

c. Justify why it is important to control the maximum acceleration in such machines for fragile products.

(20 marks)

HINT

*Conduct **Practice Paper 2**. It should cover the contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section. Learners' papers should be marked immediately and scores entered into the SAP.*

TABLE OF SPECIFICATIONMultiple choice

Sub-strand	Indicators	Type	1	2	3	4	Total
Introduction to Physics	**1.1.1.LI.1** Identify careers that are related to physics in various sectors of the economy.	MCQs					
		Essay					
		Practical					
	1.1.1.LI.2 Use basic mathematical concepts to solve problems – trigonometric ratios, Pythagoras's theorem, sine and cosine rule, indices.	MCQs					
		Essay					
		Practical					
	1.1.1.LI.1 Identify the basic units in physics	MCQs					
		Essay					
		Practical					
	1.1.1.LI.2 Determine the dimensions of physical quantities (velocity, acceleration, mass, length, time, weight, energy, force)	MCQs					
		Essay					
		Practical					
	1.1.1.LI.3 Identify the errors in the use of meter rule, protractor, electronic balance, vernier calliper and the micrometer screw gauge.	MCQs					
		Essay					
		Practical					
	1.1.1.LI.4 Explain the types of errors – systematic, random and parallax	MCQs					
		Essay					
		Practical					

	1.1.1.LI.5 Explain scientific notation and their unit multipliers.	MCQs					
		Essay					
		Practical					
	1.1.1.LI.6 Distinguish scalars from vectors (qualitative treatment)	MCQs					
		Essay					
		Practical					
Basic Physics	**2.1.1.LI.1** Explain density	MCQs					
		Essay					
		Practical					
	2.1.1.LI.2 State Archimedes' principle	MCQs					
		Essay					
		Practical					
	2.1.1.LI.3 State principle of flotation	MCQs					
		Essay					
		Practical					
	2.1.1.LI.4 Apply Archimedes' principle and principle of flotation to solve problems	MCQs					
		Essay					
		Practical					
	2.1.1.LI.1 Check validity of equations	MCQs					
		Essay					
		Practical					
	2.1.1.LI.2 Establish the relationship between quantities	MCQs					
		Essay					
		Practical					
	2.1.1.LI.1 Resolve vectors into their components	MCQs					
		Essay					
		Practical					
	2.1.1.LI.2 Determine the resultant of two vectors	MCQs		1			1
		Essay					
		Practical					

	3.1.1.LI.1 Explain moments	MCQs					
		Essay					
		Practical					
	3.1.1.LI.2 State the principle of moments	MCQs					
		Essay					
		Practical					
	3.1.1.LI.3 State the conditions necessary for a body to be in equilibrium	MCQs					
		Essay	1				1
		Practical					
	3.1.1.LI.4 Calculate the reactions at supports	MCQs					
		Essay					
		Practical					
	3.1.1.LI.1 State Newton's law of universal gravitation	MCQs	1				1
		Essay					
		Practical					
	3.1.1.LI.2 Deduce the relationship between acceleration due to gravity, g and universal gravitation constant, G	MCQs					
		Essay					
		Practical					
	3.1.1.LI.3 Deduce the period of rotation of a satellite moving in circular orbit	MCQs					
		Essay					
		Practical					
	3.1.1.LI.4 Explain weightlessness	MCQs					
		Essay					
		Practical					
	3.1.1.LI.1 Explain the universe and its composition as applied to astronomy and cosmology	MCQs					
		Essay					
		Practical					
	3.1.1.LI.2 Explain how our indigenous culture benefits from and applies to astronomy and cosmology.	MCQs					
		Essay					
		Practical					

	3.1.1.LI.3 Explain the formation of the sun, planets and stars	MCQs					
		Essay					
		Practical					
	3.1.1.LI.4 Describe galaxies and their various types - elliptical, spiral, irregular, quasars, blazers, Lenticular, active, seyfert.	MCQs	1				1
		Essay					
		Practical					
Matter	**1.1.2.LI.1** Identify the various states of matter	MCQs					
		Essay					
		Practical					
	1.1.2.LI.2 Distinguish between molecular arrangement of the various states	MCQs					
		Essay					
		Practical					
	2.1.2.LI.1 Distinguish elastic deformation from plastic deformation	MCQs					
		Essay					
		Practical					
	2.1.2.LI.2 State Hooke's law	MCQs					
		Essay	1				1
		Practical					
	2.1.2.LI.3 Calculate the energy stored in in an elastic material	MCQs		1			1
		Essay					
		Practical					
	2.1.2.LI.4 Calculate Young's modulus	MCQs					
		Essay					
		Practical					
Kinematics	**1.1.3.LI.1** Describe the various types of motion i.e. circular, oscillatory, rectilinear, spin and random	MCQs					
		Essay					
		Practical					

	1.1.3.LI.2 Establish equations of uniformly accelerated motion and its application in everyday life	MCQs					
		Essay					
		Practical					
	1.1.3.LI.3 Represent the motion of objects graphically i.e. distance-time, displacement-time and velocity-time as well as deducing equations that can be made from it	MCQs					
		Essay			1		1
		Practical					
	2.1.3.LI.1 Identify some games and sports where projectiles are seen of circular motion	MCQs					
		Essay					
		Practical					
	2.1.3.LI.2 Determine the time taken by a projectile to reach maximum height and the maximum height	MCQs		1			1
		Essay					
		Practical					
	2.1.3.LI.3 Determine the range of a projectile	MCQs		1			1
		Essay					
		Practical					
	2.1.3.LI.1 Explain circular motion and give some examples of circular motion	MCQs					
		Essay					
		Practical					
	2.1.3.LI.2 Explain and calculate centripetal force	MCQs					
		Essay					
		Practical					
	2.1.3.LI.3 Explain banking and skidding	MCQs					
		Essay					
		Practical					
	2.1.3.LI.4 Calculate maximum and minimum tension in a string	MCQs					
		Essay		1			1
		Practical					

	3.1.2.LI.1 Explain simple harmonic motion and give some examples of such type of motion	MCQs					
		Essay					
		Practical					
	3.1.2.LI.2 Determine the velocity, acceleration and kinetic energy of a body performing SHM	MCQs		1			1
		Essay					
		Practical		1		1	2
	3.1.2.LI.3 Explain the variation of potential and kinetic energy of a body performing SHM	MCQs					
		Essay					
		Practical					
	3.1.2.LI.4 Determine the energy stored in a system performing SHM	MCQs					
		Essay					
		Practical					
Dynamics	**1.1.4.LI.1** State Newton's laws of motion	MCQs					
		Essay	1				1
		Practical					
	1.1.4.LI.2 Apply Newton's second law to establish the relationship between force, mass and acceleration	MCQs					
		Essay					
		Practical					
	1.1.4.LI.3 Identify daily applications of Newton's laws of motion	MCQs					
		Essay					
		Practical					
	1.1.4.LI.1 Explain how pressure changes with depth in a fluid.	MCQs		1			1
		Essay		1			1
		Practical					
	1.1.4.LI.1 Explain the operation of brake systems in vehicles and the operation of the hydraulic press	MCQs					
		Essay					
		Practical					
	1.1.4.LI.1 State Pascal's principle.	MCQs					
		Essay					
		Practical					

	2.1.4.LI.1 Identify some effects and applications of friction	MCQs	1				1
		Essay					
		Practical					
	2.1.4.LI.2 Determine the coefficient of friction	MCQs					
		Essay					
		Practical					
	3.1.3.LI.1 Distinguish between elastic and inelastic collisions	MCQs					
		Essay					
		Practical					
	3.1.3.LI.2 Use momentum change to establish impulse and hence deduce Newton's second law of motion	MCQs		1			1
		Essay		1			1
		Practical					
	3.1.3.LI.3 Verify Newton's third law of motion from momentum change	MCQs					
		Essay					
		Practical					
Heat	**1.2.1.LI.1** Discuss the thermometric substances and properties and their associated characteristics	MCQs	1				1
		Essay	1				1
		Practical					
	1.2.1.LI.2 Describe the features and uses of different types of thermometers	MCQs					
		Essay					
		Practical					
	1.2.1.LI.3 Describe the various temperature scales and the construction of their corresponding thermometers	MCQs					
		Essay					
		Practical					
	1.2.1.LI.4 Derive the relationship between the Celsius, Fahrenheit and the Kelvin scales.	MCQs		1			1
		Essay					
		Practical					

	2.2.1.LI.1 Explain the specific heat capacity and classify substances into good and bad conductors of heat	MCQs					
		Essay					
		Practical					
	2.2.1.LI.2 Calculate the specific heat capacities of substances	MCQs		1			1
		Essay					
		Practical					
	2.2.1.LI.3 Describe how to determine the specific heat capacity of a solid using a liquid of a known specific heat capacity	MCQs					
		Essay					
		Practical					
	2.2.1.LI.4 Explain latent heat of fusion and vaporisation and specific latent heat of fusion and vaporisation	MCQs					
		Essay					
		Practical					
	3.2.1.LI.1 Explain linear, area and volume expansivities	MCQs					
		Essay					
		Practical					
	3.2.1.LI.2 Calculate the linear, area and volume expansivities of metals	MCQs		1			1
		Essay			1		1
		Practical					
	3.2.1.LI.3 Group metals in increasing order of expansion property using their linear expansivities	MCQs					
		Essay					
		Practical					
Wave	**1.2.2.LI.1** Describe the process involved in image formation in plane mirrors and their characteristics	MCQs					
		Essay					
		Practical					
	1.2.2.LI.2 Deduce the laws of reflection	MCQs		1			1
		Essay					
		Practical					

	1.2.2.LI.3 Determine the number of images formed by inclined mirrors	MCQs		1			1
		Essay					
		Practical					
	1.2.2.LI.1 Explain terminologies associated with spherical mirrors	MCQs	1				1
		Essay	1				1
		Practical					
	1.2.2.LI.2 Describe the processes involved in image formation in spherical mirrors and their characteristics using ray tracing	MCQs					
		Essay					
		Practical		1		1	2
	1.2.2.LI.3 Determine the position and characteristics of images formed by spherical mirrors with mirror formula and magnification formula	MCQs		1			1
		Essay					
		Practical					
	1.2.2.LI.1 Explain refraction and state the laws of refraction	MCQs					
		Essay					
		Practical					
	1.2.2.LI.2 Determine refractive index of a medium	MCQs		1			1
		Essay		1			1
		Practical					
	1.2.2.LI.3 Explain total internal reflection	MCQs					
		Essay					
		Practical					
	1.2.2.LI.4 Establish the relationship between the real depth, apparent depth and the refractive index.	MCQs		1			1
		Essay					
		Practical					
	2.2.2.LI.1 Identify types of waves with properties	MCQs					
		Essay					
		Practical					

	2.2.2.LI.2 Classify waves under longitudinal, transverse, electromagnetic, mechanical, progressive and stationary	MCQs	1				1
		Essay					
		Practical					
	2.2.2.LI.3 Determine the amplitude, velocity, frequency, period, wavelength from a sinusoidal wave signal	MCQs		1			1
		Essay		1			1
		Practical					
	2.2.2.LI.4 Given the amplitude, velocity, frequency, period, wavelength of a wave, deduce the wave equation	MCQs					
		Essay					
		Practical					
	2.2.2.LI.1 Explain the production, nature and transmission of sound	MCQs					
		Essay					
		Practical					
	2.2.2.LI.2 Classify sound into infrasonic, audio-sonic and ultrasonic	MCQs					
		Essay					
		Practical					
	2.2.2.LI.3 Explain how an echo comes about and apply the phenomenon in the determination of the depth of rivers.	MCQs					
		Essay					
		Practical					
	2.2.2.LI.4 Apply the concept of resonance in the determination of speed of sound in air.	MCQs		1			1
		Essay					
		Practical					
	3.2.2.LI.1 Identify the types and features of lenses	MCQs		1			1
		Essay					

	3.2.2.LI.2 Describe how images are formed by lenses	MCQs					
		Essay					
		Practical					
	3.2.2.LI.3 Calculate the image distance and magnification using the lens formula	MCQs		1			1
		Essay		1			1
		Practical					
	3.2.2.LI.1 Identify features of laser configuration	MCQs					
		Essay					
		Practical					
	3.2.2.LI.2 Describe the production of laser beam	MCQs					
		Essay					
		Practical					
	3.2.2.LI.3 Identify the properties of lasers	MCQs					
		Essay					
Electrostatics	**1.3.1.LI.1** Explain how the gold leaf electroscope can be used to detect the charge carried by a body	MCQs		1			1
		Essay					
		Practical					
	1.3.1.LI.2 Identify electrons as mobile charge carriers	MCQs					
		Essay					
		Practical					
	1.3.1.LI.3 Explain how charge carriers in conductors, semiconductors and insulators behave.	MCQs					
		Essay					
		Practical					
	1.3.1.LI.4 Explain the distribution of charges on surfaces; spherical, pear-shaped and sharp point	MCQs					
		Essay					
		Practical					

	1.3.1.LI.1 Define charge as a fundamental property of matter(like mass)	MCQs					
		Essay					
		Practical					
	1.3.1.LI.2 Explain the conservation of charge and its behaviour	MCQs		1			1
		Essay					
		Practical					
	1.3.1.LI.3 Differentiate between two charges (positive and negative)	MCQs					
		Practical					
	2.3.1.LI.1 Explain and show how an electric field is represented and their characteristics	MCQs	1				
		Essay	1				1
		Practical					
	2.3.1.LI.2 State Coulomb's law of electrostatics and calculate electrostatic force acting on the charges	MCQs		1			1
		Essay			1		1
		Practical					
	2.3.1.LI.3 Determine the electric field/ intensity at a point due to a point charge	MCQs					
		Essay					
		Practical					
	1.3.1.LI.4 Define and calculate potential difference	MCQs		1			1
		Essay					
		Practical					
	2.3.1.LI.1 Describe the structure and operation of capacitors	MCQs					
		Essay					
		Practical					
	2.3.1.LI.2 Determine the effective capacitance of a number of capacitors arranged in : **(i)** series **(ii)** parallel	MCQs					
		Essay					
		Practical					
	2.3.1.LI.3 Determine the capacitance of a parallel plate capacitors	MCQs					
		Essay			1		1
		Practical					

	2.3.1.LI.4 Describe the behaviour of a capacitor in DC and AC circuits	MCQs					
		Essay					
		Practical					
	2.3.1.LI.5 Calculate the energy stored in a capacitor	MCQs		1			1
		Essay			1		1
		Practical					
Direct current	**3.3.1.LI.1** Explain the key terminologies of circuitry and how they are related to one another	MCQs					
		Essay					
		Practical					
	3.3.1.LI.2 Express Ohm's law and its relationship to electrical resistance; ohmic and non-ohmic conductors	MCQs					
		Essay					
		Practical		1		1	2
	3.3.1.LI.1 Describe and demonstrate the structure and working principle of resistors and their arrangements in circuits	MCQs					
		Essay					
		Practical					
	3.3.1.LI.2 Describe and demonstrate the types of variable resistors i.e. potentiometers and rheostats and their working principles.	MCQs					
		Essay					
		Practical					
	3.3.1.LI.1 State Kirchhoff's laws of electrical networks	MCQs					
		Essay					
		Practical					
	3.3.1.LI.2 Determine the current flowing through a branch in electrical networks	MCQs					
		Essay					
		Practical					
	3.3.1.LI.3 Discuss how a galvanometer can be adapted as an ammeter and a voltmeter	MCQs		1			1
		Essay					
		Practical					

Magnetostatics	**1.3.2.LI.1** Distinguish between magnets, magnetic and non-magnetic materials.	MCQs					
		Essay					
		Practical					
	1.3.2.LI.2 Describe the magnetic field	MCQs					
		Essay					
		Practical					
	1.3.2.LI.3 Describe the processes involved in magnetisation and demagnetisation	MCQs	1	1			2
		Essay					
		Practical					
Electromagnetism	2.3.2.LI.1 Describe the force exerted on a current-carrying conductor in a magnetic field	MCQs		1			1
		Essay					
		Practical					
	2.3.2.LI.2 Discuss the factors that affect the magnitude of the magnetic force on a current-carrying conductor in a magnetic field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.3 Fleming's left-hand rule	MCQs		1			1
		Essay					
		Practical					
	2.3.2.LI.1 Explain the forces acting between parallel conductors carrying current in a magnetic field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.2 Explain the torque on a rectangular current-carrying coil in a magnetic field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.3 Describe and analyse the structure and working principle of the motor and moving coil galvanometer	MCQs					
		Essay					
		Practical					
	2.3.2.LI.1 Calculate force on a charged particle in a magnetic field.	MCQs					
		Essay			1		1
		Practical					

	2.3.2.LI.2 Describe a force on a moving charged particle in an electric field	MCQs					
		Essay					
		Practical					
	2.3.2.LI.2 Calculate a force on a moving charged particle in a crossed field (Lorentz force)	MCQs					
		Essay					
		Practical					
Alternating current	**3.3.2.LI.1** Discuss the characteristics of alternating current/voltage	MCQs					
		Essay					
		Practical					
	3.3.2.LI.2 Distinguish between the types of AC waveforms	MCQs					
		Essay					
		Practical					
	3.3.2.LI.3 Using mathematical relationships to define alternating current and alternating voltage	MCQs					
		Essay	1				1
		Practical					
	3.3.2.LI.1 Describe a.c. circuit connections using resistors, inductors, capacitors in series	MCQs					
		Essay			1		1
		Practical					
	3.3.2.LI.2 Describe and distinguish between resistance and impedance	MCQs	1				1
		Essay					
		Practical					
	3.3.2.LI.3 Describe the power triangle and explain the power factor using mathematical concepts	MCQs		1			1
		Essay					
		Practical					
Analogue Electronics	**1.3.3.LI.1** Describe the formation of the two types of conductors; n-type and p-type	MCQs	1				1
		Essay					
		Practical					

	1.3.3.LI.2 Describe the basic structure and application of the PN junction diode in reverse and forward-biased circuits	MCQs					
		Essay					
		Practical					
	1.3.3.LI.3 Analyse the benefits of using LEDs and I-V characteristics of Zener diodes and applications	MCQs					
		Essay					
		Practical					
	1.3.3.LI.1 Explain the terminologies "input" and "output" of a transducer with examples	MCQs					
		Essay					
		Practical					
	1.3.3.LI.2 Explain the effect of temperature changes on resistance using a thermistor, light dependent resistor (LDR), infra-red diode and the microphone to analyse the characteristic graphs of thermistors and LDRs	MCQs					
		Essay					
		Practical					
	1.3.3.LI.3 Describe the processes involved in the operation of the following transducers; microphone, loudspeaker, buzzer, low voltage DC motor, electromagnetic relays and infra-red diode	MCQs					
		Essay					
		Practical					
	1.3.3.LI.1 Describe the construction and action of the bipolar junction transistor	MCQs					
		Essay					
		Practical					
	1.3.3.LI.2 Describe transistor biasing	MCQs	1				1
		Essay					
		Practical					

	1.3.3.LI.3 Describe various transistor configurations and the use of an N-P-N transistor as a small signal amplifier.	MCQs					
		Essay					
		Practical					
Digital Electronics	**2.3.3.LI.1** Describe analogue and digital signals	MCQs					
		Essay					
		Practical					
	2.3.3.LI.2 Distinguish between pull-up and pull-down resistors	MCQs		1			1
		Essay					
		Practical					
	2.3.3.LI.3 Describe and use the 7-segment display module	MCQs					
		Essay					
		Practical					
	2.3.3.LI.1 Distinguish between analogue and digital signals and describe their functions	MCQs					
		Essay					
		Practical					
	2.3.3.LI.2 Describe the characteristics of basic logic and universal gates	MCQs					
		Essay			1		1
		Practical					
	2.3.3.LI.3 Describe and explain sum of product (Boolean expression)	MCQs					
		Essay					
		Practical					
	2.3.3.LI.4 Describe combinational logic applications and microcontroller.	MCQs					
		Essay					
		Practical					
	2.3.3.LI.1 Describe simple integrated circuits	MCQs					
		Essay					
		Practical					

	2.3.3.LI.2 Design and describe the fabrication of a simple integrated circuit	MCQs					
		Essay					
		Practical					
Electromagnetic induction and application	**3.3.3.LI.1** Explain electromagnetic induction	MCQs					
		Essay					
		Practical					
	3.3.3.LI.2 Using experimentation, verify the laws of electromagnetic induction	MCQs					
		Essay					
		Practical					
	3.3.3.LI.3 Describe the factors that affect induced emf and explain direction of induced current using mnemonics and Fleming's Right Hand Rule	MCQs					
		Essay					
		Practical					
	3.3.3.LI.1 Explain inductance and obtain a mathematical expression for the relationship	MCQs					
		Essay					
		Practical					
	3.3.3.LI.2 Discuss the behaviour of the inductor in a.c and d.c. circuits	MCQs					
		Essay					
		Practical					
	3.3.3.LI.3 Explain how energy is stored in an inductor.	MCQs		1			1
		Essay					
		Practical					
	3.3.3.LI.1 Discuss the structure, uses and principle of operation of a transformer	MCQs					
		Essay					
		Practical					
	3.3.3.LI.2 Discuss the factors that affect the transmission of power and efficiency of a transformer and ways of improving its efficiency	MCQs					
		Essay					
		Practical					

	3.3.3.LI.3 Explain Eddy current, effects and applications	MCQs					
		Essay					
		Practical					
Application of electronics	**3.3.4.LI.1** Design a half wave rectifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.2 Design a full wave rectifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.3 Design a smoother/filter circuit using a capacitor	MCQs					
		Essay					
		Practical					
	3.3.4.LI.1 Design a PNP amplifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.2 Design an NPN amplifier	MCQs					
		Essay					
		Practical					
	3.3.4.LI.1 Design a darkness detector	MCQs					
		Essay					
		Practical					
	3.3.4.LI.2 Design a battery charger	MCQs					
		Essay					
		Practical					
Atomic Physics	**1.4.1.LI.1** Explain various atomic models and their limitations	MCQs					
		Essay					
		Practical					
	1.4.1.LI.2 Calculate the energy of a photon during a transition	MCQs		1			1
		Essay					
		Practical					
	2.4.1.LI.1 Explain photoelectric effect and wave-particle duality	MCQs					
		Essay					
		Practical					

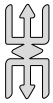
	2.4.1.LI.2 State the laws of photoelectric effect	MCQs	1				1
		Essay	1				
		Practical					
	2.4.1.LI.3 Identify areas of application of photoelectric effect and how they are applied	MCQs					
		Essay					
		Practical					
	3.4.1.LI.1 Describe how x-rays are produced	MCQs					
		Essay					
		Practical					
	3.4.1.LI.2 Distinguish between hard x-rays and soft x-rays	MCQs	1				1
		Essay					
		Practical					
	3.4.1.LI.3 Calculate the energy, frequency and wavelength of x-rays	MCQs		1			1
		Essay		1			1
		Practical					
	3.4.1.LI.4 Identify sectors where x-rays are applied and how they are applied	MCQs					
		Essay		1			1
		Practical					
Nuclear Physics	**1.4.2.LI.1** Describe the structure of the nucleus of the atom	MCQs	1				1
		Essay					
		Practical					
	1.4.2.LI.2 Explain radioactivity	MCQs	1				
		Essay					
		Practical					
	1.4.2.LI.3 Balanced basic nuclear reactions	MCQs					
		Essay					
		Practical					
	2.4.2.LI.1 State the radioactive decay law	MCQs					
		Essay			1		1
		Practical					

	2.4.2.LI.2 Calculate the half-life of a radioactive sample	MCQs					
		Essay					
		Practical					
	2.4.2.LI.3 Calculate the age of a bone specimen	MCQs		1			1
		Essay			1		1
		Practical					
	3.4.2.LI.1 Calculate the energy released in a nuclear reaction	MCQs					
		Essay					
		Practical					
	3.4.2.LI.2 Distinguish between fission and fusion	MCQs					
		Essay					
		Practical					
	3.4.2.LI.3 Describe the process of power generation using a nuclear reactor	MCQs					
		Essay					
		Practical					
	Total		23	45	10	3	81

PLC Session 18

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



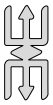
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   a. The key assessment for the week is ***Practice Paper 2***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through the problem individually for 3–4 minutes
   c. the group then works through it together the problem, step by step
   d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 19

Learning Indicators

1. *Explain the variation of potential and kinetic energy of body performing SHM*
2. *Determine the energy stored in a system performing SHM*

FOCAL AREA: ENERGY TRANSFORMATION IN SIMPLE HARMONIC MOTION

Kinetic Energy (KE)

Kinetic energy is the energy possessed by a body due to its motion.

$$KE = \frac{1}{2}mv^2$$

Substitute $v = A\omega\cos(\omega t + \phi)$ into the kinetic energy equation

$$KE = \frac{1}{2}m(A\omega\cos(\omega t + \phi))^2$$

$$KE = \frac{1}{2}m\omega^2A^2cos^2(\omega t + \phi)$$

$$KE = \frac{1}{2}m\omega^2(A^2 - x^2)$$

Maximum Kinetic Energy (KE_{max}): Occurs when velocity is maximum, i.e., at the equilibrium position (x = 0).

$$KE_{max} = \frac{1}{2}m\omega^2A^2$$

Minimum Kinetic Energy: Kinetic energy is zero at the extreme positions (x = ±A), where the velocity is momentarily zero.

Potential Energy (PE)

Potential energy in SHM is the energy stored due to the displacement from the equilibrium position (e.g., elastic potential energy in a spring).

$PE = \frac{1}{2}kx^2$ (for a spring-mass system)

$$F = ma = -kx$$

$$m\omega^2x = kx$$

$$k = m\omega^2$$

$$PE = \frac{m\omega^2x^2}{2}$$

$$PE = \frac{m\omega^2x^2}{2}$$

$$PE = \frac{m\omega^2(A\sin(\omega t + \phi))^2}{2}$$

$$PE = \frac{m\omega^2 A^2}{2} sin^2(\omega t + \phi)$$

Total Mechanical Energy (E)

The total mechanical energy in an ideal (undamped) SHM system is conserved and is the sum of kinetic and potential energy.

$$E = KE + PE$$

$$E = \frac{1}{2}m\omega^2(A^2 - x^2) + \frac{m\omega^2 x^2}{2}$$

$$E = \frac{1}{2}m\omega^2 A^2$$

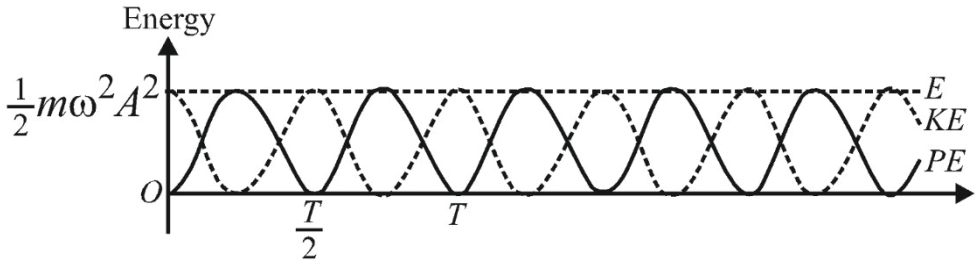


Figure 9.4: *Energy Exchange in Simple Harmonic Motion*

The total mechanical energy is constant and directly proportional to the square of the amplitude and the square of the angular frequency. At any point, the energy continuously converts between kinetic and potential forms.

Variation of potential and kinetic energy with displacement

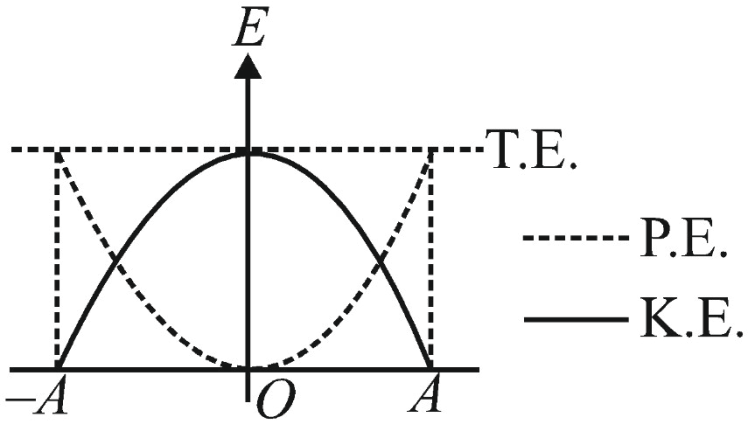


Figure 9.5: *Energy-Displacement Graph for Simple Harmonic Motion*

At $x = 0$, $PE = 0$ and the energy is purely kinetic i.e.,

$$E = KE_{max} = \frac{1}{2}m\omega^2 A^2$$

At extreme points or turning points of the SHM, kinetic energy is zero and the energy is purely potential i.e.,

$$E = PE_{max} = \frac{1}{2}m\omega^2 A^2$$

Thus, the total energy remains constant for the system no matter where the particle is.

Note that the frequency of vibration of the kinetic and potential energy is twice that of the frequency of oscillation.

Learning Tasks

1. Derive energy expressions for P.E. and K.E. in SHM using $x = A\sin(\omega t)$ and explain energy variation over time.
2. Use a simulation to observe and record how P.E. and K.E. change during SHM, then sketch energy vs. time and displacement graphs.
3. Conduct a spring experiment to calculate total energy, P.E., and K.E. at different displacements using measured and derived values.
4. Interpret energy graphs in small groups to describe energy transformation and identify when P.E. or K.E. is maximum.
5. Compare real-life systems like swings or pendulums to SHM and explain when P.E. and K.E. are maximum, presenting group findings to the class.

Pedagogical Exemplars

Talk for Learning

Guide learners through the derivation of expressions for potential energy and kinetic energy of SHM using displacement $x = A\sin(\omega t)$. Use this to explain energy variation over time.

Enquiry-Based Learning

Let learners use a simulation (such as PhET's mass-spring system) to observe how kinetic energy (K.E.) and potential energy (P.E.) vary as a mass oscillates. Learners should pause the simulation at various positions and record K.E. and P.E. values to see how the sum remains constant. Let them sketch graphs showing variation of P.E., K.E., and total energy with displacement and time.

Experiential Learning

Using a real mass-spring setup, guide learners to measure amplitude and frequency. Then help them calculate total energy stored using $E = \frac{1}{2}k\,A^2$. Challenge them to determine P.E. and K.E. at different displacements using formulas $PE = \frac{1}{2}kx^2$ and $KE = \frac{1}{2}mv^2$, using values of x and v derived from SHM equations.

Collaborative Learning

Provide learners with pre-drawn or simulated graphs of K.E., P.E., and total energy vs. displacement. In small groups, ask them to interpret the graphs, describe energy transformations, and identify key points (e.g., when K.E. is maximum, P.E. is zero and vice versa). Let them explain what the constant total energy indicates about the system.

Problem-Based Learning

Provide learners with a worked example showing how to calculate potential, kinetic, and total energy for a body in SHM using given values of amplitude, spring constant, and displacement. Then assign a

tiered worksheet where problems progress from basic (e.g. calculate PE at equilibrium) to more complex (e.g. calculate displacement at a point where KE is half of total energy). Offer hints or step-by-step guides to support different learner needs.

Project-Based Learning

Ask learners to compare energy transformation in SHM to systems like a child on a swing, a pendulum, or a car suspension. Let them describe when P.E. and K.E. are maximum in these systems, and relate it to mass-spring SHM energy behaviour. Let groups present their examples to the class.

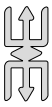
Key Assessment Level: Homework

A physics student is investigating the energy transformations in an oscillating system for a science fair project. A 0.5 kg mass is attached to a spring (k = 50 N/m) and oscillates horizontally on a frictionless surface with a maximum displacement of 0.2 m. Analyse and explain how the potential energy (PE) and kinetic energy (KE) vary as the mass moves from maximum displacement, through the equilibrium position, to the opposite maximum displacement. Additionally, create an energy diagram that shows the variation of PE, KE, and total energy throughout one complete oscillation cycle.

PLC Session 19

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



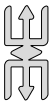
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***homework***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the homework (NTS 3k-3q).

10 minutes | Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes | Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes | Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 20

Learning Indicators

1. *Distinguish between elastic and inelastic collision*
2. *Use momentum change to establish impulse and hence deduce Newton's second law of motion*
3. *Verify Newton's third law of motion from momentum change*

FOCAL AREA: MOMENTUM, IMPULSE, AND COLLISIONS

Linear Momentum

Momentum = mass × velocity

$\rho = mv$

For an object speeding up or slowing down:
Final momentum = mass × final velocity (mv)
Initial momentum = mass × initial velocity (mu)
Change in momentum = final momentum – initial momentum (mv – mu)

Newton's second law of motion (Review from Year 1)

Newton's second law of motion states that the time rate of change of momentum is directly proportional to the force applied and it takes place in the direction of the force.
Mathematically

$$F \propto \frac{mv - mu}{t}$$

$$F = k\frac{mv - mu}{t} \qquad k = 1$$

$$F = \frac{mv - mu}{t}$$

Impulse

Impulse is the effect of a force acting on an object for a period of time. Impulse can be calculated as the product of a force acting on a body and the time during which it acts.

Mathematically

$$I = Ft$$

From Newton's second law

$$F = \frac{mv - mu}{t}$$

Examples

Car Crashes: Airbags increase the time Δt over which the force acts on a passenger, thereby reducing the average force Favg for the same change in momentum (Δp).

Catching a Ball: When catching a fast-moving ball, pulling your hand back increases the time over which the ball's momentum changes, reducing the force exerted on your hand.

Conservation of Momentum

The principle of conservation of momentum is a fundamental law in physics that applies to isolated systems.The law of conservation of linear momentum states that in a closed system or isolated system of colliding bodies, the total linear momentum in a given direction remains unchanged.

Isolated System: An isolated system is one where there are no external forces (or the net external force is zero). Internal forces (forces between objects within the system) do not change the total momentum of the system, as they always occur in equal and opposite pairs.

From Newton's second law

$$Ft = mv - mu$$

If there is no external force acting, F = 0

$$0 = mv - mu$$

$$mu = mv$$

Initial momentum = final momentum

showing that momentum is conserved

For a system of two interacting objects (e.g., m1 and m2):

$$p_{initial} = p_{final}$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

(This can be extended for more than two objects).

Examples

Collisions: When two billiard balls collide, the total momentum of the two-ball system before the collision is equal to their total momentum after the collision (assuming negligible friction).

Explosions: When a firework explodes in the air, the total momentum of all the fragments immediately after the explosion is equal to the momentum of the firework just before it exploded.

Recoil of a Gun: When a bullet is fired from a gun, the forward momentum of the bullet is equal in magnitude and opposite in direction to the backward momentum (recoil) of the gun. The total momentum of the gun-bullet system remains zero (if initially at rest).

Verification of Newton's Third Law from Momentum Change

Newton's third law of motion (Review from Year 1)

Newton's third law of motion states that to every action there is an equal and opposite reaction.

$$Action = -Reaction$$

Consider two bodies 1 and 2 of masses m_1 and m_2 acting mutually on each other. Let their initial velocities be u_1 and u_2 respectively and let their final velocities be v_1 and v_2. From the Impulse-Momentum theorem

For body 1: $I_1 = F_1t = m_1v_1 - m_1u_1$

For body 2: $I_2 = F_2t = m_2v_2 - m_2u_2$

From the principle of conservation of momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$m_1u_1 - m_1v_1 = m_2v_2 - m_2u_2$$

$$-(m_1v_1 - m_1u_1) = m_2v_2 - m_2u_2$$

$$-I_1 = I_2$$

$$-F_1t = F_2t$$

$$-F_1 = F_2$$

This derivation shows that if momentum is conserved in an isolated system, then the forces between interacting objects must be equal in magnitude and opposite in direction, which is precisely Newton's Third Law. It underscores the fundamental nature of momentum conservation as a consequence of how forces interact.

Example: When a person pushes a wall, the wall pushes back on the person with an equal and opposite force. This is why the person's momentum changes (they might move backwards), while the wall's momentum (and velocity) changes negligibly due to its much larger mass.

Elastic Collisions

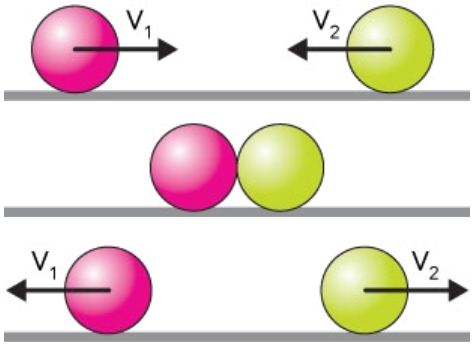


Figure 9.6:

An elastic collision is a collision in which both **momentum** and **kinetic energy** are conserved. This means the total kinetic energy of the system *before* the collision is equal to the total kinetic energy *after* the collision.

Characteristics

1. Total momentum is conserved.
2. Total kinetic energy is conserved.
3. No deformation of objects or generation of heat/sound due to the collision itself (in an ideal elastic collision).
4. Objects usually rebound off each other without sticking.

Mathematical conditions

Conservation of momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Conservation of kinetic energy

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_2^2 + \frac{1}{2}m_1v_2^2$$

Examples

1. Collisions between billiard balls (approximated as elastic, as very little energy is lost).
2. Collisions between subatomic particles (often perfectly elastic).
3. Balls in Newton's cradle.

Inelastic Collision

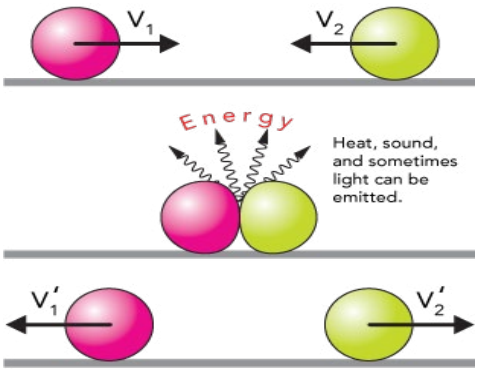


Figure 9.7:*An inelastic collision is a collision in which* **momentum is conserved**, *but* **kinetic energy is NOT conserved**. *Some of the initial kinetic energy is converted into other forms of energy, such as heat, sound, or deformation (e.g., crumpling, breaking).*

Characteristics

1. Total momentum is conserved.
2. Total kinetic energy is NOT conserved (it decreases).
3. Energy is transformed into other forms (heat, sound, deformation).
4. Objects may deform, or stick together, after the collision.

Mathematical Conditions

Conservation of momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Examples of Inelastic Collisions (General)

1. Car crashes
2. A clay ball hitting a wall and sticking to it.
3. A dropped ball not bouncing back to its original height (some energy lost to heat and sound on impact).

Perfectly Inelastic Collision: This is a special and extreme case of an inelastic collision where the colliding objects stick together and move as a single combined mass after the collision. This particular type of inelastic collision results in the maximum possible loss of kinetic energy (consistent with momentum conservation).

Example: A bullet embedding itself in a wooden block (ballistic pendulum), two cars colliding and sticking together. In this specific case, the objects share a common final velocity.

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

Learning Tasks

1. Solve simple problems to calculate momentum and impulse using mass, velocity, and time.
2. Observe videos of collisions and decide if they are elastic or inelastic, then list the differences.
3. Use toy carts or a simulation to test if momentum is the same before and after a collision.
4. Find a real-life example of a collision (like in sports or cars) and explain how momentum is involved.

Pedagogical Exemplars

Talk for Learning

Begin by reviewing Newton's Second Law from Year 1, focusing on how force relates to change in momentum. Use simple scenarios like kicking a ball or catching a moving object to illustrate impulse.

Guide learners to verify Newton's third law from momentum change by analysing a two-body elastic collision. Present them with masses and , initial velocities and , and final velocities and . Then using given values for mass and velocity before and after collision, ask them to compute the momentum change of both bodies, verify that the values are equal in magnitude and opposite in direction, and discuss how this illustrates Newton's third law.

Use animations or video clips showing different types of collisions (e.g., two bouncing balls vs. two clay balls sticking together). Lead a class discussion to classify each as elastic or inelastic, highlighting energy and momentum considerations. Learners then record definitions, differences, and real-world examples of each collision type.

Experiential Learning

Drop an egg onto different surfaces (soft cloth vs hard floor). Let learners observe the outcomes and explain using impulse and momentum change. Prompt them to relate how increased stopping time reduces the impact force and prevents breakage.

Design an activity where two learners push off each other on skateboards or low-friction trolleys. Use video analysis or observations to show that both experience equal and opposite momentum changes. Relate this to Newton's Third Law and guide learners to write qualitative and quantitative observations.

Collaborative Learning

Let learners work in pairs using simulation tools or toy carts on a smooth surface to model two-body collisions. Guide them to measure or estimate velocities and masses before and after collision. Learners calculate total momentum before and after the event and confirm conservation. Reinforce with class discussion and a follow-up problem-solving exercise.

Enquiry-Based Learning

Use an online simulation (e.g., PhET "Collision Lab") to allow learners to model elastic and inelastic collisions by adjusting masses and velocities. Learners explore momentum conservation and kinetic energy change, then summarise differences between collision types using tables and diagrams.

Problem-Based Learning

Learners calculate momentum and impulse from given masses, velocities, and time intervals using worked examples and then complete a short worksheet.

Provide learners with a variety of problems on elastic and inelastic collisions involving mass and velocity. Let them use conservation of momentum and, in the case of elastic collisions, kinetic energy conservation. Begin with worked examples, then assign individual tasks for practice with feedback.

Assign problem-solving practice using varied collision scenarios. Include both elastic and inelastic examples requiring application of conservation of momentum and energy principles. Use differentiated worksheets with guiding hints for less confident learners and challenge problems for others. Include peer discussion to compare methods.

Project-Based Learning

Ask learners to research real-world examples of collisions such as snooker, car crashes, or sports impacts. In small groups, they prepare short presentations explaining how momentum conservation and collision type apply to their chosen example, supported with diagrams or short videos.

Key Assessment Level 3: Essay

1. During a football match in Ghana, a moving ball hits a stationary player and bounces off in a different direction. Using your understanding of elastic and inelastic collisions, explain what type of collision this represents. Justify your answer with energy and momentum concepts, and suggest how such knowledge could help improve sports training in Ghana.

(10 marks)

2. A 2.0 kg metal cart moving at 3.0 m/s collides head-on with a 1.5 kg wooden cart moving toward it at 2.0 m/s on a frictionless track. After the collision, the metal cart reverses direction and moves at 1.0 m/s.
   a. Find the velocity of the wooden cart after the collision.
   b. Justify whether the collision is perfectly elastic.
   c. Suggest a real-life Ghanaian scenario to simulate this type of collision.

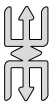
(10 marks)

PLC Session 20

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



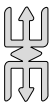
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***essay***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the essay (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 9 Review

Over the past three weeks, the section has developed essential knowledge and skills related to oscillatory motion and the interaction of bodies through force and momentum, both in ideal and real-world conditions.

In week 18, attention was given to simple harmonic motion. This type of periodic motion is characterised by a restoring force proportional to the displacement and directed towards the equilibrium position. The foundational conditions for SHM were outlined, and the motion was mathematically described using differential equations. Important expressions for displacement, velocity, and acceleration were derived and applied. Common systems that exhibit SHM, such as the simple pendulum and mass-spring systems, were examined, showing how they obey the conditions for SHM under small displacements. Graphs of displacement, velocity, and acceleration were also analysed to highlight the sinusoidal nature of the motion.

In week 19, the focus shifted to the energy transformation within SHM systems. The variation of kinetic and potential energy throughout the motion was explored, with emphasis on how energy shifts from one form to another while the total mechanical energy remains constant in an ideal system. Graphs were used to illustrate how energy depends on displacement and time. The relationships between energy, amplitude, and angular frequency were also discussed. Experimental and simulation-based tasks reinforced these concepts by allowing measurements and calculations of energy at different positions in the motion.

In week 20, the section covered the principles of momentum, impulse, and collisions. Linear momentum was defined, and its relationship with force and time was used to derive the concept of impulse. Newton's second and third laws were revisited and verified using the impulse-momentum theorem and the principle of momentum conservation. Different types of collisions—elastic, inelastic, and perfectly inelastic—were introduced, and the distinctions between them were analysed based on momentum and energy conservation. Examples from sports, vehicles, and laboratory setups were used to demonstrate how these principles apply to real interactions.

By the end of the three-week period, a thorough understanding should have been developed of how systems oscillate under SHM, how energy behaves within these systems, and how momentum and impulse govern the behaviour of colliding bodies. These concepts form the foundation for more advanced topics in waves, dynamics, and mechanical systems.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 18

Question 1

What to expect in a successful experiment

1. **Setup:** A string hanging from a support with a weight (bob) at the end, able to swing freely
2. **Measurements**
   - learner should measure at least 3 different string lengths (e.g., 30cm, 50cm, 70cm)
   - For each length, time 20 complete swings (back and forth equals one swing)
   - Divide total time by 20 to get period (T)
   - Square this value to get T^2
3. **Graph**
   - Should show a straight line going through or near the origin
   - As length increases, T^2 increases proportionally
4. **Calculating g**
   - The formula relating these is: $T^2 = 4\pi^2 L/g$
   - So slope of graph $= 4\pi^2/g$
   - Therefore $g = 4\pi^2/\text{slope}$
   - Result should be approximately 9.8 m/s^2
5. **Common errors and assumptions**
   - Timing errors (human reaction time)
   - Measuring length incorrectly (should be to centre of bob)
   - Air resistance
   - Assumption that string is massless
   - Small angles needed because the formula is an approximation that works only for small swings

Component	Mark Level	What to Look For
Equipment Setup [2 marks]	*2 marks*	*• Securely attaches string to retort stand* *• Ensures pendulum can swing freely without obstacles* *• Measures length accurately from pivot point to centre of bob* *• Sets up in location with minimal air disturbance* *• Creates stable setup that won't move during measurements*
	1 mark	*• Basic functional setup with minor issues* *• Some instability or obstacles* *• Generally correct but with some measurement concerns* *• Setup allows experiment to proceed*

Data Collection [2 marks]	*2 marks*	*• Tests at least 3 different lengths* *• Times 20 complete oscillations for each length* *• Uses appropriate timing technique (starts/stops at same position)* *• Records all data clearly with proper units* *• May perform repeat measurements for reliability* *• Shows systematic approach to measurement*
	1 mark	*• Tests minimum number of lengths* *• Some timing inconsistencies* *• Basic data recording with some gaps* *• Some unit omissions* *• Generally systematic but with errors*
Calculations [2 marks]	*2 marks*	*• Correctly calculates period (T) by dividing total time by 20* *• Accurately calculates T^2 for each length* *• Shows all working clearly* *• Uses consistent units throughout* *• Presents calculations in organised table* *• Includes appropriate precision in results*
	1 mark	*• Some calculation errors* *• Basic working shown* *• Some inconsistency in units* *• Table with some organisation issues* *• Some precision or rounding issues*
Graph Construction [2 marks]	*2 marks*	*• Plots T^2 on y-axis against length on x-axis* *• Uses appropriate scales with labelled axes and units* *• Plots points accurately* *• Draws best-fit straight line* *• Creates neat, readable graph* *• Title and key included if necessary*
	1 mark	*• Basic graph with some errors* *• Some scaling or labelling issues* *• Points plotted with minor inaccuracies* *• Line drawn with some issues* *• Generally understandable but with flaws*

Calculation of g *[1 mark]*	*1 mark*	*• Correctly calculates slope of the T^2 vs. length graph* *• Uses formula $g = 4\pi^2/\text{slope}$ to find g* *• Shows clear working* *• Obtains reasonable value for g (around 9.8 m/s^2)* *• Includes units in final answer*
Sources of Error *[1 mark]*	*1 mark*	*• Identifies two valid sources of error such as: – Timing reaction errors – Air resistance – String mass effects – Measurement inaccuracies – Friction at pivot point* *• Explanations show understanding of how these affect results*
Assumption Identification *[1 mark]*	*1 mark*	*• Identifies one valid assumption such as: – String is massless – Bob acts as a point mass – No air resistance – Pivot is frictionless* *• Shows understanding of idealised conditions*
Small Angle Explanation *[1 mark]*	*1 mark*	*• Explains that the formula $T = 2\pi\sqrt{(L/g)}$ is only valid for small angles* *• States that larger angles introduce errors due to nonlinear effects* *• May mention that period becomes amplitude-dependent at larger angles* *• Shows understanding of practical constraints of the simple pendulum formula*

Question 2

Key SHM concepts to look for

1. **Basic SHM understanding**
   - SHM is regular back-and-forth motion where acceleration is proportional to displacement but in opposite direction
   - Like a mass on a spring or a pendulum with small swings
   - Has predictable pattern with consistent frequency and amplitude
2. **Relevant equations**
   - Displacement equation: $x = A\cos(\omega t)$ [where A is amplitude, ω is angular frequency, t is time]
   - Velocity equation: $v = -A\omega\sin(\omega t)$ [velocity is maximum at center, zero at ends]
   - Acceleration equation: $a = -A\omega^2\cos(\omega t)$ [acceleration is maximum at ends, zero at center]
   - Key relationship: $a = -\omega^2 x$ [acceleration proportional to displacement]
3. **Train application**
   - Train carriages connected by couplings act like masses connected by springs
   - Starting/stopping creates compression and extension of these "springs"
   - This creates oscillatory motion resembling SHM
4. **Comfort considerations**
   - High acceleration means strong forces on passengers (uncomfortable)
   - Rapid changes in acceleration ("jerk") are particularly uncomfortable

- Lower amplitude means less extreme acceleration
- Damping reduces oscillation amplitude over time

Component	Mark Level	What to Look For
SHM Concept Understanding [2 marks]	*2 marks*	*• Correctly explains SHM as repetitive motion about an equilibrium position* *• Describes how displacement, velocity, and acceleration vary in SHM* *• Mentions key characteristics: frequency, amplitude, period* *• Explains that acceleration is proportional to displacement but in opposite direction*
	1 mark	*• Basic understanding of SHM concepts* *• Limited description of key characteristics*
Relevant Equations *[2 marks]*	*2 marks*	*• Includes at least two relevant SHM equations such as: – $x = A\cos(\omega t)$ [displacement equation] – $v = -A\omega \sin(\omega t)$ [velocity equation] – $a = -A\omega^2 \cos(\omega t)$ [acceleration equation] – $a = -\omega^2 x$ [relationship between acceleration and displacement]* *• Correctly explains what the variables represent* *• Shows how equations relate to one another*
	1 mark	*• Includes at least one relevant equation• Limited explanation of equations' meaning* *• Basic understanding demonstrated*
Train Motion Analysis *[2 marks]*	*2 marks*	*• Correctly connects train motion to SHM principles* *• Explains why starting/stopping creates oscillatory motion* *• Describes how coupling between carriages creates spring-like behaviour* *• Analyses how mass, coupling stiffness, and damping affect the motion* *• Explains that these oscillations approximate SHM under certain conditions*
	1 mark	*• Basic connection between train motion and SHM* *• Limited explanation of oscillatory behaviour* *• Some understanding of factors affecting motion*
Passenger Comfort Analysis *[2 marks]*	*2 marks*	*• Explains that rapid changes in acceleration cause discomfort* *• Connects maximum acceleration to forces felt by passengers* *• Describes how velocity changes relate to jerk (rate of change of acceleration)* *• Explains that predictable, smooth motion improves comfort* *• May mention frequency considerations (natural frequency vs. forcing frequency)*

	1 mark	*• Basic connection between acceleration and comfort* *• Some understanding of motion effects on passengers* *• Limited analysis of comfort factors* *• Some relevant points but incomplete explanation*
Design Recommendations [2 marks]	*2 marks*	*• Provides specific design recommendations based on SHM principles: - Improved suspension systems to dampen oscillations - Optimised coupling stiffness between carriages - Controlled acceleration/ deceleration rates - Frequency considerations to avoid resonance* *• Justifies recommendations using SHM equations* *• Explains trade-offs between performance and comfort*
	1 mark	*• Some design recommendations provided* *• Limited connection to SHM principles* *• Basic justification without specific equation references* *• Some understanding of design implications*

Question 3

(a) Calculation of angular frequency, maximum velocity, and maximum acceleration – 9 marks

- Frequency (f) = 5 oscillations / 10 s = 0.5 Hz → 2 marks
- Angular frequency ($\omega = 2\pi f$)
  - Correct formula: $\omega = 2\pi f$ → 1 mark
  - Correct substitution and answer: $\omega = 2\pi \times 0.5 = \pi$ rad/s ≈ 3.14 rad/s → 1 mark
- Maximum velocity ($v_{max} = A\omega$)
  - Correct formula: $v_{max} = A\omega$ → 1 mark
  - Substitution: $v_{max} = 0.2 \times 3.14$ → 1 mark
  - Final answer: $v_{max} \approx 0.628$ m/s → 1 mark
- Maximum acceleration ($a_{max} = A\omega^2$)
  - Correct formula: $a_{max} = A\omega^2$ → 1 mark
  - Substitution and answer: $a_{max} = 0.2 \times (3.14)^2 \approx 1.97$ m/s² → 1 mark

(b) Velocity and acceleration at 0.12 m from equilibrium – 6 marks

- Use of correct formula for velocity: $v = \omega\sqrt{(A^2 - x^2)}$ → 1 mark
  - Substitution: $v = 3.14 \times \sqrt{(0.2^2 - 0.12^2)}$ → 1 mark
  - Final answer: $v \approx 0.524$ m/s → 1 mark
- Use of correct formula for acceleration: $a = -\omega^2 x$ → 1 mark
  - Substitution: $a = -(3.14)^2 \times 0.12$ → 1 mark
  - Final answer: $a \approx -1.18$ m/s² → 1 mark

(c) Justification – 5 marks

- **Identification of risk (1 mark):** States that high acceleration can cause sudden jerks or impacts on fragile products.

- **Link to damage (1 mark):** Explains that excessive acceleration increases the likelihood of cracking, breaking, or damaging the products.
- **Smooth transfer (1 mark):** Mentions that controlling acceleration ensures smooth and gentle movement of products between conveyor belts.
- **Machine efficiency/product quality (1 mark):** Relates controlled acceleration to maintaining consistent product quality and reducing wastage.
- **Justification (1 mark):** Provides a logical reason linking controlled acceleration with the design requirement for packaging fragile items (e.g., safety and reliability of the packaging process).

WEEK 19

Expected/Model Answer

Energy Variation Explanation

At maximum displacement ($x = \pm 0.2$ m): The mass momentarily stops, so velocity = 0. Therefore, KE = 0 and PE = maximum ($PE = \frac{1}{2}kx^2 = \frac{1}{2}(50)(0.2)^2 = 1.0$ J). All energy is stored as elastic potential energy in the compressed/stretched spring.

At equilibrium position ($x = 0$): The spring is neither compressed nor stretched, so PE = 0. The mass moves at maximum velocity, so KE = maximum (KE = 1.0 J). All energy exists as kinetic energy of the moving mass.

Between positions: Energy continuously transforms between PE and KE. As the mass moves from maximum displacement toward equilibrium, PE decreases while KE increases. As it moves from equilibrium toward opposite maximum displacement, KE decreases while PE increases.

Total Energy: Remains constant at $E_{total} = \frac{1}{2}kA^2 = \frac{1}{2}(50)(0.2)^2 = 1.0$ J throughout the entire oscillation, demonstrating conservation of mechanical energy.

Energy Diagram

Should show sinusoidal curves with PE and KE being 180° out of phase, while total energy remains as a horizontal line at 1.0 J. PE is maximum at displacement extremes, KE is maximum at equilibrium.

Component	Mark Level	What to Look For
Energy at Maximum Displacement [3 marks]	*3 marks*	*• Correctly states that KE = 0 at maximum displacement (mass stops)* *• Correctly calculates or states that PE = maximum at this position* *• Explains that all energy stored as elastic potential energy in spring* *• May calculate $PE = \frac{1}{2}kx^2 = 1.0$ J* *• Shows understanding of velocity–energy relationship*
	2 marks	*• States that KE = 0 at maximum displacement* *• Recognises that PE is maximum at this position* *• Shows basic understanding of energy distribution• May have minor calculation errors*
	1 mark	*• Shows some understanding that energy changes at maximum displacement* *• Limited explanation with some correct elements*

Energy at Equilibrium Position [3 marks]	*3 marks*	*• Correctly states that PE = 0 at equilibrium (spring at natural length)* *• Correctly states that KE = maximum at equilibrium* *• Explains that all energy exists as kinetic energy of moving mass* *• Shows understanding that maximum velocity occurs at equilibrium• May mention maximum speed calculation*
	2 marks	*• States that PE = 0 at equilibrium* *• Recognises that KE is maximum at this position* *• Shows good understanding of energy distribution* *• Minor gaps in explanation*
	1 mark	*• Shows some understanding of energy changes at equilibrium* *• Limited but partially correct explanation*
Energy Transformation Process [4 marks]	*4 marks*	*• Clearly explains continuous energy transformation between PE and KE* *• Describes energy changes as mass moves from max displacement → equilibrium → opposite max* *• Shows understanding that transformations are gradual and continuous* *• Explains inverse relationship between PE and KE* *• May use phrases like "energy converts back and forth"*
	3 marks	*• Explains energy transformation concept clearly* *• Describes most of the oscillation cycle correctly* *• Shows good understanding of PE ↔ KE conversion* *• Minor gaps in complete cycle description*
	2 marks	*• Basic explanation of energy transformation* *• Shows understanding that energy changes during motion* *• Limited description of complete process*
	1 mark	*• Shows awareness that energy changes occur* *• Very basic understanding of transformation concept*
Total Energy Conservation [2 marks]	*2 marks*	*• Clearly states that total energy remains constant throughout oscillation* *• May calculate total energy $E = \frac{1}{2}kA^2 = 1.0$ J* *• Explains conservation of mechanical energy principle* *• Shows understanding that PE + KE = constant*
	1 mark	*• Shows awareness that total energy is conserved* *• Basic understanding of energy conservation* *• May state concept without full explanation*

Energy Diagram Quality [3 marks]	*3 marks*	*• Accurate diagram showing PE, KE, and total energy vs. position or time* *• PE and KE curves are 180° out of phase (sinusoidal patterns)* *• Total energy shown as horizontal line (constant)* *• Correct labelling of axes and energy curves* *• May include key positions (max displacement, equilibrium) marked*
	2 marks	*• Generally accurate energy diagram* *• Shows PE and KE variation correctly* *• Total energy approximately constant* *• Good labelling and presentation*
	1 mark	*• Basic energy diagram attempted* *• Shows some understanding of energy variations* *• May have errors but demonstrates partial understanding*

WEEK 19

Verification Guide

Types of collisions to understand

1. **Perfectly elastic collision:** All kinetic energy is conserved (like billiard balls)
2. **Perfectly inelastic collision:** Objects stick together after collision (maximum energy loss)
3. **Partially elastic collision:** Some kinetic energy is conserved, some is lost (most real-world collisions)

Key concepts to look for:

1. **For collision type**
   - A football bouncing off a player is partially elastic
   - The ball doesn't stick to the player (not inelastic)
   - The ball loses some energy in the collision (not perfectly elastic)
2. **For momentum**
   - Total momentum is always conserved in collisions
   - Momentum transfers from ball to player
   - Direction changes are related to momentum's vector nature
3. **For energy**
   - Some kinetic energy is lost in the collision
   - Energy converts to heat, sound, temporary deformation
   - This energy loss is why the collision is partially elastic
4. **For training applications**
   - Understanding bounce angles helps with positioning
   - Controlling body surfaces affects ball direction
   - Knowledge of collision physics improves ball control techniques

Component	Mark Level	What to Look For
Collision Type Identification[2 marks]	*2 marks*	*• Correctly identifies the collision as partially elastic* *• Explains why it's not perfectly elastic (some energy loss)* *• Explains why it's not completely inelastic (objects don't stick together)* *• Shows understanding of collision spectrum*
	1 mark	*• Identifies collision type with limited explanation* *• Some confusion about elastic vs. inelastic* *• Basic understanding demonstrated*
Momentum Justification *[2 marks]*	*2 marks*	*• Clearly explains conservation of momentum principle* *• Describes how momentum transfers from ball to player* *• Mentions that total momentum before equals total momentum after* *• May discuss vector nature (direction) of momentum* *• May mention formula p=mv (momentum = mass × velocity)*
	1 mark	*• Basic mention of momentum conservation* *• Limited explanation of momentum transfer* *• Some understanding demonstrated* *• Some misconceptions present*
Energy Justification *[2 marks]*	*2 marks*	*• Explains that kinetic energy is not fully conserved in the collision* *• Describes how some energy converts to other forms (heat, sound, deformation)* *• Connects energy loss to partially elastic nature* *• May mention that a perfectly elastic collision would conserve all kinetic energy* *• May mention formula $KE=\frac{1}{2}mv^2$*
	1 mark	*• Basic mention of energy concepts* *• Limited explanation of energy transfer* *• Some understanding of energy loss* *• Some misconceptions present*
Real-World Factors *[1 mark]*	*1 mark*	*• Identifies specific factors affecting the collision: - Ball inflation pressure - Player's muscle tension - Surface area of contact - Wetness of ball/conditions* *• Shows understanding of practical physics*
Ghanaian Context *[1 mark]*	*1 mark*	*• Makes specific references to Ghanaian football* *• May mention local teams, playing conditions, or equipment* *• Shows understanding of local sporting context* *• Connects physics to specific Ghanaian situations*

Training Applications *[2 marks]*	*2 marks*	*• Suggests at least two specific training applications, such as: – Heading technique to control ball direction – Body positioning to maximise/minimise bounce – Understanding ball control physics – Ball selection based on desired bounce characteristics – Injury prevention through proper collision techniques* *• Explains how physics understanding improves these areas* *• Shows practical connection between theory and training*
	1 mark	*• Suggests at least one training application* *• Limited explanation of how physics applies* *• Basic understanding of practical applications* *• Some connection between theory and training*

Question 2

(a) Calculation of Wooden Cart's Final Velocity (3 marks)

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

(1 mark)

$$(2.0)(3.0) + (1.5)(-2.0) = (2.0)(-1.0) + (1.5)v_2$$

(1 mark)

$$v_2 = \frac{5.0}{1.5} = 3.33\ m/s$$

(1 mark)

(b) Justify Type of Collision Using Kinetic Energy (5 marks)

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_2^2 + \frac{1}{2}m_1v_2^2$$

write conservation of energy formula (1 mark)

$$\frac{1}{2}(2.0)(3.0)^2 + \frac{1}{2}(1.5)(2.0)^2 = 9.0 + 3.0 = 12.0\ J$$

Compute total initial kinetic energy (1 mark)

$$\frac{1}{2}(2.0)(1.0)^2 + \frac{1}{2}(1.5)(3.33)^2 = 1.0 + 8.33 = 9.33\ J$$

Compute total final kinetic energy (1mark)

Initial KE ≠ Final KE → Not perfectly elastic (1 mark)

Collision is not elastic because kinetic energy is not conserved (1 mark)

Ghanaian Context Application (2 marks)

e.g., "Push trucks colliding at school sports day" or "Physics lab cart collision using ticker tape"

(1 mark)

SECTION 10: FUNCTIONAL ELECTRONIC CIRCUITS FOR RECTIFICATION, AMPLIFICATION, DETECTION, AND BATTERY CHARGING

STRAND: ELECTRIC FIELDS, MAGNETIC FIELDS AND ELECTRONICS

Sub-Strand: Applications of Electronics

Week 21

Content Standard: *Demonstrate knowledge and understanding of rectification.*

Learning Outcome: *Using diode, capacitor and a load resistor explain how an ac waveform can be rectified to direct waveform.*

Week 22

Content Standard: *Demonstrate knowledge and understanding of signal amplification.*

Learning Outcome: *Demonstrate knowledge and understanding of darkness detector circuit.*

Week 23 & 24

Content Standard: *Using a transistor explain how amplification is done.*

Learning Outcome: *Using a solar panel explain how a darkness detector works.*

INTRODUCTION AND SECTION SUMMARY

Section 10 explores foundational concepts in the application of electronics, focusing on rectification, signal amplification, darkness detection, and battery charging. It forms part of the strand Electric Fields, Magnetic Fields, and Electronics, and is structured around practical circuit design and real-world functionality.

The section begins with the concept of rectification, where alternating current (AC) is converted to direct current (DC) using diodes. Half-wave rectifiers, employing a single diode, are introduced as a simple method that passes only one half of the AC waveform, albeit with low efficiency. In contrast, full-wave rectifiers use either four diodes (in a bridge configuration) or two diodes (with a centre-tapped transformer) to utilise both halves of the AC waveform, resulting in improved efficiency and a smoother output. This is followed by the use of **filter circuits**, typically capacitors, which smooth out

the ripple in the rectified output to provide a more stable DC supply—essential for most electronic devices. Practical visualisations using simulations and oscilloscopes reinforce the theoretical concepts.

The section then transitions to **signal amplification** using transistors, particularly PNP and NPN types. The working principles of transistors as amplifiers are discussed, highlighting the importance of biasing, current flow, and terminal configuration. Amplification is explained as the process of increasing the amplitude of a signal without altering its shape. The common-emitter configuration is emphasised for its voltage gain capabilities, and the differences between PNP and NPN transistors are explored in terms of current direction, voltage requirements, and typical applications. The role of transistors in high-speed switching, logic gates, and signal amplification in systems such as radios is also outlined.

In the third part, the focus shifts to **darkness detector circuits**. These use light-dependent resistors (LDRs) whose resistance increases in the absence of light, altering the biasing of a transistor to switch on an output device such as an LED. The circuit operates on the principle of photoconductivity and demonstrates how light intensity controls conductivity and output. Typical components include an LDR, an NPN transistor, resistors, a power source, and an LED or buzzer. The circuit has practical relevance in automated lighting and security systems.

Finally, the section concludes with **battery charging circuits**, explaining the components and operation of a basic charger using a step-down transformer, rectifier, filter capacitor, and voltage regulator. The concept of voltage regulation is emphasised for maintaining safe and consistent voltage levels, preventing overcharging and undercharging of various battery types, especially in lithium-ion and lead-acid batteries. Circuit stages—transformer, rectifier, filter, and regulator—are described in detail, alongside their roles in stabilising the output for reliable charging. The importance of controlling ripple, temperature, and current is also addressed, along with design enhancements such as LED indicators and thermal protection.

The weeks and the indicators covered by the section are:

- ***Week 21***

  Design half wave rectifier.

  Design a full wave rectifier.

  Design a smoother/filter circuit using capacitor.

- ***Week 22***

  Design a PNP amplifier.

  Design a NPN amplifier.

- ***Week 23***

  Design a darkness detector.

- ***Week 24***

  Design a battery charger.

SUMMARY OF PEDAGOGICAL EXEMPLARS

The document presents a range of practical and enquiry-based activities designed to reinforce key electronic concepts: rectification, amplification, darkness detection, and battery charging. Circuit simulation tools are used to construct and observe the behaviour of half-wave and full-wave rectifier circuits, highlighting the role of diodes in controlling current direction and the effect of capacitors in smoothing voltage output. These simulations are supported by hands-on experiments where circuit waveforms are compared and ripple voltages are measured under varying load conditions.

Amplifier circuits are explored using both NPN and PNP transistors, with activities involving construction, signal measurement, and gain analysis. Visual aids and debates are used to compare transistor types in terms of efficiency and practical application. Circuit assembly is complemented by schematic analysis and explanation of how small input signals are converted into larger output signals.

Darkness detection is addressed through guided construction of circuits using LDRs and transistors. Simulations and real-world testing are used to observe circuit response under different lighting conditions. Modifications to component values allow adjustment of sensitivity, and fault-finding challenges help develop diagnostic skills.

Battery charger design involves examining each functional stage—transformer, rectifier, filter, and regulator—through videos, diagrams, and circuit simulations. Circuits are designed to meet specific voltage requirements, with additional features like LED indicators incorporated for monitoring. The activities collectively promote understanding through observation, construction, testing, and application of core electronic principles.

ASSESSMENT SUMMARY

Indicators	DOK Level	Assessment Strategy and/or Mode
Design half wave rectifier. Design a full wave rectifier. Design a smoother/filter circuit using capacitor.	Level 4	Class exercise, Project
Design a PNP amplifier. Design a NPN amplifier	Level 4	Debate, Project
Design a darkness detector	Level 4	Homework, Project
Design a battery charger.	Level 4	Essay, Project

WEEK 21

Learning Indicators

1. *Design half wave rectifier*
2. *Design a full wave rectifier*
3. *Design a smoother/filter circuit using capacitor*

FOCAL AREA: RECTIFIERS AND SMOOTHER/FILTER CIRCUITS

Half-Wave Rectifier

Uses a single diode to pass only the positive/negative half-cycle of AC input. Imagine the AC voltage like a wave going up and down continuously. In a half-wave rectifier, we use just one diode—a component that only allows current to flow in one direction. So, if the diode is placed to pass the positive half, it blocks the negative half entirely. This is like a one-way gate that lets cars through only when they're going uphill and blocks them from going downhill. Learners can visualise this better by observing waveforms on a simulation or oscilloscope, where they'll see only half of the input signal getting through.

Half-wave rectifiers have a low efficiency (~40%) due to wasted half-cycle. Since the half-wave rectifier ignores one half of the AC signal, it wastes that portion of the energy. It's like watering plants using a tap that only flows half the time—the rest of the water pressure is blocked. This makes the process inefficient. In real circuits, this means the output voltage is lower, and more energy is lost as heat or unused power. We use this point to highlight why full-wave rectifiers are usually preferred in most electronic devices—they make better use of the available power.

Full-Wave Rectifier

Utilises four diodes (bridge) or two diodes (centre-tapped transformer) to rectify both half-cycles. Think of AC current as a wave that moves up and down—positive and negative. A full-wave rectifier is like a clever system that makes use of both halves of this wave, unlike the half-wave rectifier. In a bridge rectifier, four diodes are arranged in a square so that no matter which direction the current comes from, the output is always in the same direction. Imagine a train that can go either forward or backward, but clever tracks (the diodes) always guide it out through the same tunnel. In a centre-tapped transformer setup, we only need two diodes because the transformer itself splits the AC into two halves that the diodes can rectify. Learners can use simulations to compare both methods and see how current flows through the diodes in each half-cycle.

They have a higher efficiency (~81%) and smoother output. Since both halves of the AC signal are used, the output is stronger and more continuous than with a half-wave rectifier. This means less energy is wasted, and devices powered by the circuit get more consistent voltage. It's like using both arms to carry water buckets instead of just one—you get the job done faster and more evenly. In lab work, learners can measure and compare the output of half-wave and full-wave circuits using a multimeter or oscilloscope, clearly seeing how full-wave rectification results in a steadier output with fewer gaps.

Filter Circuit: Capacitors store charge during peaks and discharge during troughs, reducing ripple voltage. After rectification, the output voltage still goes up and down—it's not a smooth line yet. This is called a ripple. Think of it like water waves after a boat passes by. A capacitor acts like a water tank that fills up when there's extra water (voltage peaks) and releases water when there's a

dip (voltage troughs). In the same way, the capacitor charges when the voltage is high and discharges when the voltage drops, helping to level out the flow of electricity. Learners can visualise this using a simulation or by observing a waveform on an oscilloscope, where the ripple becomes much smaller when a capacitor is added.

Filter circuits are critical for stable DC output in power supplies. Many electronic devices need a constant and smooth DC voltage to function properly. Without a filter, the output would still fluctuate, causing problems in sensitive components like microcontrollers or sensors. It's like trying to write on a moving bus—you need stability to work well. In lab experiments, learners can build circuits with and without filters and observe how the capacitor improves the output stability. This reinforces the real-life importance of filter circuits in phone chargers, computer adapters, and nearly every electronic device.

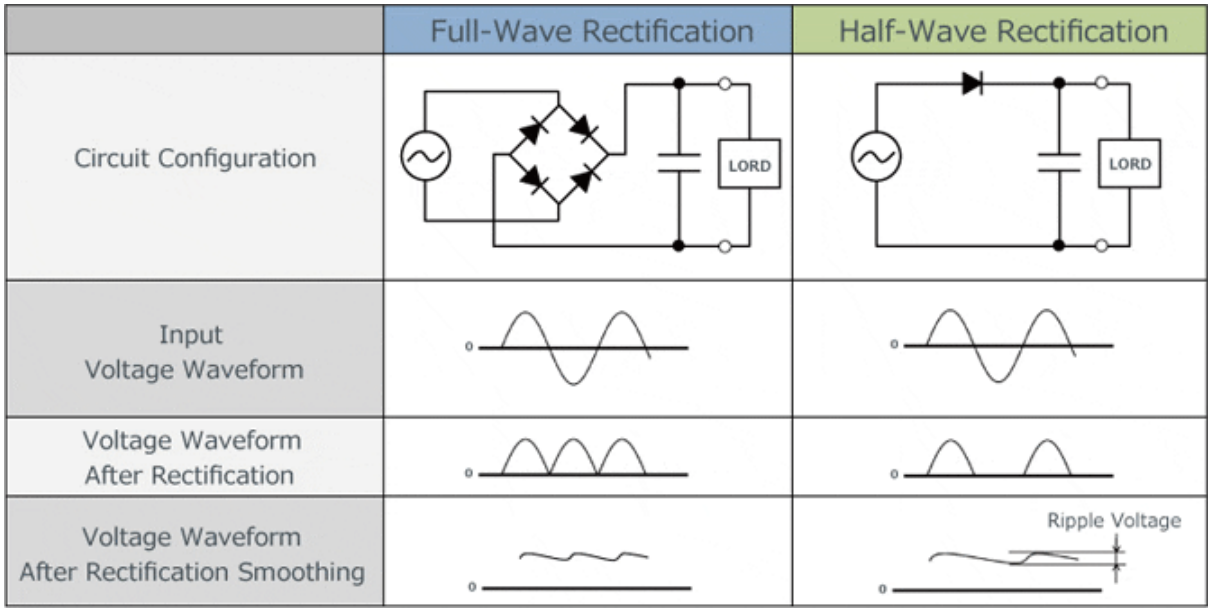


Figure 10.1: *Half-wave vs. full-wave output waveforms (circuit)*

(a.) (b.)

Figure 10.2: *Scan the QR code to observe a practical demonstration of (a.) Full-Wave Rectifier (b.) Half-Wave Rectifier*

Learning by Experimentation: Ripple Measurement Lab

In this activity, learners can build a full-wave rectifier circuit with a filter capacitor of 470 µF and observe how the output ripple voltage changes as the load current varies.

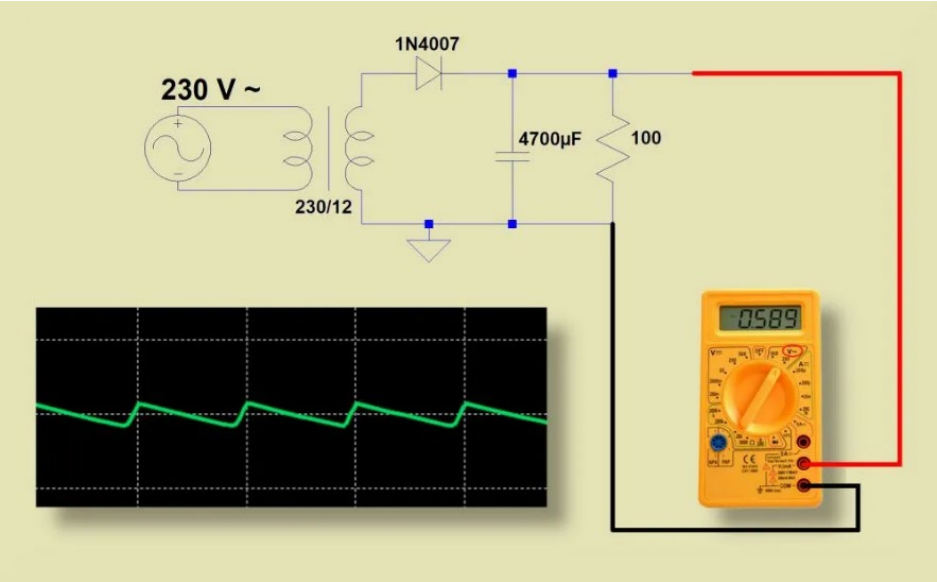


Figure 10.2: *Half-Wave Rectifier Circuit with Smoothing Capacitor and Output Voltage Measurement"*

Start by helping learners assemble the circuit step by step, reinforcing earlier concepts about diodes, rectification, and capacitor filtering. Once the circuit is running, learners adjust the load current (I_{load}) from 10 mA to 100 mA, using variable resistors or known loads.

Using the Oscilloscope for Real-Time Observation

Guide learners to connect an oscilloscope across the load and observe the ripple waveform. This makes the invisible "AC noise" in a DC output visually real. Encourage them to describe what they see: "What happens to the waveform as the current increases?"

Plotting and Interpreting Data

Learners record their ripple voltage (V_{ripple}) readings and plot V_{ripple} vs. I_{load} on a graph. As the current increases, they should see ripple voltage rise, reinforcing the inverse relationship between ripple and the product of frequency and capacitance:

$$V_{ripple} = \frac{I_{load}}{fC}$$

This is a powerful moment for connecting mathematical models with experimental results. Teachers can guide discussions on why the capacitor has less time to charge at higher current draw, and how that increases ripple. This lab promotes inquiry, data literacy, real-time observation, and critical thinking. It turns textbook formulas into lived experiences and gives learners confidence in circuit analysis and practical skills with lab tools like oscilloscopes.

Learning Tasks

1. Build a half-wave rectifier in a simulation, and draw how the input and output signals look.
2. Build a full-wave rectifier and compare its output to the half-wave version.
3. Add a capacitor to a rectifier and see how it smooths the output; draw both waveforms.
4. Research where rectifiers are used (like in phone chargers) and share your findings.

Pedagogical Exemplars

Enquiry-Based Learning

Let learners use a circuit simulation tool (like Falstad or PhET) to build and observe the operation of a half-wave rectifier. They should identify the role of the diode and observe how only one half of the AC signal is passed. Learners sketch the input and output waveforms and discuss the inefficiency and voltage gaps of the design.

Allow learners to attach a capacitor across the load resistor in a full-wave rectifier circuit. Using simulation or oscilloscope, they observe the output voltage with and without the capacitor. Let learners analyse the waveform smoothing effect and think-pair-share the role of capacitor in reducing voltage ripple.

Experiential Learning

Provide learners with a kit containing diodes, a transformer, resistors, and a breadboard. Let them construct a full-wave rectifier and use an oscilloscope or simulation to visualise the waveform. Guide them to compare it with the half-wave version and explain the advantage of continuous output in both halves of the cycle.

Facilitate a hands-on session where learners dismantle old, safe-to-handle electronic appliances to identify internal components like diodes, rectifiers, and capacitors. Encourage learners to photograph and document their findings. Groups then discuss why particular components were used in the appliance's design, referencing learned theory on rectification and filtering.

Collaborative Learning

Assign groups to research real-life uses of rectifiers, such as in phone chargers, radios, or solar power systems. Each group presents how either half-wave or full-wave rectification is used in their selected application, highlighting the importance of filtering in producing steady DC voltage.

Project-Based Learning

Assign a project-based task where learners are grouped and asked to design a low-cost rectifier circuit that maintains a ripple factor of 5%. Let learners assign roles such as circuit designer, component tester, documentation lead, and group presenter. After building or simulating the circuit, each group presents their design. Under your guidance, use rubrics to assess each design based on efficiency, creativity, ripple control, and clarity of explanation.

Key Assessment Level 4: Class Exercise

1. Using a circuit simulation tool such as Tinkercad, EveryCircuit, or Falstad, design and simulate either a half-wave or a full-wave rectifier circuit using components like a power supply, diode(s), and a load resistor. Produce a report including a labelled circuit diagram from the simulation, explaining how your circuit converts AC to DC, justifying your choice of rectifier type by highlighting its advantages, and describing one real-world application of your design in a home, workshop, or community setting.

10 marks

PLC Session 21

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand

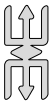
b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

a. The key assessment for the week is ***class exercise***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes **Content Exploration**

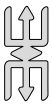
5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 22

Learning Indicators

1. *Design a PNP amplifier*
2. *Design a NPN amplifier*

FOCAL AREA: AMPLIFIERS

Transistors are semiconductor devices used to amplify or switch electronic signals. In an NPN transistor, current flows from the collector to the emitter when a small current is applied to the base, which must be at a higher voltage than the emitter. This allows the transistor to conduct and amplify signals.

In contrast, a PNP transistor conducts when the base is at a lower voltage than the emitter; current flows from the emitter to the collector when the base is effectively grounded (low voltage). Understanding the direction of current flow and the voltage relationship between terminals is crucial for designing and analysing amplifier circuits.

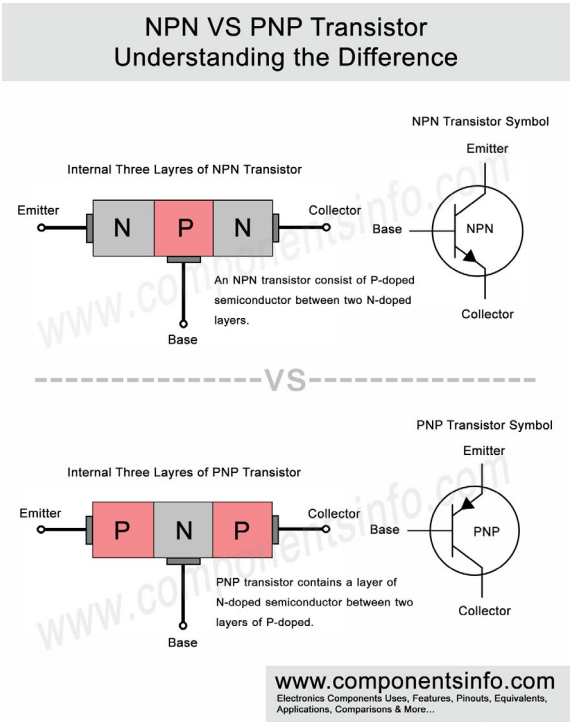


Figure 10.3: *Internal Structure and Symbol Comparison of NPN vs PNP Transistors*

NPN stands for Negative-Positive-Negative, and PNP stands for Positive-Negative-Positive. Let's delve into the differences between NPN and PNP transistors.

PNP transistors activate with a low signal, whereas NPN transistors activate with a high signal. In PNP transistors, the "P" signifies the polarity of the emitter terminal, and "N" signifies the polarity of the base terminal. In NPN transistors, "N" denotes the negatively charged coating of the material, while "P" denotes the positively charged layer. Applying a positive voltage to the collector terminal induces a current flow from the collector to the emitter in an NPN transistor. Conversely, providing a positive voltage to the emitter terminal in a PNP transistor causes current to flow from the emitter to the collector.

PNP transistors offer the advantage of a lower turn-on voltage, making them well-suited for high-speed applications. On the other hand, NPN transistors boast a higher current-carrying capacity, rendering them ideal for use in low-power applications.

How transistors work

A transistor operates as a switch or gate for electronic signals, opening and closing an electronic gate many times per second. It ensures the electronic circuit is on if the current is flowing and switched off if it isn't. Complex switching circuits that make up all modern networking and telecommunications systems rely on transistors. Circuits also offer high switching speeds, such as hundreds of Gigahertz or more than 100 billion on-and-off cycles per second.

Transistors are combined to form a logic gate, which compares multiple input signals to provide a different output. Computers with logic gates can make simple decisions using Boolean algebra. These techniques are the foundation of modern-day computing and computer programs. Transistors also play an important role in amplifying electronic signals. For example, in radio applications such as FM receivers, where the received electrical signal is weak due to disturbances, amplification provides audible output. Transistors increase signal strength to provide this amplification.

Amplifier Design

Transistors are basically used as amplifiers for amplification. The process of raising the amplitude of a weak signal without change in its frequency and shape is known as 'amplification". In order to achieve this, the input circuit of the transistor remains forward biased and the output circuit always remains to reverse biased during all parts of the signal this is known as 'transistor biasing'. The base of the transistor receives the weak signal, and the collector circuit produces an output that has been amplified. One crucial prerequisite for amplification is that the signal should only rise in magnitude and not alter in shape. The term "faithful amplification" refers to this rise in signal strength without any modification in form. Below is the circuit diagram of transistor as an amplifier.

The common-emitter configuration is widely used in amplifier circuits because it provides significant voltage gain. For stable operation, proper biasing is essential—typically requiring a base-emitter voltage of around 0.7V for silicon (Si) transistors to turn on the junction and allow controlled current flow. The voltage gain of a common-emitter amplifier is given by the formula:

$$A_v = -\frac{R_C}{R_E}$$

where R_C is the collector resistor and R_E is the emitter resistor. The negative sign indicates a phase inversion between the input and output signals.

Real-World Examples

NPN Transistors are commonly used in audio preamplifiers and sensor interface circuits where low-side switching is preferred. PNP Transistors are often found in power regulation systems and high-side switch applications where the emitter is connected to the positive supply.

Learning Tasks

1. Observe a video and compare how PNP and NPN transistors work.
2. Build PNP and NPN amplifier circuits in a simulator and see how they amplify signals.
3. Use a breadboard to build an NPN amplifier and measure the input and output.

4. Debate on whether PNP or NPN amplifiers is more efficient or suitable for a given application.

Pedagogical Exemplars

Talk for Learning

Using a video or animation, guide learners to observe the structure and operation of both PNP and NPN transistors. Let learners note how current flows and the role of emitter, base, and collector in each type. Follow this with a class discussion comparing the biasing and current direction in PNP versus NPN amplifiers.

Facilitate a classroom debate where learners argue which amplifier type (PNP or NPN) is more efficient or suitable for a given application, such as mobile devices or audio systems.

Enquiry-Based Learning

Let learners use circuit simulation software (e.g., Falstad or Tinkercad) to build basic amplifier circuits using both NPN and PNP transistors. Learners input a small AC signal and observe the amplified output, taking note of the phase change and gain. Then they write short reflections on which configuration is commonly used and why.

Experiential Learning

Assign a practical task where learners use a breadboard to build a simple NPN transistor amplifier circuit using available components (e.g., resistors, capacitors, NPN transistor). Measure input and output signals using a multimeter or oscilloscope. Discuss real-life applications where NPN amplifiers are preferred due to their characteristics.

Collaborative Learning

Divide the class into two groups—one researches PNP amplifiers, the other NPN amplifiers. Each group prepares a poster or presentation covering the structure, working principle, biasing conditions, and typical applications. Groups then teach each other, allowing peer explanation and reinforcement.

Problem-Based Learning

Provide learners with incomplete circuit diagrams for both PNP and NPN amplifiers. Ask them to complete the diagrams and explain the function of each component. This reinforces understanding of how input signal, biasing, and load work together in transistor amplifiers.

Key Assessment Level 4: Debate

1. In a structured classroom debate, argue which amplifier type—PNP or NPN—is more efficient and suitable for a specific application such as mobile devices or audio systems. Each team must present technical justifications, including differences in circuit configuration, biasing, power consumption, and signal amplification characteristics. Teams should support their arguments with relevant examples, such as usage in common electronic devices, and respond critically to opposing points to defend their position.

(12 marks)

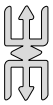
2. Design and construct either a PNP or NPN amplifier using a simulation tool (such as Tinkercad or EveryCircuit) or by assembling the circuit with locally available materials. Draw and label the circuit diagram, then explain briefly how the amplifier works. Show how it amplifies a small input signal by comparing the input and output voltages and reflect briefly on any difficulty encountered during the process.

(10 marks)

PLC Session 22

45 minutes | **Planning & Reviewing the Learning Plan**

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



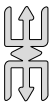
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***debate***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the debate (NTS 3k-3q).

10 minutes | **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*

- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 23

Learning Indicator: *Design a darkness detector*

FOCAL AREA: DARKNESS DETECTOR

A darkness detector is an electronic circuit that activates an output device such as a light or alarm in the absence of ambient light. The key component is the Light Dependent Resistor (LDR), which changes its resistance based on light intensity. When light decreases, the resistance of the LDR increases, altering the voltage across the base of a transistor, thereby switching the output.

LDRs work on the principle of photoconductivity whenever the light falls on its photoconductive material, it absorbs its energy and the electrons of that photoconductive material in the valence band get excited and go to the conduction band and thus increasing the conductivity as per the increase in light intensity. Also, the energy in incident light should be greater than the band gap energy so that the electrons from the valence band got excited and go to the conduction band.

Note to teachers

The arrangement of the pins (emitter, base and collector) differs between transistor types, so it cannot be assumed. To identify the pins of the transistor you are using, read the part number printed on its body (for example, BC547 or 2N2222) and search online for that number followed by the word "datasheet". The manufacturer's datasheet includes a pin diagram showing which leg is the emitter (E), base (B) and collector (C).

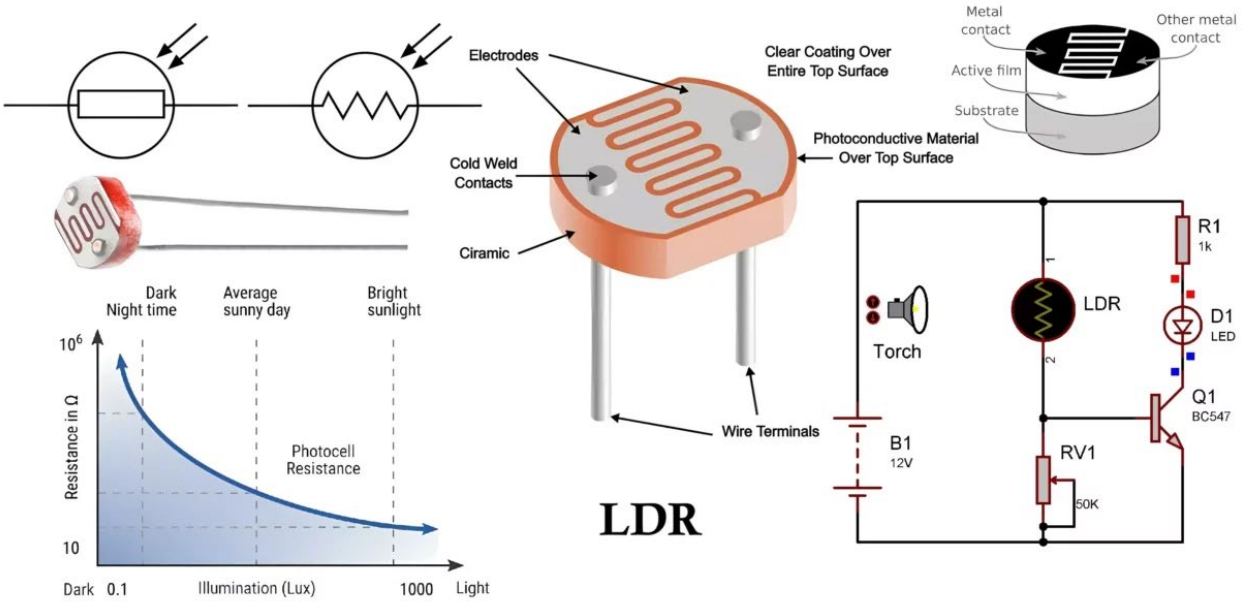


Figure 10.3: *Structure, Symbol, Characteristics, and Application Circuit of Light Dependent Resistor (LDR)*

Typical components include:

- LDR
- NPN Transistor (e.g., BC547)
- Resistors

- LED or Buzzer
- Power source (battery)

Examples

- A circuit that turns on an LED automatically when it gets dark.
- A streetlight model using an LDR to demonstrate automatic lighting.

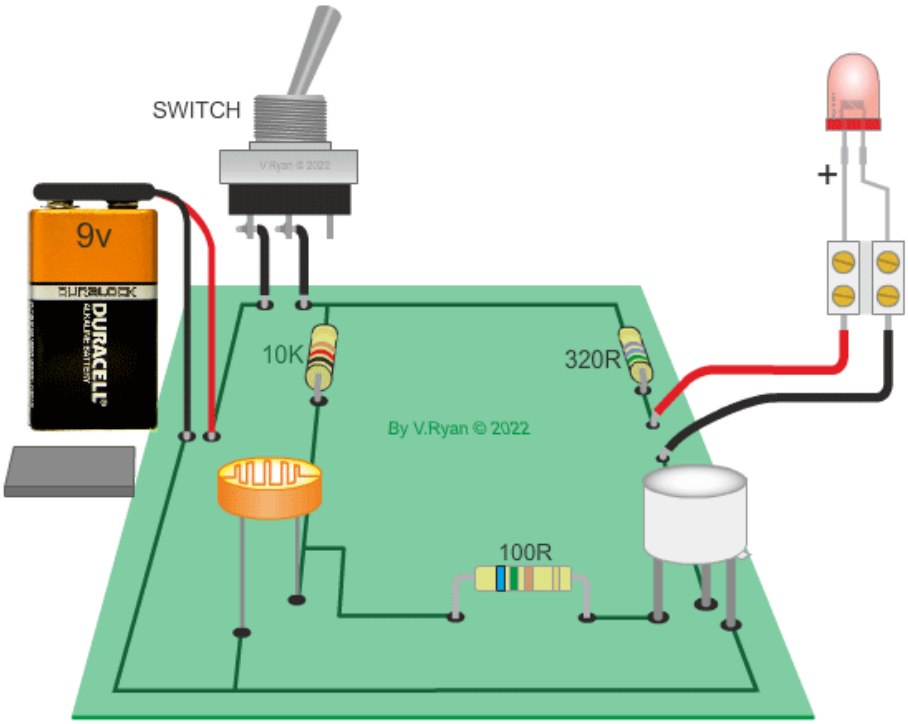


Figure 10.4: *a circuit simulation on how the LDR works*

Key Takeaways for Teachers

- Reinforce the understanding of sensor-based circuits and analogue input.
- Highlight real-world uses of darkness detection such as in security systems and smart lighting.
- Encourage students to link theory with practical, observable phenomena.

Learning Tasks

1. Observe a video and draw the darkness detector circuit with labels.
2. Build the circuit in a simulator and see how it works in light and dark.
3. Make the circuit on a breadboard and test how light affects the LED.
4. Try different resistor values to make the LED turn on at different light levels.
5. Fix a broken circuit and explain what you did to make it work.

Pedagogical Exemplars

Talk for Learning

Demonstrate the behaviour of an LDR by setting up a simple circuit measuring the resistance across an LDR with an ohmmeter, or with a voltmeter and ammeter. Let students observe the different in resistance when covered and uncovered, before providing a short lecture on the behaviour of an LDR.

Ask learners to think-pair-share to come up with some ideas as to when LDRs would be useful in the real world.

Enquiry-Based Learning

Using simulations or multimedia (such as Tinkercad or YouTube tutorials), let learners observe the step-by-step process of building a darkness detector circuit with an LDR, transistor, and LED. After observing, learners should sketch the circuit diagram and label each component, then explain the role of the LDR in controlling the LED based on ambient light levels.

Experiential Learning

Provide learners with a circuit diagram of a basic darkness detector using an LDR (light-dependent resistor), NPN transistor, and an LED. Let learners assemble the circuit on a breadboard, observe how it behaves under different light levels, and explain how the resistance of the LDR changes with light intensity to control the transistor.

Challenge learners to improve the sensitivity of the darkness detector. In small groups, let them modify the resistor values in the voltage divider network and observe the effect on when the LED turns on.

Introduce a fault-finding challenge: give learners a non-working darkness detector circuit with one deliberate wiring or component error. Ask them to diagnose and fix the fault.

Project-Based Learning

Link the darkness detector to real-world applications. Ask learners to investigate where such devices are used (e.g., streetlights, emergency lights, or solar garden lamps), then propose and justify a use case in their local environment or community.

Key Assessment Level 4: Project

1. Describe the working principle of a darkness detector circuit and the function of each component. **(12 marks)**
2. Design a **darkness detector circuit** using either a simulation tool (e.g., Tinkercad, EveryCircuit) or **locally available materials** such as an LDR, transistor, resistor, and LED. Draw and label the circuit diagram, explain how the circuit works to detect changes in light, test the circuit under different lighting conditions, and describe how the LED responds. Conclude with a brief reflection on the effectiveness of your design and any improvements you would suggest.

(10 marks)

PLC Session 23

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand

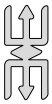
b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

a. The key assessment for the week is ***project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes **Content Exploration**

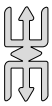
5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 24

Learning Indicator: *Design a battery charger*

FOCAL AREA: BATTERY CHARGER

What are Rechargeable Batteries, Storage Batteries, or Secondary Cells?

Rechargeable batteries, also known as secondary cells, are electrochemical energy storage devices capable of being recharged and used multiple times when they rundown. They differ from primary batteries, which are single-use and cannot be recharged. These batteries store electrical energy chemically and can convert it back to electrical energy through reversible electrochemical reactions. They are widely used in portable electronic devices (PEDs) due to their ability to provide rechargeable power sources.

Charging refers to the process of replenishing the chemical energy within a rechargeable battery by applying an external electrical energy source. This process involves reversing the electrochemical reactions that occur during discharge, restoring the active materials to their original state. Proper charging requires control circuits to ensure safe operation, prevent overcharging, and prolong battery life.

Types of Batteries Available



Figure 10.5: *Types of batteries*

1. **Lead-acid batteries**: The oldest, with low cost and high discharge currents; used mainly stationary applications but also in some PEDs.

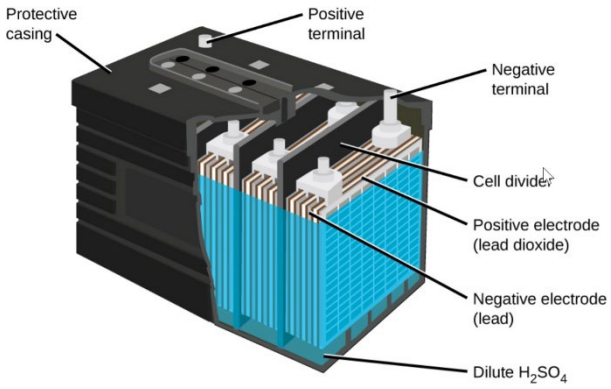


Figure 10.6: *Lead acid battery*

2. **Nickel-cadmium (Ni-Cd) batteries**: Known for their moderate energy density and durability but high toxicity.

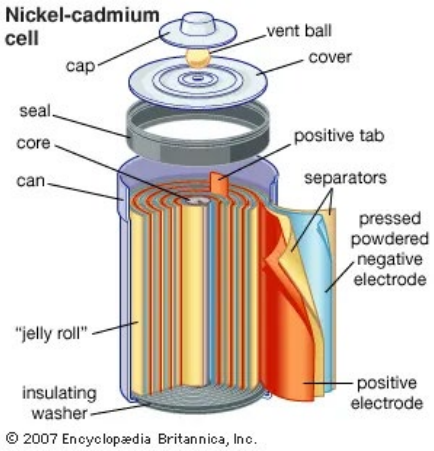


Figure 10.7: *Nickel-cadmium (Ni-Cd) battery*

3. **Nickel-metal hydride (Ni-MH) batteries**: Have higher energy density than Ni-Cd and lower toxicity.

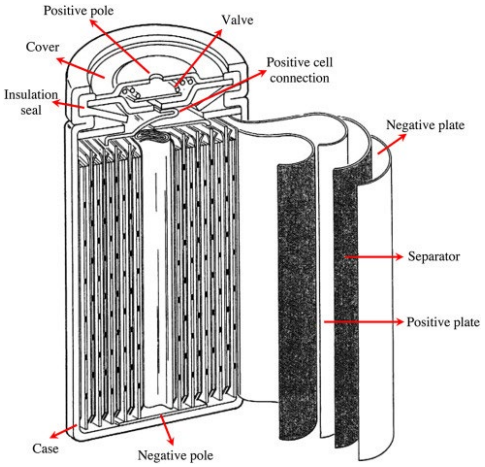


Figure 10.7: *Nickel-metal hydride (Ni-MH) battery*

4. **Lithium-ion (Li-ion) batteries**: The most prevalent for modern PEDs, offering high energy density, long cycle life, and low self-discharge rates. Variants include lithium polymer batteries used in smartphones, laptops, and drones.



Figure 10.8: *Lithium-ion (Li-ion) batteries*

Recent developments are exploring new battery chemistries such as lithium metal and sodium-ion batteries, as well as solid-state electrolytes, to enhance performance.

Applications of Rechargeable Batteries

Rechargeable batteries are fundamental to numerous PEDs and applications, including:

1. **Mobile phones and smartphones:** Providing portable power with high energy density.
2. **Laptops and tablets:** Requiring long-lasting, lightweight power sources.
3. **Consumer drones and UAVs:** Demanding high-capacity, lightweight batteries for extended flight time.
4. **Wearable devices and health monitors:** Necessitating compact, safe, and reliable energy storage.
5. **Automotive and EVs:** Although beyond PEDs, lithium-ion batteries are crucial in electric vehicles.

Table 10.1: *Development of mobile phone and their batteries:*

Period	Historical stages	Representative product	Actual Photo	Lunch time	Battery type	Voltage (v)	Capacity (mAh)
1983-1993	Era of cellular phone	Motorola DynaTac 8000X (the world's first mobile phone)		1983	Ni-Cd battery	7.5	500
1993-1995	Miniaturisation and intelligence	IBM Simon (the world's first smart phone) Motorola 8900 (the world's first flip phone)		1993 1995	Ni-Cd battery Ni-Cd battery	7.5 6	950
1995-1997	Era of Ni-MH battery	Motorola 166C		1997	Ni-MH battery	6	1300
1998-2007	Era of popularization of mobile phone	Motorola GC87C		1998	Liquefied Li-ion battery	7.2	1200
2007-present	Era of new smart mobile phone	iPhone Galaxy SIII iPhone 6 Huawei mate 20p		2007 2012 2014 2018	Li-ion polymer battery Soft-pouch liquefied Li-ion battery Li-ion polymer battery Li-ion polymer battery	3.7 3.8 3.8 3.82	1500 2100 1810 4200

Experiment to design a 12 V battery charger circuit

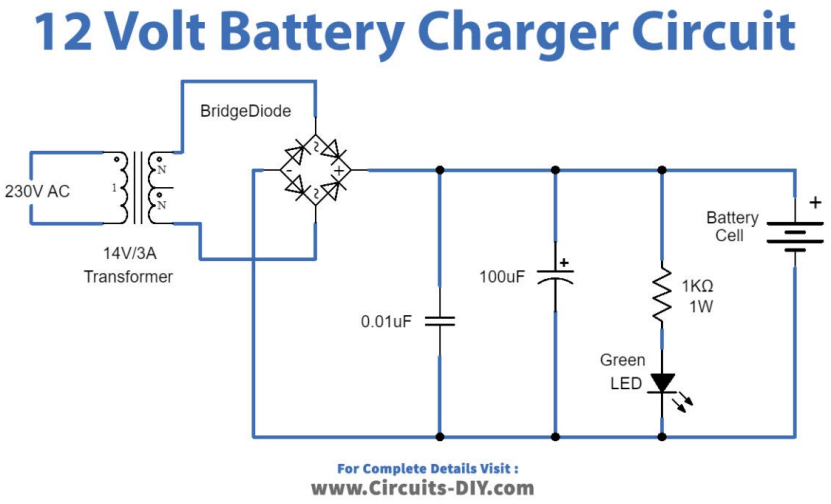


Figure 10.9: *12 Volt Battery Charger Circuit Diagram*

Objective: To design and test a basic 12V battery charger using a transformer, bridge rectifier, filter capacitors, resistor, and indicator LED.

Components Required

- 230V to 14V/3A step-down transformer
- Bridge diode rectifier (4 diodes or a bridge module)
- Capacitors: 0.01µF and 100µF
- Green LED
- 1kΩ, 1W resistor
- Rechargeable 12V battery cell
- Breadboard or PCB and connecting wires

Procedure

1. Connect the transformer to the 230V AC supply to step down the voltage to 14V AC.
2. Use a bridge diode to convert the 14V AC to DC.
3. Filter the output using a 100µF capacitor (parallel) and a 0.01µF capacitor to reduce ripple.
4. Insert a 1kΩ resistor in series with a green LED to indicate charging activity.
5. Connect the filtered DC output to the battery terminals, ensuring correct polarity.
6. Monitor battery voltage during charging to ensure it remains under safe limits.
7. Discuss improvements such as adding thermal protection or using a voltage regulator.

Learning Tasks

1. Observe a video and label the parts of a battery charger.
2. Use a simulator to make a 6V or 12V battery charger and explain your design.
3. Design a small solar charger and choose parts that fit the size and cost limits.
4. Make a charger circuit with an LED that shows when the battery is full.

Pedagogical Exemplars

Enquiry-Based Learning

Using videos or simulations, guide learners to observe how a basic battery charger works, focusing on the key components: transformer, rectifier, filter, and voltage regulator. Let them label a block diagram of a battery charger and explain the function of each stage in writing.

Problem-Based Learning

Provide learners with a problem-solving task: "Design a portable battery charger using solar input." Give them constraints such as maximum size or cost. Learners research and draw a functional circuit diagram, then discuss trade-offs involved in component selection (e.g., diode type, battery capacity).

Project-Based Learning

In small groups, let learners use circuit simulation tools (e.g., Tinkercad or EveryCircuit) to design a simple 6V or 12V battery charger circuit. It should include an LED indicator for full charge. Scaffold the task by first reviewing Zener diode voltage regulation, then challenge them to integrate this concept into their design. Provide sample parameters such as input AC voltage and required output current. Each group presents their design and justifies their choice of components.

Key Assessment Level 4: Project

1. Explain why voltage regulation is important in battery charging.

(10 marks)

2. Design a battery charger circuit for a 6V or 12V battery using either a simulation platform (e.g., Tinkercad, EveryCircuit) or locally available materials such as a transformer, rectifier diodes, filter capacitor, and voltage regulator. Draw and label the circuit diagram, explain how each stage (step-down transformer, rectifier, filter, and regulator) functions in the charging process, test the circuit or simulation with appropriate input, and describe how the output safely charges the battery. Include a short reflection on how to improve the circuit for efficiency or safety.

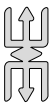
(12 marks)

PLC Session 24

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified

in your subject area (NTS 3a-3c).



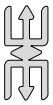
Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes **Content Exploration**

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- *This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?*
- *If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.*
- *Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.*

30 minutes **Enactment**

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes **Reflection**

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 10 Review

This section focuses on four key topics within the strand of *Electric Fields, Magnetic Fields, and Electronics*: **Rectification**, **Amplification**, **Darkness Detection**, and **Battery Charging**. Over the course of four weeks, the section develops essential concepts and circuit applications that underpin how electrical systems convert, control, detect, and regulate power in practical devices.

In week 21, the focus was on **rectification**, the process of converting alternating current (AC) to direct current (DC). Rectifiers are categorised into half-wave and full-wave types, depending on how much of the AC cycle they convert. Half-wave rectifiers use a single diode and pass only one half of the AC input, while full-wave rectifiers—especially bridge rectifiers—use four diodes to convert both halves of the AC waveform, increasing efficiency. Filter circuits, typically involving capacitors, are introduced to smooth the rectified output and reduce ripple voltage. These principles are applied to practical power supply systems where a stable DC voltage is required.

In week 22, attention turns to **signal amplification** using bipolar junction transistors (BJTs), specifically NPN and PNP types. The function of a transistor as an amplifier is explained, with a focus on current flow, terminal configuration, and the importance of biasing. The common-emitter configuration is emphasised for its voltage gain and usefulness in many practical circuits, including audio amplifiers. The key differences between NPN and PNP transistors are analysed, and examples are drawn from real-life applications such as radios and mobile devices.

In week 23, the topic shifts to **darkness detection**, where simple circuits respond to changes in ambient light. The main components are a light-dependent resistor (LDR) and a transistor. As light decreases, the resistance of the LDR increases, changing the base voltage of the transistor and triggering an output device like an LED. The circuit demonstrates photoconductivity and introduces basic sensing and switching concepts. This principle is widely used in applications such as automatic lighting, alarm systems, and night-activated devices.

In week 24, the section addresses **battery charging circuits**, focusing on the components and design needed to safely charge rechargeable batteries. A complete charging circuit includes a step-down transformer, a rectifier (usually full-wave), a smoothing capacitor, and a voltage regulator. These stages work together to deliver a stable output suitable for battery charging. The importance of maintaining constant voltage, avoiding overcharging, and ensuring thermal safety is stressed. Additional features such as LED indicators are included to enhance usability and monitoring.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 21

Question 1

Verification Guide

Basic rectifier concepts

1. **Half-wave rectifier**
   - Uses a single diode
   - Only passes positive (or negative) half of the AC wave
   - Blocks the other half completely
   - Simpler design with fewer components
   - Less efficient (uses only half the input power)
   - Results in more "ripple" (variation) in output
2. **Full-wave rectifier**
   - Uses four diodes in "bridge" configuration (or two diodes with centre-tapped transformer)
   - Converts both positive and negative halves of AC wave to positive DC
   - More efficient (uses all input power)
   - Smoother output with less ripple
   - More complex design with more components

What to look for in the simulation

- For half-wave: single diode between AC source and resistor
- For full-wave: four diodes arranged in bridge configuration
- AC source (usually sine wave)
- Load resistor
- Possibly a capacitor for smoothing (not required but good addition)

Output waveforms

- Input should be sine wave (alternating positive and negative)
- Half-wave output: Only positive bumps with flat areas between
- Full-wave output: All-positive bumps with no flat areas
- With capacitor: Much smoother output with less variation

Component	Mark Level	What to Look For
Circuit Simulation [2 marks]	*2 marks*	*• Successfully creates working rectifier circuit in simulation tool• Circuit includes correct components: – AC power source with appropriate voltage – Diodes in correct configuration – Load resistor of appropriate value – (Optional) Capacitor for smoothing• Simulation runs correctly showing expected behaviour• Shows proficiency with simulation software*

	1 mark	*• Creates basic circuit with some errors• Most required components present• Some connection or value issues• Simulation runs but with unexpected results• Basic understanding of simulation tool*
Circuit Diagram [2 marks]	*2 marks*	*• Provides clear screenshot or export of circuit from simulation• All components properly labelled• Component values clearly indicated• Shows input and output points• Neat, professional presentation• For half-wave: shows single diode configuration• For full-wave: shows bridge rectifier or centre-tapped transformer*
	1 mark	*• Basic diagram provided but with limited labels• Some components unlabelled• Some values missing• Basic presentation• Diagram shows general circuit but lacks detail*
AC to DC Conversion Explanation[2 marks]	*2 marks*	*• Clearly explains how diodes allow current flow in one direction only• Describes what happens during positive and negative half-cycles of AC• For half-wave: explains that negative half-cycles are blocked• For full-wave: explains how both half-cycles are converted to positive• May include simulation waveform images showing before/after• Uses correct terminology (e.g., forward bias, reverse bias)*
	1 mark	*• Basic explanation of rectification process• Some understanding of diode function• Limited explanation of half-cycles• Some terminology used correctly*
Rectifier Type Justification[2 marks]	*2 marks*	*• Clearly states whether design is half-wave or full-wave rectifier• Provides specific advantages of chosen type: - Half-wave: simplicity, fewer components, lower cost - Full-wave: better efficiency, less ripple, more complete rectification• Acknowledges limitations of chosen type• Compares to alternative type• Shows understanding of design trade-offs*
	1 mark	*• Identifies rectifier type• Lists some advantages with limited explanation• Limited comparison to alternative• Some understanding of trade-offs*
Real-World Application [2 marks]	*2 marks*	*• Describes specific, realistic application in home/workshop/community• Application properly matches rectifier type chosen• Explains why DC is needed for this application• Connects circuit characteristics to application requirements• Shows understanding of practical implementation• Examples might include: - Simple phone charger or power adapter - Battery charging system - LED lighting power supply - Solar panel controller - Power supply for electronic devices*
	1 mark	*• Describes general application with limited specificity• Application somewhat matches rectifier type• Basic explanation of DC requirement• Limited connection to circuit characteristics• Some practical understanding demonstrated*

WEEK 22

Question 1

Verification Guide

Basic differences between PNP and NPN transistors:

1. **Current Flow**
   - NPN: Current flows from collector to emitter

- PNP: Current flows from emitter to collector

2. **Biasing**
   - NPN: Requires positive voltage at base (relative to emitter)
   - PNP: Requires negative voltage at base (relative to emitter)
3. **Common Usage**
   - NPN: More commonly used in general electronics
   - PNP: Often used in specific applications or complementary circuits

Key points students might make

For NPN advantages

- More widely available and used
- Often cheaper due to manufacturing processes
- Better switching speeds in many applications
- Works well with positive-ground systems
- Common in digital electronics

For PNP advantages

- Better for high-side switching applications
- Can be advantageous in certain power management circuits
- Sometimes better noise characteristics in specific applications
- Useful in complementary push-pull configurations
- Can simplify some circuit designs

Component	Mark Level	What to Look For
Technical Understanding[2 marks]	*2 marks*	*• Demonstrates accurate understanding of both PNP and NPN transistors• Correctly explains how each type works• Describes technical differences between types• Uses proper terminology (emitter, base, collector, etc.)• Shows understanding of current flow direction in each type*
	1 mark	*• Shows basic understanding of transistor types* *• Some technical inaccuracies present* *• Limited explanation of differences* *• Some correct terminology used*
Circuit Configuration Analysis *[2 marks]*	*2 marks*	*• Clearly explains circuit configurations for chosen type* *• Discusses how components are arranged differently* *• Compares power supply connections (positive/negative)* *• Explains signal path through circuit* *• Shows understanding of practical circuit design*

	1 mark	*• Basic explanation of circuit configurations* *• Some understanding of component arrangements* *• Limited comparison of power connections* *• Some understanding of signal path*
Biasing & Power Consumption [2 marks]	*2 marks*	*• Correctly explains biasing requirements for each type* *• Compares power consumption characteristics* *• Discusses efficiency considerations* *• Explains standby current differences* *• Shows understanding of power management issues*
	1 mark	*• Basic explanation of biasing* *• Some comparison of power characteristics* *• Limited discussion of efficiency* *• Some understanding of power issues*
Application Suitability[2 marks]	*2 marks*	*• Makes specific connections between transistor type and application* *• Explains why chosen type is better for specific use case* *• Discusses practical considerations (size, heat, reliability)* *• Shows understanding of application requirements* *• Provides logical reasoning for recommendations*
	1 mark	*• Some connection between type and application* *• Limited explanation of suitability* *• Some practical considerations mentioned* *• Basic understanding of requirements* *• Some logical reasoning provided*
Supporting Examples *[1 mark]*	*1 mark*	*• Provides specific, relevant examples of devices using chosen type* *• Examples are accurate and appropriate* *• Shows understanding of real-world applications* *• Connects examples to technical advantages* *• Demonstrates research beyond basic knowledge*
Response to Opposition[2 marks]	*2 marks*	*• Effectively addresses opposing arguments• Shows understanding of opposing position• Provides specific counter-arguments• Defends position with technical reasoning• Remains respectful while challenging opposing views*
	1 mark	*• Some response to opposing arguments• Limited understanding of opposing position • Basic counter-arguments provided• Some defense of a position• Generally respectful approach*

Debate Skills[1 mark]	*1 mark*	*• Clear, organised presentation* *• Logical progression of arguments* *• Effective use of speaking time* *• Engages audience with presentation style* *• Collaborative teamwork evident* *• Respectful participation in debate format*

Question 2Verification Guide

Basic transistor amplifier concepts

1. **Transistor types**
   - NPN: Most common type, activated by positive voltage at base
   - PNP: Less common, activated by negative voltage at base
   - Both have three terminals: Emitter (E), Base (B), and Collector (C)
2. **Basic amplifier circuit components**
   - Transistor (PNP or NPN)
   - Input connection (usually to base through a resistor)
   - Output connection (usually from collector)
   - Biasing resistors (to set proper operating point)
   - Power supply connection
   - Load resistor (where amplified signal appears)
3. **How amplification works**
   - A small current at the base controls a much larger current between collector and emitter
   - This creates a larger output signal than the input signal
   - Gain = Output signal ÷ Input signal

What to look for in diagrams

- For NPN: Arrow on emitter points OUT from base
- For PNP: Arrow on emitter points IN toward base
- Base connection should have input signal and biasing
- Collector should connect to power supply through resistor
- Emitter typically connects to ground (NPN) or power (PNP)

Signs of working amplification

- Output signal should be larger than input signal
- Shape of output should generally follow input (might be inverted)
- Student should provide measurements showing amplification

Component	Mark Level	What to Look For
Circuit Design & Construction [2 marks]	*2 marks*	*• Successfully designs either PNP or NPN transistor amplifier • Circuit includes all necessary components: – Transistor (clearly identified as PNP or NPN) – Input and output connections – Biasing resistors – Power supply connection – Load resistor• Design is functional (simulated or constructed)• Shows understanding of amplifier configuration*
	1 mark	*• Basic design with some component errors or omissions• Most required components present • Some connection issues• Partially functional design• Shows basic understanding with some misconceptions*
Circuit Diagram [2 marks]	*2 marks*	*• Provides clear, neat circuit diagram• All components properly labelled• Component values clearly indicated• Shows input and output points• Correct transistor symbol with proper orientation• Shows power supply connections• Professionally presented*
	1 mark	*• Basic diagram provided but with limited labels• Some components unlabelled• Some values missing• Basic presentation with some errors• Transistor symbol present but with orientation issues*
Amplifier Working Principle[2 marks]	*2 marks*	*• Clearly explains how transistor amplifies signal• Describes how small base current controls larger collector current• Explains biasing and its purpose• Describes signal path through circuit• Shows understanding of transistor as current-controlled device• Uses correct terminology (emitter, base, collector)*
	1 mark	*• Basic explanation of amplification• Some understanding of transistor function• Limited explanation of biasing• Some terminology used correctly*
Signal Amplification Demonstration[2 marks]	*2 marks*	*• Clearly shows input and output signals• Demonstrates measurable amplification• Provides specific voltage values for input and output• Calculates gain (output/input ratio)• May include oscilloscope screenshots or measurements• Shows understanding of amplification measurement*
	1 mark	*• Shows some evidence of amplification• Limited comparison of input and output• Some measurements provided• Limited calculation of gain• Basic understanding demonstrated*
Circuit Type Identification[1 mark]	*1 mark*	*• Correctly identifies amplifier as PNP or NPN• Explains why that type was chosen• Shows understanding of difference between types• Mentions polarity considerations*
Process Reflection [1 mark]	*1 mark*	*• Thoughtfully reflects on difficulties encountered• Identifies specific challenges (component selection, biasing, etc.)• Explains how challenges were addressed• Shows learning from the process• Reflection is honest and insightful*

WEEK 23

Question 1

Verification Guide

Basic darkness detector circuit components and functions

1. **Light Sensor (LDR - Light Dependent Resistor)**
   - Resistance increases in darkness, decreases in light
   - Forms part of a voltage divider circuit
   - Acts as the “eyes” of the circuit, detecting light levels
2. **Transistor**
   - Acts as a switch or amplifier
   - When LDR is in darkness (high resistance), transistor turns ON
   - When LDR is in light (low resistance), transistor turns OFF
   - Controls the flow of current to the output device
3. **Resistors**
   - Fixed resistors set the sensitivity threshold
   - Form voltage divider with LDR
   - Limit current to protect LED or other components
   - Determine how dark it needs to be before circuit activates
4. **Variable Resistor (optional)**
   - Allows adjustment of sensitivity
   - Used to calibrate when the circuit triggers
   - Helps adapt to different environments
5. **Output Device**
   - LED light (most common)
   - Buzzer or alarm
   - Relay to control larger devices
   - Turns on when darkness is detected
6. **Power Supply**
   - Battery or power adapter
   - Provides voltage needed to operate circuit
   - Typically 3-12 V depending on design

Circuit operation: When light levels drop, the LDR›s resistance increases. This changes the voltage at the transistor›s base, causing it to switch on. When the transistor switches on, it allows current to flow to the output device (LED/buzzer), activating it.

Component	Mark Level	What to Look For
Overall Working Principle[2 marks]	*2 marks*	*• Clearly explains that circuit detects low light levels• Describes how circuit triggers an output (light/buzzer/etc.) in darkness • Explains that circuit uses a light-sensitive component to detect changes• Mentions that circuit compares light level to a threshold• Shows understanding of automatic operation*
	1 mark	*• Basic explanation of darkness detection• Limited description of triggering mechanism• Some understanding of light sensitivity*
Light Sensor Component [2 marks]	*2 marks*	*• Identifies and describes light-dependent resistor (LDR) or phototransistor• Explains how resistance changes with light level (increases in darkness)• Describes physical principle of operation• Explains placement in voltage divider or sensing circuit• Shows understanding of sensor's role in detection*
	1 mark	*• Identifies light sensor with limited description• Some explanation of light-resistance relationship• Limited understanding of operation• Basic explanation of sensor's role*
Transistor Function[2 marks]	*2 marks*	*• Identifies transistor as switching element• Explains how transistor amplifies small current changes• Describes how base current controls larger collector-emitter current• Explains transistor's role in activating output device• Shows understanding of threshold behaviour*
	1 mark	*• Identifies transistor with limited explanation• Some understanding of switching function• Basic explanation of current control• Limited description of output activation*
Resistor Functions[2 marks]	*2 marks*	*• Explains role of various resistors in the circuit• Describes how resistors set sensitivity/threshold• Explains current-limiting function for LED/output• Describes voltage divider arrangement with LDR • Shows understanding of resistor value selection*
	1 mark	*• Basic explanation of some resistor functions• Limited understanding of threshold setting• Some explanation of current limiting• Basic understanding of voltage division*
Output Component[1 mark]	*1 mark*	*• Identifies and describes output device (LED, buzzer, relay, etc.)• Explains how output is activated by transistor• Describes power requirements for output• Shows understanding of output component selection*
Power Supply [1 mark]	*1 mark*	*• Mentions power supply requirements• Describes appropriate voltage range• Shows understanding of power connections• May mention battery vs. mains options*
Variable Resistor (if included)[1 mark]	*1 mark*	*• Explains role of potentiometer/variable resistor• Describes how it adjusts sensitivity threshold• Shows understanding of manual calibration• Explains placement in circuit*
Circuit Operation Sequence[1 mark]	*1 mark*	*• Describes sequence of operation from light change to output• Explains cause-and-effect relationship between components• Shows understanding of signal flow through circuit• Presents logical operational sequence*

Question 2Verification Guide

What a basic darkness detector circuit should include:

1. **Components**
   - LDR (Light Dependent Resistor)
   - Transistor (usually NPN type like BC547, 2N2222, etc.)
   - Fixed resistor (typically 10kΩ) forming voltage divider with LDR
   - LED (any colour)
   - Current-limiting resistor for LED (typically 220Ω-1kΩ)
   - Power source (battery or power supply, 3-12V)
   - Optional: variable resistor to adjust sensitivity
2. **Correct Circuit Configuration**
   - LDR and fixed resistor forming voltage divider
   - Voltage divider connected to transistor base
   - Transistor collector connected to LED via current-limiting resistor
   - Transistor emitter connected to ground
   - LED connected to positive power supply
   - All components properly connected to power and ground
3. **Expected Behaviour**
   - In bright light: LED should be off
   - In darkness: LED should turn on
   - There should be a specific light threshold where switching occurs

Testing to look for

- Testing in bright light (LED should be off)
- Testing in dim light (may be on or off depending on circuit sensitivity)
- Testing in darkness (LED should be on)
- Testing the transition point (finding when LED switches on/off)

Component	Mark Level	What to Look For
Circuit Design[2 marks]	*2 marks*	*• Creates functional darkness detector circuit• Includes all necessary components: – LDR (Light Dependent Resistor) – Transistor (NPN or PNP with correct orientation) – Resistors with appropriate values – LED with current–limiting resistor – Power source• Components connected correctly • Design shows understanding of circuit principles*
	1 mark	*• Basic circuit with some errors or omissions• Most required components present• Some connection issues• Circuit partially functional• Limited understanding of design principles*
Circuit Diagram[2 marks]	*2 marks*	*• Provides clear, neat circuit diagram• All components properly labelled• Component values clearly indicated• Correct symbols used for all components• Shows all connections accurately• Professional presentation*

	1 mark	*• Basic diagram with some labelling issues• Some component values missing• Some symbol or connection errors• Generally understandable but with flaws• Adequate presentation*
Working Principle Explanation[2 marks]	*2 marks*	*• Clearly explains how LDR resistance changes with light• Describes voltage divider action between LDR and resistor• Explains how transistor switches based on base voltage• Describes how LED is activated in darkness• Shows understanding of complete signal path• Explains threshold behaviour*
	1 mark	*• Basic explanation of light detection• Some understanding of resistance changes• Limited explanation of transistor action• Some description of LED activation*
Testing Procedure [2 marks]	*2 marks*	*• Tests circuit under at least three different lighting conditions• Describes specific test conditions (e.g., bright light, dim light, darkness) • Records observations systematically• Describes LED response for each condition• Tests sensitivity threshold (when LED turns on/off)• Shows thorough testing approach*
	1 mark	*• Tests circuit under limited conditions• Vague description of test conditions• Limited observations recorded• Basic description of LED response• Limited testing of sensitivity• Basic testing approach*
Results Reporting [1 mark]	*1 mark*	*• Clearly describes how LED responds to different light levels• Notes transition point between on and off states• Describes brightness changes if applicable• Reports results in organised manner• Includes specific observations*
Design Reflection[1 mark]	*1 mark*	*• Honestly evaluates effectiveness of design• Identifies specific strengths and weaknesses• Provides thoughtful analysis of performance• Shows understanding of design limitations• Reflection shows critical thinking*

WEEK 24

Question 1

Verification Guide

Key concepts about voltage regulation in battery charging

1. **Basic concept**
   - Voltage regulation keeps voltage at a specific level regardless of input fluctuations
   - Batteries require specific voltage ranges for proper charging
   - Too high or too low voltage can damage batteries
2. **Overcharging problems (too high voltage)**
   - Excessive heat generation
   - Electrolyte loss/gassing (especially in lead-acid batteries)
   - Internal damage to battery cells
   - Reduced battery life
   - Safety hazards (leaking, swelling, or in extreme cases, fire/explosion)
3. **Undercharging problems (too low voltage)**
   - Incomplete charging

- Formation of sulphate crystals in lead-acid batteries
- Reduced capacity
- Shortened battery life

4. **Different battery types need different voltages**
   - Lead-acid: ~14.4V for a 12V battery
   - Lithium-ion: ~4.2V per cell (8.4V for 2-cell, 12.6V for 3-cell)
   - NiMH/NiCd: ~1.4-1.6V per cell
5. **Charging stages274**
   - Most batteries charge in multiple stages with different voltage requirements
   - Initial bulk charging (higher current, lower voltage)
   - Absorption charging (rising voltage, decreasing current)
   - Float/maintenance charging (lower voltage to maintain full charge)

Component	Mark Level	What to Look For
Basic Concept of Voltage Regulation [2 marks]	*2 marks*	*• Clearly defines voltage regulation as maintaining consistent voltage• Explains that regulators prevent voltage fluctuations• Describes how regulators compensate for input variations• Shows understanding that batteries require specific voltage ranges • May mention types of voltage regulators (linear, switching)*
	1 mark	*• Basic definition of voltage regulation• Limited explanation of fluctuation prevention• Some understanding of battery voltage requirements• Limited technical understanding*
Overcharging Prevention[2 marks]	*2 marks*	*• Explains that excessive voltage causes overcharging• Describes specific consequences of overcharging: – Battery overheating – Gas production/electrolyte loss – Reduced battery capacity – Shortened battery life – Potential safety hazards (leakage, explosion)• Shows understanding of chemical processes involved• Explains how voltage regulation prevents these issues*
	1 mark	*• Basic explanation of overcharging• Mentions some consequences• Limited understanding of battery chemistry• Some connection to voltage regulation*
Undercharging Prevention[2 marks]	*2 marks*	*• Explains that insufficient voltage causes undercharging• Describes consequences of undercharging: – Incomplete charge – Sulfation in lead-acid batteries – Reduced capacity – Shortened battery life• Shows understanding of minimum voltage requirements• Explains how voltage regulation ensures adequate charging*
	1 mark	*• Basic explanation of undercharging• Mentions some consequences• Limited understanding of voltage thresholds• Some connection to voltage regulation*

Charging Efficiency [2 marks]	*2 marks*	*• Explains how proper voltage improves charging efficiency• Describes relationship between voltage and charging current• Explains concept of optimal charging voltage• Shows understanding of energy conversion efficiency• May mention reduced heat generation and energy waste*
	1 mark	*• Basic explanation of efficiency• Limited understanding of voltage–current relationship• Some mention of optimal charging* *• Limited technical detail*
Battery Type Considerations[2 marks]	*2 marks*	*• Explains that different battery types require different charging voltages• Provides specific voltage ranges for common battery types: – Lead–acid (~14.4V for 12V battery) – Lithium–ion (~4.2V per cell) – NiMH (~1.4–1.6V per cell)• Explains why these differences exist• Shows understanding of battery chemistry variations*
	1 mark	*• Mentions different battery types need different voltages• Limited specific voltage information• Some understanding of battery differences• Limited technical detail*
Charging Stages [2 marks]	*2 marks*	*• Explains that proper charging involves multiple voltage stages• Describes common charging stages: – Bulk/constant current (initial charging) – Absorption/constant voltage (later charging) – Float/maintenance (fully charged)• Explains how voltage regulation adapts to these stages• Shows understanding of complete charging cycle*
	1 mark	*• Basic mention of charging stages• Limited description of different stages• Some understanding of voltage changes during charging• Limited technical detail*

Question 2

Verification Guide

What a basic battery charger circuit should include

1. **Four Essential Stages**
   - **Transformer Stage:** Steps down household AC voltage (e.g., 240V or 120V) to lower AC voltage
   - **Rectifier Stage:** Converts AC to pulsating DC using diodes (usually bridge rectifier)
   - **Filter Stage:** Smooths pulsating DC using capacitors
   - **Regulator Stage:** Stabilises voltage to appropriate level for battery (6V or 12V)
2. **Key Components**
   - Step-down transformer
   - Four diodes (bridge rectifier) or two diodes (centre-tapped)
   - Large filter capacitor (typically 1000µF or higher)
   - Voltage regulator (LM7806 for 6V or LM7812 for 12V)
   - Current-limiting resistor or circuit
   - Optional indicators (LED to show charging)

3. **Expected Output**
   - For 6V battery: Stable DC output around 6.9-7.2V (slightly higher than battery voltage)
   - For 12V battery: Stable DC output around 13.8-14.4V (slightly higher than battery voltage)
   - Limited charging current (should not be excessive)

Safety features to look for

- Current limiting to prevent excessive charging current
- Voltage regulation to prevent overcharging
- Possibly temperature monitoring
- Proper isolation from mains voltage

Component	Mark Level	What to Look For
Circuit Design[2 marks]	*2 marks*	*• Creates functional battery charger circuit• Includes all necessary stages: – Step-down transformer or equivalent – Rectifier (bridge or centre-tapped) – Filter capacitor(s) – Voltage regulator – Current limiting component• Components connected correctly• Design shows understanding of charging principles• Output voltage appropriate for stated battery (6V or 12V)*
	1 mark	*• Basic circuit with some stage errors or omissions• Most required stages present• Some connection issues• Circuit partially functional• Output voltage inappropriate or unsafe• Limited understanding of charging principles*
Circuit Diagram [2 marks]	*2 marks*	*• Provides clear, neat circuit diagram• All components properly labelled• Component values clearly indicated• Correct symbols used for all components• Shows all connections accurately • Professional presentation*
	1 mark	*• Basic diagram with some labelling issues• Some component values missing• Some symbol or connection errors• Generally understandable but with flaws• Adequate but unprofessional presentation*
Transformer Stage Explanation [1 mark]	*1 mark*	*• Correctly explains transformer's role in reducing AC voltage• Describes turns ratio relationship to voltage reduction• Explains isolation function for safety• Shows understanding of appropriate voltage levels• May mention VA rating or current capabilities*
Rectifier Stage Explanation[1 mark]	*1 mark*	*• Correctly explains rectifier's role in converting AC to DC• Describes diode configuration (bridge or centre-tapped)• Explains one-way current flow through diodes• Shows understanding of full-wave rectification• May mention voltage drop across diodes*
Filter Stage Explanation[1 mark]	*1 mark*	*• Correctly explains capacitor's role in smoothing DC• Describes how capacitor charges and discharges• Explains reduction of ripple voltage• Shows understanding of capacitor value selection• May mention ripple frequency or filtering effectiveness*

Regulator Stage Explanation[1 mark]	*1 mark*	*• Correctly explains regulator's role in stabilising voltage• Describes how regulator maintains constant output• Explains protection from voltage fluctuations• Shows understanding of appropriate regulator selection• May mention heat dissipation or efficiency considerations*
Testing Procedure & Results[2 marks]	*2 marks*	*• Tests circuit with appropriate input voltage• Measures output voltage and confirms it matches battery requirements• May measure or discuss charging current• Records observations systematically• Confirms stable operation under various conditions• Shows thorough testing approach*
	1 mark	*• Tests circuit with limited conditions• Basic measurement of output voltage• Limited discussion of charging current• Basic observations recorded• Limited testing of stability • Basic testing approach*
Safety Considerations [1 marks]	*1 mark*	*• Identifies specific safety features in design• Describes how circuit prevents overcharging• Mentions current limiting or thermal protection• Shows understanding of battery charging hazards• Discusses electrical safety considerations*
Improvement Reflection[1 mark]	*1 mark*	*• Suggests specific, relevant improvements• Discusses efficiency enhancements• Proposes additional safety features• Shows understanding of circuit limitations• Reflection demonstrates critical thinking*

REFERENCES

- All About Circuits. (n.d.-a). *Eddy current loss in a solid core* [Image]. https://www.allaboutcircuits.com/uploads/articles/eddy-current-loss-what-it-is-and-how-to-reduce-it-with-laminated-cores-fig1.jpg
- All About Circuits. (n.d.-b). *Eddy current loss reduction with laminated cores* [Image]. https://www.allaboutcircuits.com/uploads/articles/eddy-current-loss-what-it-is-and-how-to-reduce-it-with-laminated-cores-fig2.jpg
- Alternative Assessment. (2016, July). *Thermal expansion demonstration with ball and ring apparatus* [Image]. https://alternativeassessment.wordpress.com/wp-content/uploads/2016/07/a1m6l4rimage3.jpg
- ApogeeWeb. (2020, July 13). Circuit diagram with resistors and components [Image]. https://www.apogeeweb.net/upload/image/20200713/2020071314353359.jpg
- Bartleby. (2021, August 3). *Gravitation: Gravitational force and Newton's law of gravitation*. https://cms-media.bartleby.com/wp-content/uploads/sites/2/2021/08/03062724/Gravitation-Gravitational-Force-and-Newton_s-Law-of-Gravitation-2.jpg
- Bartleby. (2021, June 30). *Simple pendulum diagram* [Image]. https://cms-media.bartleby.com/wp-content/uploads/sites/2/2021/06/30073249/Simple-Pendulum-2.png
- BBC Bitesize. (n.d.). *Centre of mass and stability*. BBC. https://www.bbc.co.uk/bitesize/articles/z96g3j6#zs8h6g8
- BBC Bitesize. (n.d.). *Diagram showing factors affecting stability*. https://bam.files.bbci.co.uk/bam/live/content/zmxqwnb/large
- Blog UPS Battery Center. (2023, March). *Inside a typical lead-acid battery* [Image]. https://blog.upsbatterycenter.com/wp-content/uploads/2023/03/Drawing-What-is-Inside-a-Typical-Lead-Acid-Battery-Open-Stax-BY-CC-4.0-International-702x459.png
- Blogger. (n.d.). *Transformer with laminated core* [Image]. https://blogger.googleusercontent.com/img/b/R29vZ2xl/AVvXsEirQxDjZH2K2dJZ7E2y5PV4XWjl6i5ZAEeBX2a536IXUh8709GPBfV67PNEUC5yM4GbQqMC3-AydR2qwvgt6IuWzYtVGwClk63XGHyYVyuYVBBwOlo3dVlQUtaXDWTxqcNvLV4bNFbjPfs/s16000/transformer.webp
- CalcKit. (n.d.). *Power triangle* [Image]. https://calckit.io/tool_assets/electronics/power-triangle/power-triangle.png
- CDN Tardigrade. (n.d.). Physics question diagram on resistors [Image]. https://cdn.tardigrade.in/img/question/physics/fe957c36656896b6bcf372061d74501e-.jpeg
- Cloudfront. (n.d.). *Magnetic core with field lines* [Image]. https://d1yqpar94jqbqm.cloudfront.net/styles/media_full/s3/images/b15d6646a93d00d04bcc9c06c0ee827c3cd3f86a.jpg?itok=EnkfM8ox
- Components Info. (2022, October). *NPN vs. PNP transistor* [Image]. https://www.componentsinfo.com/wp-content/uploads/2022/10/npn-vs-pnp-transistor-807x1024.gif
- ElectricalWorkbook. (n.d.). *What is RC series circuit? Circuit diagram, phasor diagram, derivation & formula*. https://electricalworkbook.com/what-is-rc-series-circuit-circuit-diagram-phasor-diagram-derivation-formula/

- Electronics Tutorials. (2018, May). *AC circuit showing current and voltage waveforms* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp2.gif
- Electronics Tutorials. (2018, May). *AC power triangle representation* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp154a.gif
- Electronics Tutorials. (2018, May). *Impedance triangle and phasor diagram* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp119.gif
- Electronics Tutorials. (2018, May). *Phasor diagram for an AC circuit (resistor + capacitor)* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp79.gif
- Electronics Tutorials. (2018, May). *Phasor diagram of RL circuit (basic)* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp92.gif
- Electronics Tutorials. (2018, May). *Phasor diagram of RL circuit (with power factor)* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp93.gif
- Electronics Tutorials. (2018, May). *Phasor diagram of series RLC circuit* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp94.gif
- Electronics Tutorials. (2018, May). *Series RLC impedance and power factor triangle* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp120.gif
- Electronics Tutorials. (2018, May). *Series RLC phasor triangle with power* [Image]. https://www.electronics-tutorials.ws/wp-content/uploads/2018/05/accircuits-acp121.gif
- Engineers Garage. (2021, June). *Nickel-cadmium battery diagram* [Image]. https://www.engineersgarage.com/wp-content/uploads/2021/06/Nickel-Cadmium-Battery.png
- Fictiv. (2023, March). *Bimetallic strip* [Image]. https://www.fictiv.com/wp-content/uploads/2023/03/bimetallic-strip.jpeg.webp
- GeeksforGeeks. (2024, July 30). *Parts of a convex lens* [Image]. https://media.geeksforgeeks.org/wp-content/uploads/20240730111712/Parts-of-convex-lens.png
- GeeksforGeeks. (2024, March 7). *Convex lens image 1* [Image]. https://media.geeksforgeeks.org/wp-content/uploads/20240307184722/Convex-lens-1.png
- GeeksforGeeks. (2024, March 7). *Convex lens image 4* [Image]. https://media.geeksforgeeks.org/wp-content/uploads/20240307184915/Convex-lens-4.png
- GeeksforGeeks. (2024, March 7). *Convex lens image 5* [Image]. https://media.geeksforgeeks.org/wp-content/uploads/20240307185118/Convex-lens-5.png
- GeeksforGeeks. (2024, March 7). *Convex lens image 6* [Image]. https://media.geeksforgeeks.org/wp-content/uploads/20240307185220/Convex-lens-6.png
- GeeksforGeeks. (2024, March 7). *Types of convex lens* [Image]. https://media.geeksforgeeks.org/wp-content/uploads/20240307185319/Types-of-Convex-lens.png
- https://infographicsite.com/infographic/history-of-the-universe-timeline/
- ICRFQ. (2023, April). Electrical components and connections diagram [Image]. https://www.icrfq.net/wp-content/uploads/2023/04/wps_doc_1-2.png
- IECPL. (n.d.). Rheostat image from IECPL [Image]. https://www.iecpl.com.au/images/products//878/878-main.jpg
- Ilee, John D, Cassandra Hall, Catherine Walsh, Izaskun Jiménez-Serra, Christophe Pinte, Jason Terry, Tyler L Bourke, and Melvin Hoare. “Observing Protoplanetary Discs with the Square

Kilometre Array – I. Characterising Pebble Substructure Caused by Forming Planets." *Monthly Notices of the Royal Astronomical Society* 498, no. 4 (September 30, 2020): 5116–27. https://doi.org/10.1093/mnras/staa2699.

- IQS Directory. (n.d.). *Inductor coil component* [Image]. https://www.iqsdirectory.com/articles/electric-coil/inductors-and-inductor-coils/inductor.jpg
- Okwei, E T-O, A Forson, E Proven-Adzri, K Ahenkora-Duodu, J Kalognia, S Abotsi-Masters, and F Andorful. "Promoting Radio Astronomy in Ghana through School Visits and Astronomy Clubs." *Physics Education* 57, no. 5 (September 1, 2022): 055033. https://doi.org/10.1088/1361-6552/ac832b.
- PCBoard.ca. (n.d.). Resistor colour code chart [Image]. https://www.pcboard.ca/image/cache/catalog/special_pages/dropping_resistor/resistor-color-chart-800x800.jpg
- Physics Catalyst. (n.d.). *AC circuit waveform diagram* [Image]. https://physicscatalyst.com/elecmagnetism/fig3_ac.png
- Physics Max. (n.d.). *To locate centre of gravity by means of a plumbline*. https://physicsmax.com/to-locate-centre-of-gravity-by-means-of-a-plumbline-5966
- Physics Wallah. (n.d.). *Simple harmonic motion, dynamics, velocity and acceleration – important topics for JEE 2024* [Blog post image]. https://static.pw.live/5eb393ee95fab7468a79d189/GLOBAL_CMS_BLOGS/dd331ad2-7cae-4aaf-aa0d-58b4dc3d01d4.jpg
- Power Electronics News. (2020, September 21). *Tester circuit diagram* [Image]. https://www.powerelectronicsnews.com/wp-content/uploads/sites/3/2020/09/figure-02-tester-20200921.jpg?w=1000
- Q S Study. (2016, April). Potentiometer circuit image [Image]. https://qsstudy.com/wp-content/uploads/2016/04/a1-23.jpg
- Radiology Key. (2021, May). *Cross-sectional view of nuclear imaging device* [GIF]. https://radiologykey.com/wp-content/uploads/2021/05/C6-FF1.gif
- ResearchGate. (2015). *Basic components of a laser system* [Image]. https://www.researchgate.net/profile/Asloob-Mudassar/publication/281235580/figure/fig1/AS:391582953033730@1470372059328/Figure-Q21-Scheme-showing-basic-components-of-a-laser-system.png
- Save My Exams. (n.d.). *Geostationary orbit satellite*. https://cdn.savemyexams.com/cdn-cgi/image/f=auto,width=1920/https://cdn.savemyexams.com/uploads/2020/10/13.1.2.6-Geostationary-orbit-satellite.png
- School Physics. (n.d.). *Stability*. https://www.schoolphysics.co.uk/age11-14/Mechanics/Statics/text/Stability_/index.html
- Schulz, Norbert S. *The Formation and Early Evolution of Stars*. Astronomy and Astrophysics Library. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012. https://doi.org/10.1007/978-3-642-23926-7.
- Shivsons. (2017, December). Analog voltmeter equipment image [Image]. https://www.shivsons.com/wp-content/uploads/2017/12/PH50450.jpg
- Sokol Blosser. (2021, April). *John Cameron – Vineyard image* [Image]. https://sokolblosser.com/wp-content/uploads/2021/04/john-cameron-F_EooJ3-uTs-unsplash-2048x814.jpg
- Springer Nature. (n.d.). *Optical ray diagram from physics text* [Image]. https://media.springernature.com/lw685/springer-static/image/chp%3A10.1007%2F978-3-319-99895-4_2/MediaObjects/73261_1_En_2_Fig2_HTML.png

- Unacademy. (2022, February). Potentiometer working principle diagram [Image]. https://unacademy.com/content/wp-content/uploads/sites/2/2022/02/potentiometer.png
- Unknown Author. (n.d.). *Damped SHM waveform from Googleusercontent* [Image]. https://lh7-us.googleusercontent.com/1EeWHPEYNCVNgZfAPxaZxHTz3vJWz7HwZJ5l8KFRXG_iCzTucHG6nLbGLsB4GWfo2nORlM-eOUDRmRpEyPh9SSboHH3Fyqjsya-1EYZeemP-5BrZRC8xJgwNoo5jyNOt1v1RF8Ggy4m65uMcGFHRyQ
- Vedantu. (n.d.). *Centre of gravity multiple choice question*. https://www.vedantu.com/question-sets/f803e72d-58bf-40f4-ae4d-41c11376200e2926111568069723779.png
- Vedantu. (n.d.). *Electromagnetic induction concept illustration* [Image]. https://www.vedantu.com/question-sets/663c52eb-f2f6-4382-88cd-149832715cf95140788638862031652.png
- Vedantu. (n.d.). *Lens diagram from question set* [Image]. https://www.vedantu.com/question-sets/a755dad4-e66f-4dd8-b2e7-503c73ef65512189055832502388880.png
- Wikimedia Commons. (n.d.). *Magnox reactor schematic* [Image]. https://upload.wikimedia.org/wikipedia/commons/thumb/1/10/Magnox_reactor_schematic.svg/525px-Magnox_reactor_schematic.svg.png
- WSIMG. (n.d.). *Transformer labelled diagram* [Image]. https://img1.wsimg.com/isteam/ip/bff1d4f7-4d2c-4fc3-a79b-6a5750f3ab2d/pic%201-bd1319f.png/:/rs=w:1280
- X-Engineer. (2017, December). *Areal thermal expansion* [Image]. https://x-engineer.org/wp-content/uploads/2017/12/Areal-thermal-expansion.jpg
- X-Engineer. (2017, December). *Linear thermal expansion* [Image]. https://x-engineer.org/wp-content/uploads/2017/12/Linear-thermal-expansion.jpg
- X-Engineer. (2017, December). *Particles expansion and contraction* [Image]. https://x-engineer.org/wp-content/uploads/2017/12/Particles-expansion-contraction.jpg
- X-Engineer. (2017, December). *Thermal expansion – volume* [Image]. https://x-engineer.org/wp-content/uploads/2017/12/Thermal-expansion-volume.jpg
- Xaktly. (n.d.-a). *Elastic collision diagram* [Image]. https://xaktly.com/Images/Physics/Momentum/ElasticCollisionFigure.png
- Xaktly. (n.d.-b). *Inelastic collision diagram* [Image]. https://xaktly.com/Images/Physics/Momentum/InelasticCollisionFigure.png