Physics

Teacher Guide
Grade 10

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Introduction to the Teacher's Guide

Some general aims of physics education

Physics is an important subject that contributes to the development of our country in many ways. A knowledge and understanding of physics helps students to understand the world and appreciate how it works. It contributes to a society that benefits from this understanding, and produces people who realise how the environment can be exploited in a sustainable way for the benefit of society. It prepares students for employment, both in a general way and as a preparation for careers that require knowledge of the subject, such as engineering or communications. However, a study of physics does not just mean learning facts. Physics, as with the other sciences, requires the student to develop problem-solving skills.

The Secondary physics curriculum takes a competency-based, active learning approach, underpinned by three broad outcomes: knowledge, values and attitudes, and skills. The Students' Book and Teacher's Guide places emphasis on learner-centred classroom and field activities, not only to help students to acquire knowledge, but also to develop problem-solving and decision-making skills, as well as a good attitude to society and the world around us.

The teacher must make the students aware that science is a dynamic activity, a body of knowledge that constantly grows and is modified by experimentation. He or she can utilise new approaches to teaching and learning, involving a range of teaching styles, along with practical activities and field work, summarised in the 'Teaching Methods' section below.

General objectives of the Grade 10 physics course

When students have completed Grade 10 physics they should:

- Understand the motion of objects in horizontal, vertical, and inclined planes, and with reference to the forces acting on the objects; the laws of conservation of energy and of momentum for objects moving in one and two dimensions
- Develop basic manipulative skills to investigate motion in a plane, and solve problems involving the forces acting on an object in linear, projectile, and circular motion, with the aid of vectors, graphs, and free-body diagrams
- Understand the concepts of electrical, gravitational, and magnetic fields; electromagnetic radiation; electromagnetic induction, and the interface between energy and matter, the common applications of electrical and electronic circuits, and the function and configuration of the components used in circuits
- Develop skills in using measuring instruments and familiar electrical devices; constructing simple electrical circuits using common tools appropriately and safely
- Appreciate the applications of electrical and electronic technologies to the community

Each unit of study has specific learning competencies, and these are listed at the beginning of each unit in both the Students' Book and the Teacher's Guide, providing a useful checklist for both students and teachers.

Teaching methods

The subject content can be delivered in different ways in order to achieve the specific objectives. The type of teaching method used will affect the skills and attitudes that the students develop. The teacher will want to use the most effective methods for teaching a particular topic. In Physics, it is recommended that the teacher use more than one teaching method in a single lesson – the discussion method might be suitable for the beginning of the lesson, followed by the discovery method, or a practical activity. The strengths and weaknesses of a range of different methods are summarised in the table below:

Method	Strengths and weaknesses
Lecture – content is delivered to students by teacher	Students receive correct factual information from the teacher. Useful to stimulate thinking. Students develop skills such as identification, observation, recording, making predictions, synthesis, analysis and drawing conclusions. Students develop qualities such as self-confidence, curiosity and enquiry. Useful for large numbers of students. Makes students passive because it is one-way communication. Makes learning difficult to assess.
Discovery – teacher guides students to discover scientific facts for themselves	Students develop skills such as identification, observation, recording, making predictions, synthesis, analysis and drawing conclusions. Students develop qualities such as self-confidence, curiosity, interest and co-operation.
Discussion – sharing of ideas between students and teacher	Allows sharing of each other's ideas. Can be useful at start of a lesson to motivate students. Allows everyone to participate actively. A few people may end up dominating the discussion. Not easy to conduct for large classes. Can be time-consuming. Teacher can easily lose track of the argument.
Question and answer – teacher asks questions, students answer. Students also ask questions	Useful for gauging students' understanding or knowledge of fact or concept. Useful for beginning and ending a lesson. Need to ensure sufficient questions are framed to stimulate thinking – closed questions do not achieve this. Can be counterproductive if the teacher asks too many questions.
Problem solving – students are presented with an exercise where they must find an answer to a problem	Students develop skills such as identification, observation, recording, making predictions, synthesis, analysis and drawing conclusions. Students develop desirable qualities such as seeking knowledge, curiosity, enquiry and responsibility. Worked examples in the Students' Book can usefully be presented as problems for students to solve – see notes for each topic for further details. Can waste time if not properly planned and guided.

Assignments – specific task given to students to find out about a particular problem or issue	Students have the opportunity to research a topic and look for information on their own.
Worksheets – handouts to guide students in practical work	Allows students to think for themselves without outside influence. Allows individual ideas to be shared in a group.
Demonstration – teacher carries out practical work if materials/equipment are inadequate or the procedure is too complex or unsafe for students	Students develop skills such as identification, observation, recording, making predictions, synthesis, analysis and drawing conclusions. Students develop desirable qualities such as self-confidence, curiosity, interest and cooperation.
Practical activities – students carry out practical work individually or in groups; students gain hands-on experience *This method is highly recommended and should be used as much as possible.*	Gives teacher an opportunity to develop students' interest in the subject. Teacher has opportunity to interact with students. Teacher provides the standard/expected results for each activity. Can be used with discussion method (during discussion of results). Students develop skills such as identification, observation, collecting, measurement, manipulation, data recording, investigation, making predictions, interpretation, evaluation, synthesis and drawing conclusions. Students develop desirable qualities such as self-confidence, curiosity, interest and co-operation.
Field work – outdoor learning activity	Helps students develop skills such as identification, observation, collecting, measurement, data manipulation, recording, analysis, report writing and verbal reporting. Students appreciate the environment. Can waste time if not properly planned and guided.
Project – short- or long-term investigation	Helps students develop (among others) report-writing, presentation and data-analysis skills. Students develop skills in using scientific methods. Can be time-wasting if not properly planned and guided.
Case study – study carried out on a particular natural environment, then applied to another similar setting	Allows students to apply new knowledge and skills. Allows development of analytical and problem-solving skills. Allows exploration of solutions for seemingly complex problems. Students may not see application to their own situation. Students may get wrong results due to insufficient information.

Schemes of work, lesson plans and records of work

A **scheme of work** is a plan for how the topics in the syllabus will be covered over the course of the year. The scheme should be based on the Secondary Biology syllabus. The construction of a scheme of work is an important role of a teacher. In this Teacher's Guide, a sequence of activities is suggested for each topic. However, it may be necessary to vary this sequence from one school to another depending on factors such as funding, laboratory facilities, seasonal availability of teaching materials and time available for teaching, in addition to teacher preferences.

An effective scheme can be developed and modified over a period of time, improving it from year to year as a result of teachers' experience. Schemes of work should always be prepared at the beginning of the school year. It is easier to keep soft copies that can be updated when necessary.

A **lesson plan** acts as a guide for the teacher, outlining the activities that will be carried out in order to achieve the specific objectives of the lesson. Lesson plans are vital to ensure that teaching and learning is focused on objectives to be achieved but teachers should not be afraid to deviate from plans occasionally if necessary for the students. A **record of work** is compiled after every lesson. It is a brief report summarising what has been covered in the lessons. The record of work should note areas of deviations from the lesson plan and reasons for this. Time spent reflecting on a lesson is time well spent since it enables more effective teaching and learning.

It is hoped that the schemes of work and ideas for lesson plans in this Teacher's Guide will motivate teachers to develop their own schemes and lesson plans to suit their preferred teaching methods and resources available in their school.

Each topic in this book contains the following sections:

- learning competencies
- suggested scheme of work for each topic
- guidelines for practical activities
- skills and attitudes to be developed
- answers to questions in the Students' Book

Assessment: tests and examinations

Assessment helps you identify whether learning has occurred, and is part of the teaching and learning process. The syllabus and minimum learning competency documents (included at the back of this teacher guide) give a large number of objectives that students are expected to achieve during the year. The review questions and end-of-unit questions are set to help test these. However, it is unlikely that teachers will be able to test every single objective in a term or year: if we did that, there would be probably little or no time left for teaching! There is in fact a danger that we spend too much time testing and too little time teaching.

We want to avoid this danger; yet at the same time it is important to meet the requirements of the syllabus, which indicate that we should do our best to find out, in one way or another, how far we have achieved the objectives set at the start of a given unit. The answer is that we should carry out continuous assessment. This means that in the course of ordinary classroom teaching, and setting and marking assignments, we need to keep a record of how well the class does.

Continuous assessment helps teachers to ensure that all students have the opportunity to succeed in school – in any class there may be a wide range of abilities or needs, and by using continuous assessment, teachers can adapt their approach to all of them. The teacher should continually observe the students to see what they know and can do. There are many different kinds of assessment activities included in this course: some, like the review questions, ask students to recall information, while others, such as the boxed activities, focus on processes such as analysis, constructing or showing a skill. There is a wide range of approaches that can be used for this, including classroom experiments, field trips, debating, role play, and research projects.

In both continuous assessment and regular testing/exam-setting, teachers should assess all aspects of knowledge and understanding – knowledge, comprehension, application, analysis, synthesis and evaluation.

Knowledge means recalling previously learned information, such as terminology, classifications, sequences and methods. In tests, some of the key words used for this sort of question are: *list, define, describe, label, name.*

Comprehension means understanding the meaning of information. A comprehension question uses key words such as: *summarise, interpret, contrast, predict, distinguish, estimate, discuss.*

Application is the use of previously learned information to solve problems in new situations. It is identified by key words such as: *demonstrate, calculate, complete, illustrate, relate, classify*.

Analysis means the breaking down of information into its component parts, examining and trying to understand such information to develop conclusions by identifying causes, making inferences, and/or finding evidence to support generalisations. Questions contain key words such as: *explain, separate, order, arrange, compare, select, compile*.

Synthesis means applying prior knowledge and skills creatively to produce a new or original thing. Questions contain key words such as: *plan, rearrange, combine, modify, substitute, rewrite*.

Evaluation means judging the value of something based on personal opinion, resulting in a final opinion, with a given purpose, without really right or wrong answers. Students might have to compare and discriminate between ideas, assess the value of some evidence of a theory, or make choices based on a reasoned argument. Examples of key words are: *assess, recommend, convince, select, summaries, criticise, conclude, defend*.

Model lesson plan

Topic: Electric charge
Sub–topic: Charging materials
Duration: 40 minutes
Class: Grade 10
Date: 20 February 2011

Rationale

This is the first lesson in Unit 2: Electrostatics. In this lesson students will learn how the topic relates to their everyday experience and thus motivate them for further exploration in subsequent lessons.

Lesson objectives

By the end of the lesson students should be able to:

- state the law of conservation of charge
- describe and explain how charged bodies attract or repel each other.

Pre–requisite skills and knowledge

- students will need to have studied Unit 1 in order to successfully complete Activity 1.

Teaching/learning resources

- large sheets of paper for students to record ideas
- apparatus shown in Students' Book Figure 2.2

Stage (time)	**Teaching and learning activities**	**Learning points**
Introduction (5 min)	Discuss where students have experienced electrostatics in everyday life as described in Students' Book page 50	Electrostatics is something we experience in everyday life and has important applications. There are also associated hazards of which students should be aware
Development (10 min)	Discuss electric charge: Atoms Positive charge Negative charge [Possible link to students' experience in Chemistry: have they seen diagrams of atoms showing nucleus and electrons?]	Positive and negative charges usually balance each other
	Discuss conservation of charge and how charge cannot be created or destroyed, only transferred	Transfer of charge from one material to another means balance between positive and negative upset and material becomes charged
	Divide class into small groups and give each group piece of paper on which to record ideas. Students should attempt Activity 1. Allow 5 minutes for this and then bring class back together to discuss ideas	There are many physical quantities that are conserved – students should be beginning to understand that physics is not a series of unrelated topics but rather a set of related ideas
	Demonstrate rubbing a piece of Perspex and show how it attracts small pieces of paper	It is possible to charge materials by rubbing them
	Divide the class into small groups (the number in each group will depend on how many sets of apparatus are available) and tell them to carry out Activity 2. The students should discuss and try to explain their observations in the small group before you bring the class back together to summarise the results	Charged bodies attract or repel each other

Summary and conclusion (7 min)	What are the main points that we have learnt in this lesson? Discuss with students and ask them to explain their learning in their own words	Matter consists of atoms, which have positive and negative particles which normally balance each other Conservation of charge Many physical quantities are conserved Materials can be charged by rubbing Charged materials attract or repel each other
Evaluation	Students have opportunity to ask questions and comment on the activity – they may be asked to write a summary of the lesson for homework	

Note taking

During physics lessons, students should be actively involved in their learning. It is important that they develop strategies for recording what they are doing in the lesson which will enable them to revisit the concepts away from the classroom, either to complete assignments or to revise for tests. Practical activities should be recorded in such a way that another person could repeat the activity at a later date (this is the principle on which scientific papers are written and, although we do not need students to go into quite the detail given in such papers, we do want them to begin to learn to record practical work accurately). The following headings are recommended for a practical report:

- Aim of activity
- Apparatus used (with diagram)
- Method
- Results (which may include numerical data, which may be presented as a table and/or graph)

Conclusion

Students should be taught that sometimes results from practical work are not quite as the theory may predict – they should be encouraged to see this as a positive learning experience and be taught that they should never attempt to fit results to the theory but rather explain why their results may not fit the theory (even if the explanation turns out to be that they did not take measurements accurately enough)!

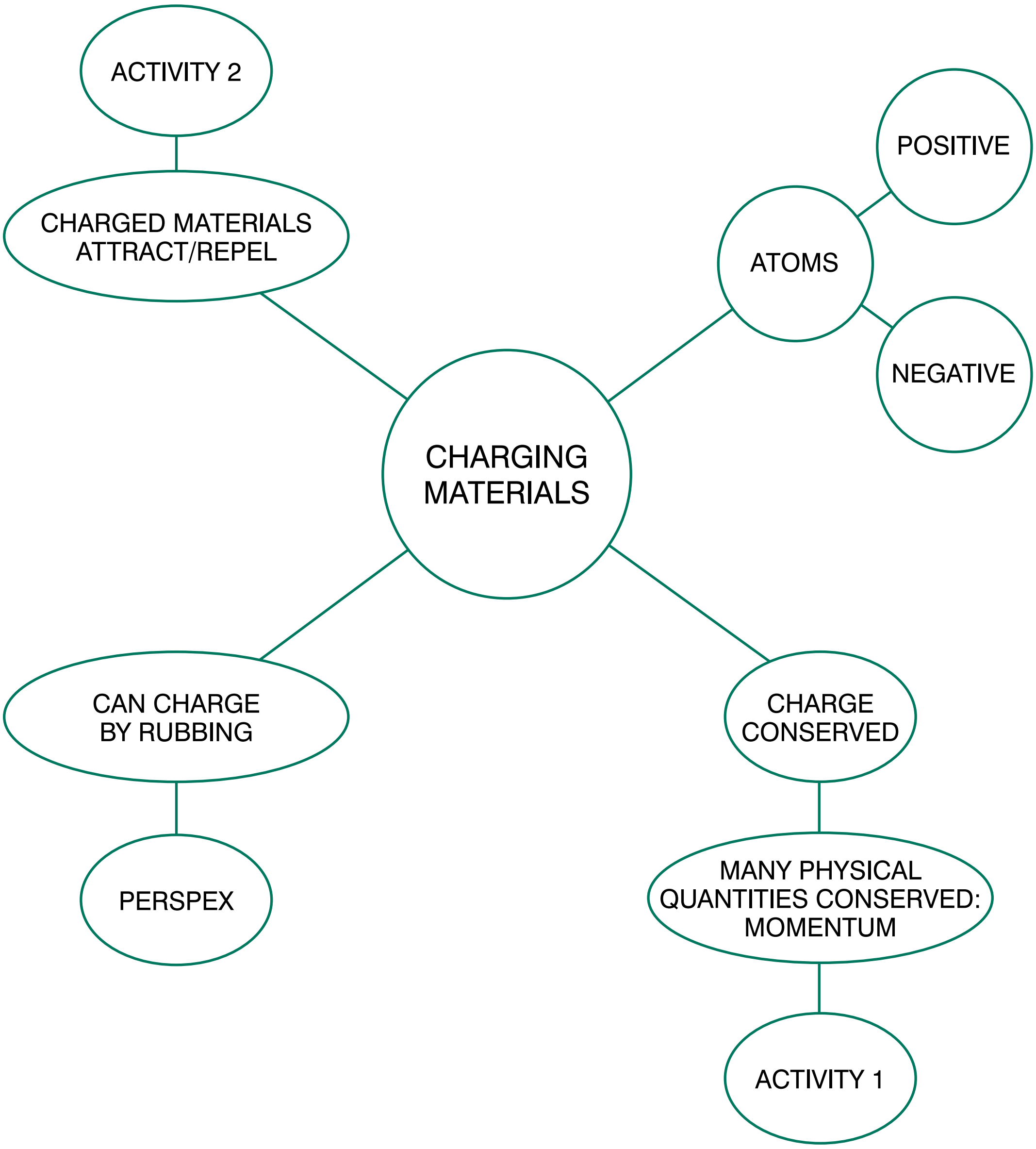
When summarising the main learning points of the lesson as indicated in the lesson plan above, students can use the methods listed here.

Use bullet points to summarise the main points, for example, from the lesson above, these would be:

- Matter consists of atoms, which have positive and negative particles which normally balance each other
- Conservation of charge
- Many physical quantities are conserved

- Materials can be charged by rubbing
- Charged materials attract or repel each other

Construct a spider diagram, for example, from the lesson above, this would look like this:



Motion in 2D

Unit 1

Learning Competencies for Unit 1

By the end of this unit students should be able to:

- Define the term projectile (and provide several examples).
- Explain the difference between 1D and 2D motion.
- Correctly use the terms angle of elevation and angle of depression, and explain the importance of the angle when it comes to launching projectiles.
- Explain the effect gravity has on the motion of an object.
- Describe what happens to the horizontal and vertical velocities of a projectile and the important characteristics of its flight.
- Demonstrate how to use the equations for uniform acceleration and how to apply these to projectile motion.
- Define the term centre of mass.
- Conduct simple experiments to determine the centre of mass of 2D objects.
- List the characteristics of uniform circular motion.
- Describe the relationships between radius, mass, forces and velocity for an object following a circular path.
- Define the terms angular and tangential displacement, and angular and tangential velocity.
- Express angles in terms of revolutions, radians and degrees.
- Define the term angular acceleration, and list its key characteristics.
- Identify the SI unit of angular velocity and angular acceleration.
- Explain the relationships between angular displacement, tangential displacement, angular velocity, tangential velocity and angular acceleration.
- Demonstrate how to use the equations of constant angular acceleration and compare them with equations of constant acceleration.
- Define the moment of inertia of a point mass.
- Define rotational kinetic energy of a body.
- Solve simple problems relating to moment of inertia and rotational kinetic energy.
- Define the term torque.
- Identify the SI unit of torque, N m, which is not the same as Joule.
- Express torque in terms of moment of inertia and angular acceleration.

This unit should fill approximately **22 periods** of teaching time.

- Derive an expression for the work done by the torque.
- Use the formula $W = \tau\theta$ to solve problems related to work done by torque.
- Define the angular momentum of a particle of mass *m* and write its SI unit.
- State the law of conservation of angular momentum.
- Solve problems using the law of conservation of angular momentum.
- State the first and second conditions of equilibrium.
- Solve problems related to conditions of equilibrium.
- Define the term centre of mass (centre of gravity) of a solid body.
- Determine the centre of gravity using a plumb-line method.
- Define the terms stable, unstable and neutral equilibrium.
- State Newton's law of universal gravitation.
- Determine the magnitude of the force of attraction between two masses separated by a distance *r*.
- Calculate the value of *g* at any distance above the surface of the Earth.
- State Kepler's laws of planetary motion.
- Use Kepler's laws of planetary motion to determine the period of any planet.
- Differentiate between orbital and escape velocity of a satellite.
- Determine the period of a satellite around a planet.
- Calculate the orbital and escape velocity of a satellite.
- Describe the period, position and function of a geostationary satellite.

1.1 Projectile motion

This section should fill approximately **5 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Define the term projectile (and provide several examples).
- Explain the difference between 1D and 2D motion.
- Correctly use the terms angle of elevation and angle of depression, and explain the importance of the angle when it comes to launching projectiles.
- Explain the effect gravity has on the motion of an object.
- Describe what happens to the horizontal and vertical velocities of a projectile and the important characteristics of its flight.
- Demonstrate how to use the equations for uniform acceleration and how to apply these to projectile motion.
- Define the term centre of mass.
- Conduct simple experiments to determine the centre of mass of 2D objects.
- List the characteristics of uniform circular motion.
- Describe the relationships between radius, mass, forces and velocity for an object following a circular path.

Starting off

This is a quite a large section in what is a reasonably large unit. However, the actual amount of new physics is relatively small. Students are challenged to apply their understanding of the equations of uniform acceleration to two dimensions. This begins with projectiles but in later sections goes on to look at circular motion.

Projectile mathematics is quite complex, especially if you factor in air resistance. Students really benefit from plenty of practice questions and examples. Throughout this section air resistance is assumed to be neglible.

Teaching notes

Begin by asking the students to list different examples of projectiles. Most will go down the route of weaponry. Discuss their suggestions and lead them to the correct definition of a projectile (any object moving through the air without an engine or motive force). Give alternative examples: a football, tennis ball, an oil drop from the underside of a car, etc.

Activity 1.1: Answer

Football, tennis ball, oil drop from underside of car, etc.

Discuss what makes projectile motion different from the motion they have studied mathematically in the past. It is very important to draw out the idea that this kind of motion is an example of 2D motion.

Explain that the horizontal and vertical components of the velocity may be treated separately (more on this later) and revise resolving vectors (see Grade 9 Teacher's Book). Limit examples to velocity and get the students to practise resolving a couple of vectors (see Figure 1.3 in the Students' Book). This is essentially just revision of trigonometry, but is worth spending time on to ensure that all students can resolve simple velocities into horizontal and vertical components.

First discuss the horizontal component of the velocity. Explain that throughout this section we will be ignoring air resistance. This may be worth discussing further, but in essence as long as the projectile is not too big or going too fast this is a fair assumption. Explain that taking into account air resistance is very complex and beyond the scope of this course.

Revise simple use of:

$$\text{displacement} = \text{average velocity} \times \text{time}$$

Apply this to the horizontal velocity and discuss its key implication (a projectile will travel further through the air if the horizontal velocity is greater or the time it spends in the air is greater).

Ask the students what happens to the vertical velocity of the projectile, again ignoring air resistance. This time the velocity increases as the projectile is accelerated due to gravity (there are some good illustrations in the Students' Book). Stress to students that all objects will accelerate at the same rate of 9.81 m/s^2 if air resistance is ignored. You could extend this by describing Galileo's famous experiment dropping balls from the leaning tower of Pisa (even though recent research suggests that he may never actually have carried this out).

Ask the students to sketch the displacement–time and velocity–time graphs for a ball which has been dropped. Discuss their shapes, in particular the velocity–time graph (see Figure 1.5 in the Students' Book). The gradient is constant, so what does this tell us about the motion of the ball? (It is uniformly accelerated.)

Explain that as the motion under gravity is an example of uniformly accelerated motion, we can use the equations of uniformly accelerated motion:

1. $v = u + at$
2. $s = \frac{1}{2}(u + v)t$
3. $s = ut + \frac{1}{2}at^2$
4. $v^2 = u^2 + 2as$
5. $s = vt - \frac{1}{2}at^2$

Equations of uniform acceleration

s = displacement

v = final velocity

u = initial velocity

a = acceleration (in this case 9.81 m/s^2)

t = time

Spend some time revising these and applying them to a dropped ball as shown in worked example 1.1. Students should practise using the equations through simple calculations. It is very important to stress that these equations apply only to the vertical velocity of the ball. The horizontal velocity remains constant and so the acceleration is zero.

Students could conduct a simple experiment dropping a ball from various heights and timing how long it takes to hit the ground. They could then calculate what the time should be from each height and discuss the differences between the theoretical and experimental values as described in Activity 1.2.

Explain to students that the path a projectile follows depends on its horizontal and vertical velocities. The shape of the path is called a parabola, the two velocities cause this:

- Horizontally the ball moves at a steady speed.
- Vertically the ball accelerates due to gravity.

Figures 1.10 and 1.11 in the Students' Book highlight this relationship. This should be discussed carefully with the students, ensuring that they are aware of the changing vertical velocity. The direction of this velocity should also be discussed. This is perhaps best done through simple examples and calculations. Students could work out the velocity of an object thrown vertically upwards after different times. (See worked example 1.3.) If they use acceleration due to gravity as 9.81 m/s^2 (as opposed to −9.81 m/s^2) they will find the velocity starts off negative, goes to zero and then becomes positive.

Move on to demonstrate projectiles launched horizontally, perhaps roll a marble off a desk (ideally from a simple track). Vary the velocity of the marble and ask the students to observe its motion carefully.

Explain to the students that the time the marble is in the air depends only on its initial height. Some may be reluctant to accept this idea, especially when more complex examples are discussed (two rifle bullets, one dropped, the other fired horizontally from the same height take the same time to hit the floor!). Again there are some time-lapse images of this in the Students' Book (Figure 1.14), and in addition students should carry out the simple experiment with the two coins and the ruler described in Activity 1.5.

Explain that this effect is a result of the independence of horizontal and vertical motion. This could be demonstrated further by rolling marbles along a board that has been tilted at an angle. If the marble is simply released it rolls vertically down the board and hits the bottom. If it is pushed so that it is travelling perpendicular to the top of the board, it follows a curved path. With a bit of practice you will be able to release two balls simultaneously and they will both hit the bottom of the board at the same time.

Additionally students could conduct an investigation into the flight time of a marble that rolls down a track and off the end of a desk as described in Activity 1.6. They will find the flight time is always the same. However, the range varies depending on the horizontal velocity and this leads back to

$$\text{Horizontal displacement} = \text{horizontal velocity} \times \text{flight time}$$

This should be summarised through some practice calculations like worked example 1.4. Students should be able to work out the flight time and range for a number of different horizontally projected objects. Additionally they could draw the trajectory of a known projectile, to scale, using a set of calculations (see Students' Book Activity 1.7 overleaf).

Finally, as part of horizontal projection, they could use the calculations to determine the initial velocity of a projectile. This could either be a marble rolling off a desk or they could make a simple projectile cannon. To do this they use a stiff cardboard tube with a rubber band attached at one end. To make a projectile they either use a marble or tightly roll up a piece of aluminium foil. They could

Activity 1.2: Answer

Students' own results.

Activity 1.3: Answer

Path is a parabola. Distance travelled varies with angle at which it is thrown.

Activity 1.4: Answer

a) 60.9 m
b) -33.42 m

Activity 1.5: Answer

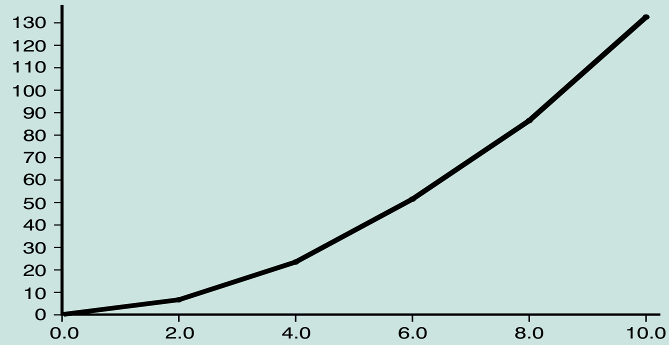
Students' own results.

Activity 1.6: Answer

Students' own results.

Activity 1.7: Answer

Time/s	Vertical displacement y/m	Horizontal displacement x/m
1.0	6.91	2.0
2.0	23.62	4.0
3.0	50.15	6.0
4.0	86.48	8.0
5.0	132.63	10.0



Activity 1.8: Answer

Students' own results.

Activity 1.9: Answer

Since 2 sinθ cosθ = sin 2θ

$$\frac{2u^2 \sin\theta \times \cos\theta}{a}$$

$$= \frac{u^2 \sin 2\theta}{a}$$

fire the cannon horizontally from a known height and calculate the initial velocity of the projectile from its range and flight time. (See also Activity 1.8) They could carefully pull the elastic band back different distances and so calibrate the cannon (i.e. 1 cm pulled back may give a velocity of 0.8 m/s, etc.). This is particularly useful later on in this unit.

Move on to projectiles launched at angles, revise the shape of the flight and resolving velocities. Explain the terms angle of elevation and angle of depression as shown in Figures 1.20a and 120b (although in this course only angles of elevation will be used). Discuss the key features of the flight (maximum height, range, etc.). Students should carry out a few simple calculations to determine the maximum height of various projectiles fired at angles. Take care to stress it is the vertical velocity that changes; the horizontal velocity remains the same and is useful only in determining the range of the projectile.

Go on to show how the range of a projectile and its flight time may be calculated using the equations. This can get quite complex and mathematical: it is perhaps best to take time over this and complete it step by step. The Students' Book contains some good examples.

The students could then use their calibrated aluminium foil cannon and calculate its range (for a given angle). They should then fire the projectile into a cup that they have placed the correct distance away. This could be written up as a report, with a focus on discussing the limitations (friction, not properly calibrated, etc.).

Students benefit from plenty of practice on these questions. They could make up their own, including a clearly worked-through mark scheme, and test a partner.

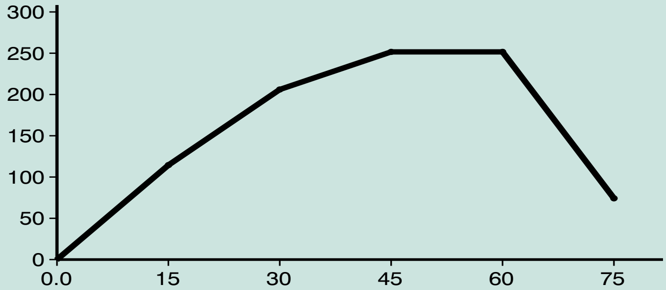
To round off projectiles, the concept of the maximum range of projectiles should be discussed. Students could use their cannon and fire it at different angles, measuring the range each time. Once they have collected a set of results they should plot a graph of angle against range. They could also carry out Activity 1.10. Explain that the maximum range of any projectile is reached when it is fired at 45° (you may wish to prove this mathematically using the range equation in the Students' Book).

This section then moves on to look at centre of mass. This might seem a strange jump but it is essential before other types of 2D motion can be explored (circular motion, moment of inertia, etc.).

Define centre of mass and give a few simple examples. Explain to students that the terms centre of mass and centre of gravity are often muddled. They are in the same place, except in a non-uniform gravitation field. Students could draw lines of

Activity 1.10: Answer

Using range = $\frac{u^2 \sin 2\theta}{a}$



θ (º)	sθ (º)	sin2θ	u (m/s)	u^2 (m^2/s^2)	a (m/s^2)	range (m)
15	30	0.5	50	2500	9.81	127.42
30	60	0.87	50	2500	9.81	221.7
45	90	1	50	2500	9.81	254.8
60	120	0.87	50	2500	9.81	221.7
75	150	0.5	50	2500	9.81	127.42

symmetry through simple, regular shapes to determine the position of their centre of mass (different triangles are good for this one). They could carry out Activity 1.11.

Discuss irregular objects (no calculations will be required). You could demonstrate the position of the centre of mass of an irregular object by attaching a small, bright LED to the object and throwing it through the air. If the light is at the centre of mass, it will follow a parabolic path; if it is not, it will wobble as it moves through the air. Discuss the centre of mass theorem. Students should carry out Activity 1.12 at this point.

Students should experimentally determine the centre of mass of an irregular 2D shape (this is described in the Students' Book in Activity 1.13).

The final part of this unit deals with uniform circular motion as another example of 2D motion. Ask the students to attempt to define uniform circular motion, and use this to stress the importance of steady speed. Ensure students are aware that when an object is performing uniform circular motion it is still accelerating. Revise the idea of acceleration as a change in velocity. This is very important.

Revise Newton's second law and discuss the fact that as any object undergoing uniform circular motion is accelerating, there must be a net force acting on the object. For now, just explain that this force is called centripetal force and it acts towards the centre of the circle (more on this in Section 1.2).

Students should carry out a simple investigation using a home-made pendulum to determine the factors that affect the size of this force (Activity 1.14 in the Students' Book). They should be able to determine that radius, velocity and mass all affect the size of the required force (they should be able to feel this as they swing the pendulum around).

Give lots of examples of centripetal forces (see Table 1.1 on page 21 of the Students' Book). Some students will assume that this force is a new type of force and fail to realise that the centripetal force is just the name given to any force (gravitational attraction, friction, etc.) that acts towards the centre of a circle. This should be explained carefully to them.

Introduce them to the centripetal force equation on page 20 of the Students' Book (this will be revisited in Section 1.2). Students should practise using this equation, including rearranging it to determine different factors and qualitatively discuss the effect of each factor. Worked examples 1.8 and 1.9 are useful starting points.

Go on to discuss what will happen if the force required to make an object follow a path of a certain radius cannot be produced. A good example of this is a car going

Activity 1.11: Answer

Students' own results.

Activity 1.12: Answer

Students' own results.

Activity 1.13: Answer

Students' own results.

Activity 1.14: Answer

Students' own results.

round a bend. What if the bend is icy or wet? The frictional force will not be large enough and so the car will follow a path of greater radius and head towards the outer edge of the road. Another example might be that if the pendulum they were swinging earlier had greater mass, the string would snap. Students should discuss the outcomes both qualitatively and quantitatively (more of this in Section 1.2).

SA = starter activity MA = main activity CA = concluding activity	
1. What are projectiles?	
SA	Students do Activity 1.1 with a partner.
MA	Students to do Activity 1.2 in a small group.
CA	Discuss the question 'How do theoretical times calculated for Activity 1.2 compare with experimental results?' with a partner.
2. Horizontal and vertical velocities	
SA	In a small group, carry out Activity 1.3.
MA	In a small group carry out Activity 1.4 Activity 1.5 Activity 1.6.
CA	Do Activity 1.7 with a partner.
3. Range	
SA	Attempt Worked example 1.4 in small groups. After 5 minutes, take feed back on methods before revealing given solution.
MA	In small group carry out Activity 1.8 Activity 1.9.
CA	In pairs, do Activity 1.10.
4. Centre of mass	
SA	Activity 1.11 in pairs.
MA	Activity 1.12 Activity 1.13 In small group.
CA	Work with a partner to produce a spider gram to summarise pages 18–19 of Student Book.
5. Centripetal force	
SA	With a partner, list as many examples of uniform circular motion as possible. Feed back ideas.
MA	In pairs, carry out Activity 1.14.
CA	Tackle review questions 1–6 in pairs.

Activities

- Drop a ball from various heights and time its flight time.
- Conduct a simple two-coin experiment.
- Investigate the flight time of projectiles launched with different horizontal velocities.
- Produce scale drawings of trajectories of horizontal projectiles.
- Construct and use a simple aluminium foil cannon (two different activities).
- Practise various calculations of the maximum height and range of projectiles.

- Carry out experimental investigations into how angle affects the range of projectiles.
- Draw lines of symmetry through simple, regular shapes to determine the position of the centre of mass.
- Determine the centre of mass of an irregular 2D shape.
- Determine factors affecting the size of the centripetal force acting on a pendulum bob.

Resources

http://www.physicsclassroom.com/class/vectors/u312a.cfm

http://phet.colorado.edu/en/simulation/projectile-motion

Where next?

This section encompasses a vast range of topics, most of which are further developed in the remaining sections of this unit. Projectile motion does not really get much more complex until air resistance starts to be factored in, but this will not happen until the second or third year of university courses. More complex examples can be given to students, but in essence they always break down into resolving and using the equations of constant acceleration.

Centre of mass is studied in much more detail as part of Section 1.3. Here the basic idea is taken further and the importance of the distribution of mass is studied as part of work into moment of inertia.

Circular motion forms the main focus of the remainder of this unit. This includes angular acceleration, angular equations for constant acceleration, torque and angular momentum, and planetary orbits.

Answers to review questions

1. a) i Negligible air resistance

   ii The weight acts downwards causing deceleration

   b) i Using $v = u + at$, $t = 0.36$ s

   ii 7.1 m (or 7.14 m)

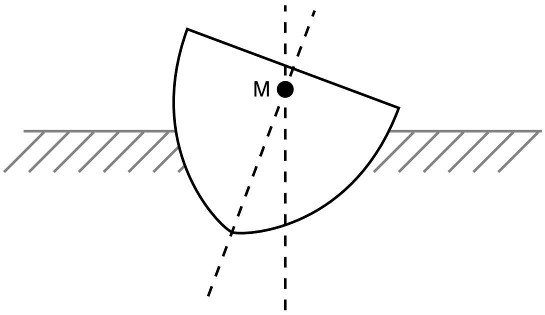
   c) i Same time t in air, so vt is greater

   ii Longer time t in air, so vt is greater

2. The point at which all the mass of the object may be considered to be concentrated.

3. On the vertical axis, the projectile will initially experience deceleration due to gravity acting on its mass (weight). This will occur until the projectile reaches its maximum height, at which point its vertical component of velocity will be zero. It will then accelerate (due to its weight) downwards until (assuming there are no losses, i.e. drag forces) it reaches its original firing vertical component of velocity, immediately before it hits the ground. The horizontal component of velocity is assumed constant with time as there is no horizontal acceleration acting on the projection (assuming no losses).

4. a) 1.3 s
   b) 2 m
   c) 17.7 m
5. 104.5 m
6. 11,600 N
7. The centre of stability of a ship is calculated using the metacentric height (the distance between its centre of gravity and its metacentre). The metacentre (M) is the point at which a vertical line through the original, vertical centre of buoyancy as shown in the diagram.



The centre of mass of a ship must be below the centre of stability to ensure that the ship remains stable in all conditions.

8. a) *t = 1s*

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

$= -19.6 \times 1 + \frac{1}{2} \times 9.8 \times 1$

$= -19.6 + 4.95$

$= -14.65$ m

Use $v = u + at$

$= -19.6 + 9.8 \times 1$

$= -9.8$ m/s i.e. upwards

t = 2s

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

$= -19.6 \times 2 + \frac{1}{2} \times 9.8 \times 4$

$= -19.6$ m

Use $v = u + at$

$= -19.6 + 9.8 \times 2$

$= 0$ m/s

t = 3s

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

$= -19.6 \times 3 + \frac{1}{2} \times 9.8 \times 9$

$= -58.8 + 44.1$

$= -14.7$ m

Use $v = u + at$

$= -19.6 + 9.8 \times 3$

$= 9.8$ m/s i.e. downwards

$t = 4s$

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

$= -19.6 \times 4 + \frac{1}{2} \times 9.8 \times 16$

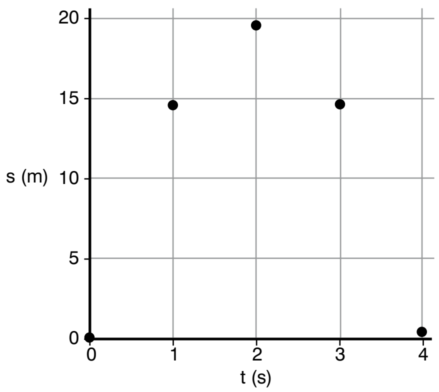
$= 0$ m

Use $v = u + at$

$= -19.6 + 9.8 \times 4$

$= 19.6$ m/s

b) i



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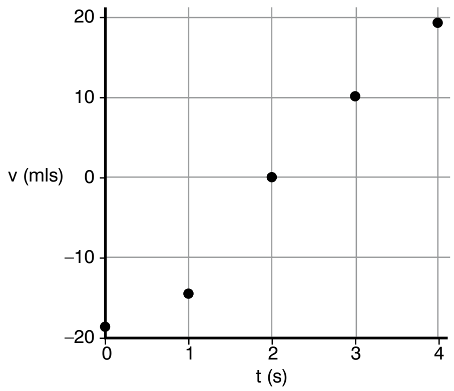


1.2 Rotational kinematics

This section takes the students' understanding in a new direction. It focuses on rotational motion, applying the ideas covered in the previous topic to rotating objects. This includes careful differentiation between rotation and linear quantities and applying the equations of constant acceleration to rotating systems.

There is slightly more new physics than in the last section: however, most of this is not conceptually challenging; just a clarification of terms and their mathematical relationships. Students really benefit from lots of practice questions, activities and examples. This section is not very experimental, but there is plenty of opportunity for students to complete practice exercises.

Learning Competencies

By the end of this section students should be able to:

- Define the terms angular and tangential displacement, and angular and tangential velocity.
- Express angles in terms of revolutions, radians and degrees.
- Define the term angular acceleration, and list its key characteristics.
- Identify the SI unit of angular velocity and angular acceleration.
- Explain the relationships between angular displacement, tangential displacement, angular velocity, tangential velocity and angular acceleration.
- Demonstrate how to use the equations of constant angular acceleration and compare them with equations of constant acceleration.

This section should fill approximately **5 periods** of teaching time.

Teaching notes

Start by swinging an object (like a small cork) on the end of a piece of string around your head. Ask the students to describe its motion. Try to elicit the terms displacement and velocity from the students. Most will describe the linear velocity and displacement of the object. Use this to lead into the idea of angular equivalents and their importance in describing rotational motion.

Start by explaining angular displacement; using diagrams such as Figure 1.31 in the Students' Book or the cork on the string helps the students to visualise what you are describing. Discuss the units for angular displacement. Spend some time going over the use of the radian and its importance. The equation

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

where θ is angular displacement in rad, l is the arc length in m and r is the radius of the circle, is helpful in demonstrating the usefulness of the radian. The students should be given time to practise converting from revolutions, radians and degrees. There is a simple activity (Activity 1.15) in the Students' Book using clock hands.

Activity 1.15: Answer

3 revs, 6π radians, 1080°

0.0278 revs, 0.17 radians, 10°

3.5 revs, 7π radians, 1260°

When the students are confident using the radian as the standard angular measure, move on to angular velocity. Most students will not have any problems with this as it is so similar to the definition and application of linear velocity. However, it is worth stressing that the equation may be written as:

$$\omega = \frac{2\pi}{T}$$

However, there is no need at this stage to relate this to frequency ($\omega = 2\pi f$). Students should practise some simple calculations of angular velocity like worked example 1.10 and Activity 1.16.

Activity 1.16: Answer

540°s^{-1} and 90 rpm

Demonstrate the cork on the string again and ask the students what would happen if the string were to break suddenly. Lead this into the idea of tangential velocity. Revise the idea that this tangential velocity is always changing (as the direction is changing) and as a consequence the object is accelerating.

Introduce $v = r\omega$ and provide the students with plenty of examples to practise calculating angular and tangential velocity. Students could carry out a simple practical activity using their own corks on string. Here they measure the time taken for ten revolutions for a given radius and then calculate v and ω. Stress the effect on tangential velocity for an increasing radius for a given angular velocity.

Go back to the idea of acceleration. Revise centripetal acceleration from the last chapter and introduce its two equations:

$$a = \frac{v^2}{r} \quad \text{and} \quad a = r\omega^2$$

There is no need to derive the first one however, this is a good summary of the radian and more able students may find this proof helpful. Again students should be given some practice questions using these quantities (Activity 1.17in the Students' Book involving planetary data). It is also worth showing how you get $F = \frac{mv^2}{r}$ (used in the previous chapter) from Newton's second law ($F = ma$) and the equation for centripetal acceleration.

Activity 1.17: Answer

Planet	Orbital period/days	Average distance from Sun/m	Angular velocity rad/s	Tangential velocity m/s	Centripetal acceleration m/s^2
Mercury	88	5.8×10^{10}	8.26×10^{-7}	47 908	0.04
Venus	225	1.1×10^{11}	3.23×10^{-7}	35 530	0.01
Mars	686	2.3×10^{11}	1.06×10^{-7}	24 380	2.58×10^{-3}
Jupiter	4330	7.8×10^{11}	1.68×10^{-8}	13 104	2.20×10^{-4}
Neptune	60 000	4.5×10^{12}	1.21×10^{-9}	5445	6.58×10^{-6}

Revise the idea of uniform circular motion and this time relate it angular velocity and steady speed. Ask the students to discuss with a partner how else might an object travelling in a circular path be accelerating. Most will describe an object getting faster as it goes around (demonstrate with the cork on the string). Explain the correct use of the term tangential acceleration and use this to introduce the notion of a changing angular velocity, and so an angular acceleration.

Sometimes students can muddle the three different accelerations covered in this section (centripetal, tangential and angular). Spend some time ensuring they are aware of the differences; a simple diagram may help, along with some careful examples and practice questions.

This section ends by introducing the equations of constant angular acceleration. Revise the equations of constant linear acceleration introduced in Section 1.1 and then see whether students can use the knowledge from this section to write equivalent equations for constant angular acceleration. When they have had time to attempt this, show them the table on page 28 of the Students' Book and discuss the comparison.

Work through the worked examples.

SA = starter activity MA = main activity CA = concluding activity	
1. Angular displacement	
SA	Discussion activity on page 24 of Student Book in pairs.
MA	Activity 1.15 in pairs.
CA	Further examples of calculations to be tackled in pairs.
2. Angular velocity	
SA	Worked example 1.10 to be tackled in pairs. Approaches to be discussed before given answer solution is revealed.
MA	Activity 1.16 to be discussed with a partner.
CA	In pairs, summarise pages 25–26 of Student Book.
3. Centripetal acceleration (1)	
SA	In pairs discuss what they understand by term 'acceleration'. Feed back ideas.
MA	Activity 1.17 in pairs.
CA	Review results of activity in small groups.

4. Centripetal acceleration (2)	
SA	Discuss why centripetal force is given by $F = \frac{mv^2}{r}$ with a partner.
MA	Discussion activity on page 27 of Student Book in pairs.
CA	Feed back results of discussion in small groups.
5. The equations of constant angular acceleration	
SA	In pairs, write down the equations of constant linear acceleration.
MA	Given the parameters on page 28 of Student Book, work with a partner to derive the equations of constant angular acceleration from the equations of constant linear acceleration. Feed back ideas.
CA	Review questions to be tackled in pairs.

Resources

http://physics.bu.edu/~duffy/py105/notes/Rotationalkin.html

http://www.pearson.com.au/linkedfiles/free/9780582547827/CPL3.pdf

Where next?

This section has defined the relationships that will be used in the remainder of this unit. Students need to be competent in using these relationships for successful completion of the unit, so it is important that they are given plenty of practice in using and manipulating the various equations. Students will study the moment of inertia, torque and the conditions for equilibrium in the next section, before moving on to look at the motion of planets and satellites in the final section of the unit.

Answers to review questions

1. a) Angular displacement is the angle through which an object moving in a circular path is displaced, as shown in Figure 1.1. Its units are revolutions, degrees or radians.

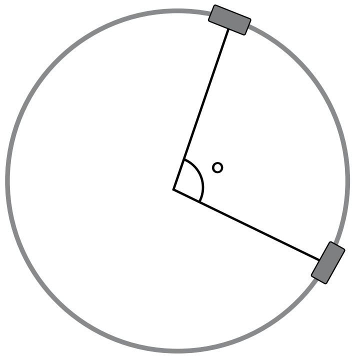


Figure 1.1

   b) Tangential displacement is the linear distance travelled by an object moving in a circular path. Its units are metres.

   c) An object that moves round a complete circle will have an angular displacement of 2π radians but a tangential displacement of 0 m because it has returned to its starting point.

2. a) Angular velocity is the angle travelled per unit of time. Its units depend on the unit used for the angle so could be rev/s, degrees/s or rad/s.

   b) Tangential velocity is the distance travelled in a linear fashion per unit time so its units are m/s.

c) $v = r\omega$

$v = 2 \times 3 = 6$ m/s

3. a) Angles may be expressed in revolutions (or fractions of a revolution), degrees or radians.

b) If you measure the angle with a protractor you will find it is 45°. This is equivalent to $\frac{1}{8}$ of a revolution or $\frac{\pi}{4}$ radians.

4. a) Angular acceleration is defined as the change in angular velocity per unit time and its units depend on the unit for the degrees. The units are therefore rev/s^2, degrees/s^2 or rad/s^2.

b) Angular acceleration acts towards the centre of the circle. It can be found using the formula $a = \frac{v^2}{r}$. If the mass of an object moving in a circle is constant then from Newton's second law, the force acting $F = \frac{mv^2}{r}$

5. a) The equations of motion with constant angular acceleration are:

$\omega = \omega_0 + \alpha t$

$\theta = \frac{1}{2}(\omega_0 + \omega)t$

$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega^2 = \omega_0{}^2 + 2\alpha\theta$

$\theta = \omega t - \frac{1}{2}\alpha t^2$

ω = final angular velocity

ω_0 = initial angular velocity

α = angular acceleration

t = time

θ = distance

b) $\omega = 5 + 2 \times 10 = 25$ rad s^{-1}

c) $\theta = 20 \times 5 - \frac{1}{2} \times 2 \times 5^2 = 100 - 25 = 75$ rad

6. Use v = rω

$\omega = 7.27 \times 10^{-5}$

r = (6 400 + 35 600) × 10^3 m

= 4.2 × 10^7 m

v = 7.27 × 10^{-5} × 4.2 × 10^7

= 3 053 m/s

7. a) $F = \frac{mv^2}{r}$

F (N)	m (kg)	v (m/s)	r (m)
?	80		5

Distance travelled in 2s = 3.14 × 10 m

= 31.4 m

Distance travelled in 1s = $\frac{31.4 \text{ m}}{2}$

= 15.7 m

$v = 15.7$ m/s

$f = \dfrac{80 \times 15.7^2}{5}$

$= 3943.8$ N

$= 3944$ N (nearest newton)

b) $\dfrac{3944}{800} = 49.3$

This force is approximately 50 times greater than the astronauts' weight.

This section should fill approximately **7 periods** of teaching time.

1.3 Rotational dynamics

Learning Competencies

By the end of this section students should be able to:

- Define the moment of inertia of a point mass.
- Define rotational kinetic energy of a body.
- Solve simple problems relating to moment of inertia and rotational kinetic energy.
- Define the term torque.
- Identify the SI unit of torque, N m, which is not the same as Joule.
- Express torque in terms of moment of inertia and angular acceleration.
- Derive an expression for the work done by the torque.
- Use the formula $W = \tau\theta$ to solve problems related to work done by torque.
- Define the angular momentum of a particle of mass *m* and write its SI unit.
- State the law of conservation of angular momentum.
- Solve problems using the law of conservation of angular momentum.
- State the first and second conditions of equilibrium.
- Solve problems related to conditions of equilibrium.
- Define the term centre of mass (centre of gravity) of a solid body.
- Determine the centre of gravity using a plumb–line method.
- Define the terms stable, unstable and neutral equilibrium.

Starting off

This section builds on the material studied in the last section so you need to begin by checking that students are comfortable with the relationships studied there. You could do this by devising a short quiz where you give one of the variables such as tangential velocity and students have to tell you how it is related to angular velocity.

Teaching notes

This section could become rather too abstract for the majority of your students. It requires quite a bit of mathematical manipulation of equations. Therefore, wherever possible, you should have some visual aids to help students to grasp the concepts.

A good example of this is the first section, 'The moment of inertia of a point mass'. If you can have two wheels of the same diameter and thickness, one like a bicycle wheel and one a wheel made from solid material, as shown in Figure 1.39 in the Students' Book, then the students will find it easier to follow the argument put forward in the text.

If possible organise the students into groups to carry out Activity 1.18. If you do not have enough equipment then it works as a demonstration, but this is a practical subject and students should have as much opportunity as possible to carry out investigations rather than watching demonstrations.

Activity 1.18: Answer

Students' own results.

We then move on to consider the rotational kinetic energy of a body. Before studying this section, ensure that the students remember the expression for linear kinetic energy, i.e. KE = $\frac{1}{2}mv^2$. It would be helpful to give some students some quick questions to make sure that they remember how to use this equation: you could use the example of the arrow on page 9 of the Students' Book with a mass of 200 g for the arrow (note that 200 g has to be converted to 0.2 kg to use in the equation – make sure that students understand why this is the case). It would be worth drawing some diagrams like these to help students to understand how the moment of inertia varies according to the axis of rotation.

Activity 1.19 gives students an opportunity to consolidate their understanding by comparing linear and rotational kinetic energy.

Activity 1.19: Answer

Starting with the expression for linear kinetic energy,

KE = $\frac{1}{2}mv^2$, we can first replace linear velocity by angular velocity ω to give

KE = $\frac{1}{2}m\omega^2$

Students should then remember that the rotational equivalent of mass is moment of inertia, I. This gives

KE = $\frac{1}{2}I\omega^2$ as required.

Now make sure that students can follow the worked examples on moments of inertia (worked examples 1.14 – 1.16). If necessary, give further practice by changing the figures given in these examples. For example, you could change the first one to 'Find the moment of inertia of a point mass of 0.005 g at a perpendicular distance of 3 m from its axis of rotation.'

Before discussing torque and its SI unit, make sure that students remember the definition of a moment (a moment at a point is the force at that point multiplied by the perpendicular distance to the pivot). Make sure that students understand how the unit N m is derived: force × distance, so N × m, but also ensure that they realise that this is different from a Joule, which is the work done when moving a force a given distance. In the case of a torque, the force itself does not move.

Activity 1.20 enables students to discuss why distance is part of the definition of a torque. This discussion could be extended to cover the point about the unit not being the same as a Joule, and why.

Activity 1.20: Answer

Movement = force × distance

torque is rotational equivalent of movement

torque = force × angle (distance)

You may want the students to try and work out how torque would be defined in terms of moment of inertia and angular acceleration before they read this section of the Students' Book. If they can work out this sort of relationship for themselves then they have really understood the underlying concepts and made connections between different areas of the syllabus.

We then consider the work done by a torque. Work through the worked examples (1.18 and 1.19) and use them as a basis for further practice questions if your students require this.

Before progressing to angular momentum, make sure that students remember how to define linear momentum. Draw out from them the law of conservation of linear momentum. If you prepare them in this way, the sections that follow will prove to be easier to grasp.

Activity 1.21: Answer

Students' own results.

Activity 1.21 is a fun way to demonstrate the principle of conservation of angular momentum in action. Activity 1.22 gives an opportunity for students to see where Physics is used in real life. Opportunities such as this can be extremely motivating and help students to develop an interest in the subject, which in turn will aid their learning.

Activity 1.22: Answer

Students' own results.

Work through the worked example 1.20 with the students and, as before, use it as the basis for further practice questions if required.

Activity 1.23: Answer

Look at the table on page 28 as a starting point.

Activity 1.23 is an opportunity for students to consolidate their learning so far in this section by making a poster to compare linear and rotational motion. Encourage students to include diagrams as well as text: they may also wish to include everyday applications where possible.

The final part of this section concerns equilibrium and the centre of mass of a solid body. A simple demonstration of a system in equilibrium can be set up as follows.

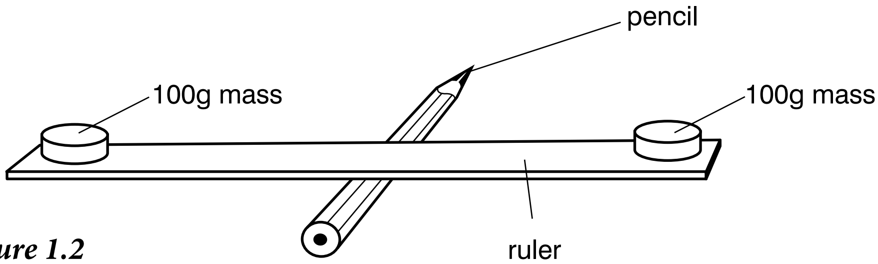


Figure 1.2

Ensure that students understand the implications of the two conditions for equilibrium.

You may wish to give further examples of systems that are in equilibrium based on the worked example if your students require more practice.

Activity 1.24: Answer

Students' own results.

Students have already considered the centre of mass of a 2D irregular shape. Now they extend this knowledge to 3D solid shapes. They explore the centre of mass of a solid object in Activity 1.24 using a similar method to that used in Activity 1.13.

You may wish to extend students by asking them to research further information about practical applications of centre of mass. The section can be rather abstract and students benefit from seeing how it its applied outside the classroom.

When considering stable, unstable and neutral equilibrium, it would be useful if you could demonstrate the differences using real objects. Figure 1.3 shows a child's toy that demonstrates stable equilibrium.

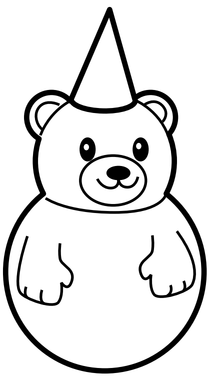


Figure 1.3

SA = starter activity MA = main activity CA = concluding activity	
1. Moment of inertia and rotational kinetic energy	
SA	In pairs, students discuss what they understand by 'inertia'. Feed back ideas.
MA	Activity 1.18 in pairs.
CA	Review questions 1–3 to be tackled with a partner.
2. Comparing linear and rotational kinetic energy	
SA	In pairs, produce definition of 'kinetic energy'. Feed back ideas.
MA	Activity 1.19 in pairs.
CA	Review activity in small groups.
3. Torque	
SA	In pairs, students write down what they know about 'moments'. Feed back ideas.
MA	Activity 1.20 in pairs.
CA	Review questions 4–7 to be tackled with a partner.
4. Angular momentum	
SA	With a partner, students write down law of conservation of momentum. Feed back ideas.
MA	Activity 1.21 with a partner.
CA	Review questions 8–9 to be tackled with a partner.
5. Applications of the principle of conservation of angular momentum	
SA	In pairs, discuss how a skater as shown in Figure 1.42 in the Student Book uses the conservation of angular momentum.
MA	Activity 1.22 in pairs.
CA	Review question 10 to be tackled with a partner.
6. Comparing linear and rotational motion	
SA	In pairs, write down Newton's first and second laws. Feed back ideas.
MA	Activity 1.23 in pairs.
CA	Present posters in small groups. Evaluate effectiveness in terms of clarity of information and attractiveness.
7. Equilibrium	
SA	In pairs, discuss what they understand by the term 'equilibrium' and try and try and suggest examples from everyday life. Feed back ideas.
MA	Activity 1.24 in pairs.
CA	Review questions 11–15 to be tackled in pairs.

Activities

- Exploring rotational inertia.
- Comparing linear and rotational kinetic energy.
- Comparing linear and rotational motion.
- Determining the centre of gravity of solid objects.

Resources

http://www.antonine-education.co.uk/Physics_A2/Options/Module_7/Topic_1/topic_I_rotational_dynamics.htm
http://dev.physicslab.org/Document.aspx?doctype=38filename=RotaryMotion_RotationalDynamicsRollingSpheres.xml

Where next?

The next section applies the concepts from this section to planetary orbits and satellites. This area can prove to be motivating to students and, if while you are studying the section, there happens to be a topical application of the content, such as the launch of a satellite or space probe, then you should use this to enhance the students' learning.

Answers to review questions

1. The moment of inertia of a point mass is a measure of the manner in which the mass is distributed in relation to the axis about which it is rotating. To find the moment of inertia of a point mass use the formula $I = MR^2$ where I is the moment of inertia, M is the mass and R is the perpendicular distance of the point mass from the axis of rotation.
2. Rotational kinetic energy of a body is the energy the body has as a result of movement around an axis. It is found using the formula KE = $\frac{1}{2}I\omega^2$ where KE is the kinetic energy, I is the moment of inertia and ω is the angular velocity.
3. a) $I = 0.005 \times 10^{-3} \text{ x } 3^2 = 0.000045$ kg m^2

   b) $I = \frac{2}{5} \times 0.3 \times 0.6^2 = 0.0432$ kg m^2

   c) KE $= \frac{1}{2} \times 0.003 \times 0.6^2 = 0.00054$ J
4. Torque = force × perpendicular distance from axis of rotation and its SI unit is N m.
5. torque = moment of inertia × angular acceleration.
6. Work done = force × distance so

   work done by torque = torque × angle it turns through = $\tau \times \theta$.
7. a) Work done $= 3.5 \times \frac{1}{2}\pi = 1.75\,\pi$ J

   b) Torque $= \frac{3}{\frac{1}{4}\pi} = 12\,\pi$ N m
8. The angular momentum of a particle of mass m is moment of inertia × angular velocity = $I\omega$. Its SI unit is N s.
9. The law of conservation of angular momentum states that if no resultant torque is acting, the angular momentum of a body cannot change.
10. Examples of uses of the law of conservation of angular momentum are when a skater folds in their arms in order to increase her rate of rotation, or conversely when she stretches out her arms in order to reduce her rate of rotation.
11. The first and second conditions of equilibrium are: if the forces in a system sum to zero then the system is in equilibrium; if the torques in a system sum to zero then the system is in equilibrium.
12. a) is in equilibrium because the torques are 3 N m anticlockwise and 3 N m clockwise.
13. The centre of mass (centre of gravity) of a solid body is the point at which the body's whole mass can be considered to be concentrated for the purpose of calculations.

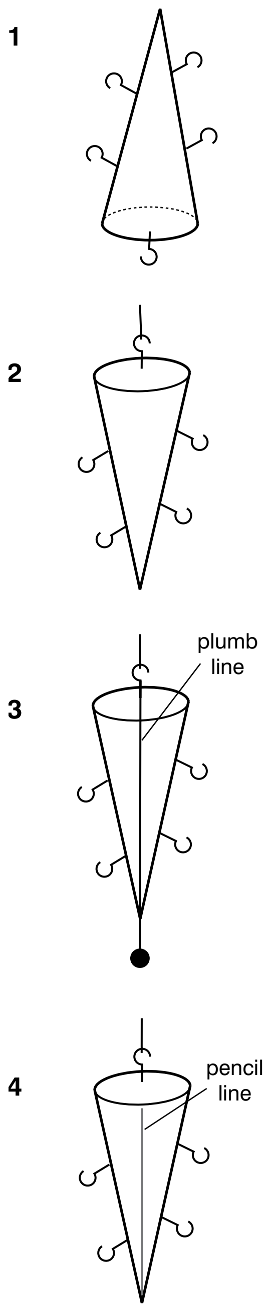


Figure 1.5

14. You can determine the centre of gravity of a solid object using a plumb-line method by:

(1) putting a series of hooks into the solid around its edges;
(2) hanging the solid from one of these hooks so that it is free to rotate;
(3) construct a simple plumb line using some string and a mass;
(4) hang this from the hook so that it hangs vertically down;
(5) use a sharp pencil to show the position of the plumb line;
(6) repeat for all the hooks;
(7) the lines should cross at the centre of gravity of the solid (see Figure 1.5).

15. An object is in stable equilibrium if, when it is slightly displaced, it returns to its original position.

An object is in unstable equilibrium if, when it is slightly displaced, it moves further away from its original position.

An object is in neutral equilibrium if, when it is slightly displaced, the system does not necessarily return to its original position but neither does it move further away. For example, if you kick a football along the ground it will roll a little way and then stop at another spot. The kick changes its position but not its stability.

1.4 Newton's law of universal gravitation

This section should fill approximately **5 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- State Newton's law of universal gravitation.
- Determine the magnitude of the force of attraction between two masses separated by a distance r.
- Calculate the value of g at any distance above the surface of the Earth.
- State Kepler's laws of planetary motion.
- Use Kepler's laws of planetary motion to determine the period of any planet.
- Differentiate between the orbital and escape velocity of a satellite.
- Determine the period of a satellite around a planet.
- Calculate the orbital and escape velocity of a satellite.
- Describe the period, position and function of a geostationary satellite.

Starting off

Discuss the motion of the planets around the Sun. Find out what students know about the Solar system and artificial satellites. Explain that this topic is the basis for space exploration and satellites. Discuss any topical space issues such as recent satellite launches, space missions, etc. If possible, ask students to carry out some research of their own into this topic, perhaps generating questions that they would like to be able to answer at the end of the study period.

Teaching notes

The section begins by considering the basic law that governs attraction between all objects in the Universe. It is worth pointing out the universal nature of the law to students as they often find this quite amazing. Work through the worked example 1.22 carefully. Stress that the force of attraction is generally not felt on Earth as it would be weak between two bodies on Earth.

When considering the variation of the value of *g* above the surface of the Earth, it is important that students realise that they need to add the height above the Earth to the radius of the Earth and use this value for *r* in the formula – it is easy to forget this and thus come up with the wrong answer to calculations.

It is worth stressing to students how amazing Kepler's research was at the time. Activity 1.25 overleaf gives students an opportunity to verify Kepler's third law.

Activity 1.26 gives students the opportunity to research some uses of geostationary satellites.

Before moving on to the section on geostationary satellites, see if students can come up with any uses of satellites in our lives on Earth. Examples may be for weather forecasting or for communications. The orbit of geostationary satellites will be above the equator.

Activity 1.25: Answer

Data that they will need is given in the table. The results should be as shown below.

Planet	Orbital period (days)	Average distance from Sun (m)	Orbital period^2	Average distance from Sun^3	Orbital period^2 / average distance from Sun^3
Mercury	88	5.8×10^{10}	7,744	1.95×10^{32}	3.97×10^{-29}
Venus	225	1.1×10^{11}	50,625	1.33×10^{33}	3.81×10^{-29}
Mars	686	2.3×10^{11}	470,596	1.22×10^{34}	3.85×10^{-29}
Jupiter	4,330	7.8×10^{11}	18,748,900	4.75×10^{35}	3.94×10^{-29}
Neptune	60,000	4.5×10^{12}	3,600,000,000	9.11×10^{37}	3.95×10^{-29}

If you consider the final column in the table, where all the figures round to 4×10^{-29}, this is a truly remarkable result and verifies Kepler's third law.

Activity 1.27: Answer

Students need to use the fact that the period of a geostationary satellite is 24 hours.

The orbital velocity will therefore be $\frac{2\pi}{24 \times 60 \times 60}$ rad s^{-1} = $\frac{6.28}{86{,}400}$

= 0.000073 rad s^{-1} = 0.26 rad h^{-1}.

SA = starter activity MA = main activity CA = concluding activity	
1. Newton's law of universal gravitation	
SA	In pairs, students write list of planets in solar system. Feed back ideas.
MA	With a partner, summarise pages 40–41 of Students' Book.
CA	Review questions 1–2 to be tackled with a partner.
2. Finding *g* at any distance	
SA	With a partner, students discuss a) value of g on Earth b) where value of *g* is used in calculations (e.g. potential energy = *mgh*). Feed back ideas.
MA	With a partner, summarise pages 41–42 of Student Book.
CA	Review question 3 to be tackled with a partner.
3. Kepler's laws of planetary motion	
SA	With a partner, discuss what keeps the planets in orbit around the Sun. Feed back ideas.
MA	Activity 1.25 in pairs.
CA	Review question 4 to be tackled in pairs.
4. Geostationary satellites	
SA	With a partner, discuss what they understand by 'satellite' and give examples. Feed back ideas.
MA	Activity 1.26 in small group.
CA	Activity 1.27 with a partner. Review question 5 to be tackled with a partner.
5. Escape velocity of a satellite	
SA	Review question 6 to be tackled in pairs.
MA	With a partner, produce a spider gram to summarise the unit.
CA	End of unit questions to be tackled with a partner.

Activities

- Verify Kepler's third law.
- Research uses of geostationary satellites.
- Calculate the orbital velocity of a satellite.
- Calculate the escape velocity of a satellite.

Resources

http://www.physicsclassroom.com

http://csep10.phys.utk.edu/astr161/Lect/history/newtongrav.html

Where next?

This section completes the unit. In Grade 11, the concepts will be extended further.

Answers to review questions

1. Newton's law of universal gravitation states that if two masses M_1 and M_2 are a distance r apart, then the force between them is proportional to the product of the masses and the inverse of the square of r. $F = G\, M_1\, M_2/r^2$ where G is the gravitational constant.
2. $F = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times\ 3.3 \times 10^{23}\ \text{kg} \times 2 \times 10^{30}\ \text{kg}\ /(5.8 \times 10^{10}\ \text{m})^2$
   $= 1.31 \times 10^{22}$ N
3. $g = \dfrac{Gm_e}{r^2}$

   $G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$ $r =\ 6378.1\ \text{km} + 1\ \text{km} = 6.3791 \times 10^6\ \text{m}$

   $m_E = 5.98 \times 10^{24}$ kg

   $g = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 5.98 \times \dfrac{10^{24}\ \text{kg}}{(6.3791 \times 10^6\ \text{m})^2} = 9.802\ \text{m/s}^2$
4. Kepler's laws of planetary motion are as follows:
   1. Each planet moves in a path called an ellipse, with the Sun at one focus.
   2. The line that joins the Sun to the orbiting planet sweeps out equal areas in equal times.
   3. The square of the time it takes the planet to go round the Sun (that is, the square of its year) is proportional to the cube of its average distance from the Sun.
5. The period of a geostationary satellite is 24 hours. It is positioned above the equator and is used for communications and weather forecasting.
6. The orbital velocity of a satellite is the velocity with which it travels around its orbit. The escape velocity of a satellite is the velocity that it would require in order to escape the Earth's potential well.

Answers to end of unit questions

1. a) A projectile is any object moving through the air without an engine or other motive force.

   b) Examples include tennis balls and rifle bullets.
2. a) Angle is important when launching projectiles since the range equation tells us that maximum range is achieved when a projectile is launched at 45°.

   b)

range (m)	*u* (m/s)	*a* (m/s2)	θ (°)	2θ (°)	sin 2θ
?	25	9.81	45	90	1

   Use range $= \dfrac{u^2 \sin 2\theta}{a}$

   $= \dfrac{25^2 \times 1}{9.81}$

   $= 63.7$ m

   c) The vertical velocity of a projectile changes because of the force of gravity but the horizontal velocity remains constant.

3. a) The centre of mass theorem states that when a force is applied to an object, the object acts as though its mass were a point mass at its centre of mass.

   b) A practical application of centre of mass is binary star system, where the stars orbit the centre of mass of the system. Centre of mass also enable the analysis of objects to be simplified since objects can be modelled as single particles.

4.

Constant linear acceleration	Constant angular acceleration
$v = u + at$	$\omega = \omega_0 + \alpha t$
$s = \frac{1}{2}(u + v)t$	$\theta = \frac{1}{2}(\omega_0 + \omega)t$
$s = ut + \frac{1}{2}at^2$	$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$
$v^2 = u^2 + 2as$	$\omega^2 = \omega_0{}^2 + 2\alpha\theta$
$s = vt + \frac{1}{2}at^2$	$\theta = \omega t - \frac{1}{2}\alpha t^2$

5.

θ (rad)	ω_0 (rad/s)	ω (rad/s)	t (s)
?	3	25	10

Use $\theta = \frac{1}{2}(\omega_0 + \omega)t$

$= \frac{1}{2}(3 + 25) \times 10$

$= \frac{1}{2} \times 28 \times 10$

$= 140$ rad

6.

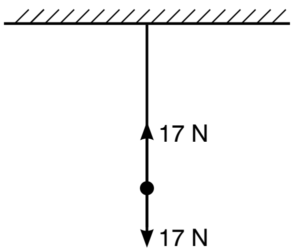
I (kgm²)	M (kg)	R (m)
?	0.75	0.4

Use $I = \frac{1}{2} MR^2$

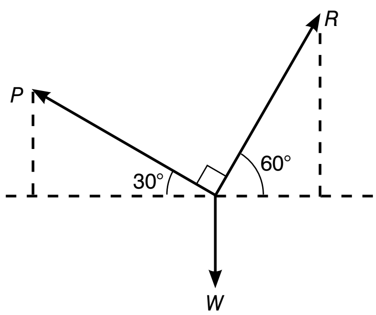
$= \frac{1}{2} \times 0.75 \times 0.4^2$

$= 0.06$ kgm²

7.



8.



Since system in equilibrium $P\sin 30 + R\sin 60 = W$

9.

F (N)	G (Nm^2 kg^{-2})	M_{moon} (kg)	M_{earth} (kg)	R (m)
?	6.67×10^{-11}	2×10^{24}	6×10^{24}	4×10^{8}

$$F = \frac{G\,M_1\,M_2}{R^2}$$

$$= \frac{6.67 \times 10^{-11} \times 2 \times 10^{24} \times 6 \times 10^{24}}{(4 \times 10^{8})^2}$$

$$= \frac{8.004 \times 10^{38}}{1.6 \times 10^{17}}$$

$$= 2.5 \times 10^{18}\ \text{N}$$

10.

g (m/s^2)	G (Nm^2 kg^{-2})	M_1 (kg)	r (m)
?	6.67×10^{-11}	6×10^{24}	4.2×10^{7}

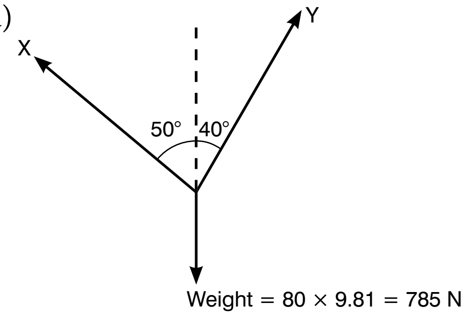
Use $g = \frac{G\,M_1}{r^2}$

$$= \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(4.2 \times 10^{7})^2}$$

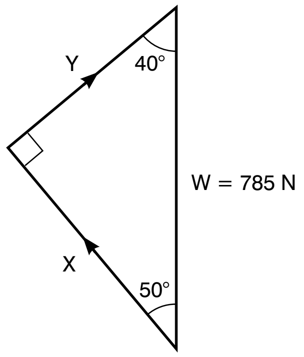
$$= \frac{4.002 \times 10^{14}}{1.764 \times 10^{15}}$$

$$= 0.226\ \text{m/s}^2$$

11. a)



b)



c) i $x = 785 \cos 50° = 505$ N
$y = 785 \cos 40° = 601$ N

12. The duration of a day would increase. The water would distribute more evenly across the globe so the moment of inertia would increase. The Earth's angular momentum would stay the same so its angular velocity would decrease.

Electrostatics

Unit 2

Learning Competencies for Unit 2

By the end of this unit students should be able to:

- State the law of conservation of charge.
- Describe and explain the charging processes: charging by rubbing, conduction and induction.
- Perform an experiment to charge an electroscope by conduction and by induction.
- Describe the distribution of charge on a conductor of variable shape.
- Explain how lightning is formed.
- Describe the use of a lightning rod.
- Describe how equipment works using electrostatic principles.
- Describe hazards and uses of electrostatics.
- Define an electric field.
- Represent diagrammatically the electric field lines around and between two points.
- Distinguish between the electric field inside, outside and between surfaces of a spherical metallic conductor.
- State Coulomb's law.
- Compare Coulomb's law and Newton's law of universal gravitation.
- Calculate the force acting on a charge due to two other charges placed on the same plane (line of action).
- Calculate the force between three charges placed in a line.
- Calculate the electric field strength at a point due to charges placed collinearly and at right angles.
- Define electric potential and its SI unit.
- Distinguish between absolute potential and potential difference.
- Show that 1 N/C = 1 V/m.
- Explain equipotential lines and surfaces.
- Draw equipotential lines and surfaces in an electric field.
- Define the term electric potential energy.
- Describe the structure of a simple capacitor.
- Define the term capacitance and its SI unit.
- Apply the definition of capacitance to solve numerical problems.

This unit should fill approximately **19 periods** of teaching time.

- Use the circuit symbol to represent a capacitor.
- Explain the charging and discharging of a capacitor.
- Define the term dielectric and explain what is meant by a dielectric material.
- Identify combination of capacitors in series, parallel and series–parallel.
- Explain the effect of inserting dielectric in the gap between the plates of a parallel plate capacitor.
- Derive an expression for the effective capacitance of capacitors connected in series and parallel.
- Draw an electric circuit diagram for a simple capacitor, series and parallel connections of two or more capacitors using symbols.
- Solve problems on combination of capacitors.
- Define parallel plate capacitor.
- Describe the factors that affect the capacitance of a parallel plate capacitor.
- Calculate the capacitance of a parallel plate capacitor.
- Find an expression for the electric potential energy stored in a capacitor.
- Calculate the energy stored in a capacitor using one of three possible formulae.
- State some uses of capacitors in everyday life.

This section should fill approximately **6 periods** of teaching time.

2.1 Electric charge

Learning Competencies

By the end of this section students should be able to:

- State the law of conservation of charge.
- Describe and explain the charging processes: charging by rubbing, conduction and induction.
- Perform an experiment to charge an electroscope by conduction and by induction.
- Describe the distribution of charge on a conductor of variable shape.
- Explain how lightning is formed.
- Describe the use of a lightning rod.
- Describe how equipment works using electrostatic principles.
- Describe hazards and uses of electrostatics.

Starting off

This unit introduces electrostatics and finishes by considering capacitors and capacitance, which are important in electronics. Many students will have experienced electrostatics in the form of the mild 'shock' from metal objects such as door handles. This section includes many practical activities that can be carried out in small groups. Encourage students to discuss their observations – by doing so they will be consolidating their understanding and supporting their peers in their learning.

Teaching notes

Begin by discussing students' experiences of electrostatic phenomena, as outlined in the Students' Book. The conservation of charge is an important concept for students to grasp, as is the concept that like charges repel and opposite charges attract. Activity 2.1 gives students an opportunity to make links between this section and the last unit – they should readily recall that angular momentum is another physical quantity that is conserved, for example. They may also talk about the conservation of energy.

We move on now to consider how materials can be charged using various methods. The first one considered is rubbing. You may wish to show students how rubbing a piece of Perspex can make it attract small pieces of paper (they will carry out a similar activity for themselves later in the unit).

Activity 2.2 demonstrates the attraction/repulsion between opposite/like charges.

You need to try Activity 2.3 yourself before you ask students to do it. You need to find out the best flow rate for the stream of water, and how much the comb needs to be rubbed in order to charge it sufficiently to attract the water stream.

Activity 2.4 is fun for the students though you might like to check that no one has a fear of balloons before you start! Students should be able to draw conclusions about the surface of the balloon and the surface to which it sticks.

We now consider charging materials by conduction. Students may have experienced this method of charging without realising what was happening, as outlined in the Students' Book. Activity 2.5 gives students an opportunity to charge an electroscope by conduction.

Go through the explanation of charging by induction carefully and ask questions along the way to check understanding. It would be worthwhile testing understanding further by asking students to redraw the diagrams in the Students' Book to show what happens if a positively charged rod is brought near a neutral metal sphere. The diagram produced should look like Figure 2.1 on this page.

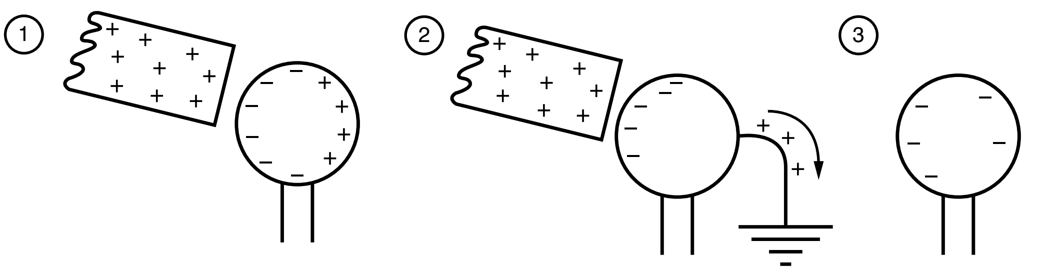


Figure 2.1

Activity 2.1: Answer

For example, momentum, angular momentum, energy

Activity 2.2: Answer

Students should conclude that the bar of Perspex carries a charge that is opposite to that of the rod of polythene.

Activity 2.3: Answer

The molecules in the water have a slight charge, which is called polarisation, and so the water stream has an overall charge that will result in it being attracted to the charged comb.

Activity 2.4: Answer

The surfaces must have opposite charges.

Activity 2.5: Answer

The electroscope has a fine sheet of gold leaf, which will move when charge is applied to the metal plate above it.

Activity 2.6: Answer

Students' own results.

Activity 2.7: Answer

The paper is attracted to the glass by electrostatic attraction, but this attraction is temporary as the glass will not hold its charge – it leaks away into the surrounding air.

Activity 2.8: Answer

It is charged.

Activity 2.9: Answer

Lightning rod conducts electric charge safely to ground so their it does not damage buildings.

Activity 2.10: Answer

The lightning will be conducted safely to earth by the body of the car.

Activity 2.11: Answer

Students' own results.

Activity 2.13: Answer

Students' own mind map.

Activity 2.6 tests understanding further by requiring students to devise and carry out an experiment to charge an electroscope by induction. By asking students to draw diagrams to explain what happens, we are testing their ability to communicate scientific ideas, which is an important skill to develop.

Activity 2.7 is an opportunity for students to carry out an investigation using small pieces of newspaper and a charged surface.

The next section on the distribution of charges on the surfaces of conductors is important ground work for the understanding of how lightning conductors work, which is covered a little later. You may wish to test students' understanding by giving them some other surfaces, such as the ones here, on which to draw the likely distribution of charge.

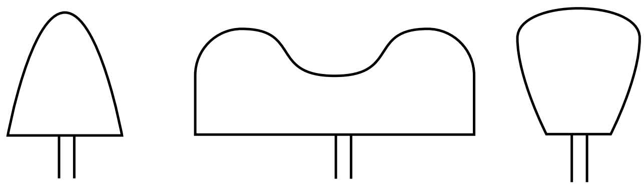


Figure 2.2

If you have access to a Van der Graaff generator, students will enjoy the demonstration outlined in Activity 2.8. If you cannot carry out the demonstration yourself, you could discuss the question posed in the Students' Book using the photograph as a stimulus.

Introduce the next section by talking about students' experiences of thunderstorms. What do they see? What do they hear? Can they describe how some tall buildings are protected from lightning? If so, can they use the information from this section to explain how lightning conductors work before they read the explanation in the Students' Book?

Divide the class into groups to discuss why the inside of a car is a safe place to shelter in a storm and to design a poster to show younger children how to stay safe in storms.

The section now moves on to discuss applications of electrostatics. Activity 2.12 gives students an opportunity to use their knowledge to design a model chimney filter. Before discussing how a photocopier works, you could arrange for the students to see one in action if you have one in school. Small groups would be best for this so that students can see the process clearly from start to finish. If you can arrange this you may want to ask students to attempt to explain what is going on before they read through the explanation in the Students' Book.

A brief discussion of the hazards of electrostatics comes before Activity 2.13 which requires students to summarise this area of the section using the technique of a mind map. This technique is a useful one for students to master as it can be used to summarise notes for revision at examination or test time.

SA = starter activity MA = main activity CA = concluding activity	
1. What is electric charge?	
SA	Activity 2.1 in small group.
MA	Activity 2.2 in small group.
CA	Review questions 1–3 to be tackled with a partner.
2. Electrostatic attraction	
SA	With a partner, discuss what is meant by 'electrostatic'. Feed back ideas.
MA	Activity 2.3 in small group. Activity 2.4 in small group.
CA	Review questions 4–6 to be tackled with a partner.
3. Charging materials	
SA	With a partner, discuss experiences of 'electric shocks'. Feed back where and how these occurred.
MA	Activity 2.5 in small group. Activity 2.6 in small group. Activity 2.7 in small group.
CA	Review question 7 to be tackled with a partner.
4. Distribution of charges	
SA	With a partner, discuss why charges on the surface of a conductor will spread out evenly. Feed back ideas.
MA	Activity 2.8 in a small group.
CA	Review question 8 with a partner.
5. Thunderstorms	
SA	Activity 2.9 in a small group.
MA	Activity 2.10 with a partner. Activity 2.11 with a partner.
CA	Review question 9 with a partner.
6. Applications of electrostatics	
SA	Activity 2.12 in a small group.
MA	Activity 2.13 in a small group.
CA	Review questions 10 and 11 to be tackled with a partner.

Activities

- Recalling physical quantities that are conserved.
- Testing how charged bodies attract or repel each other.
- Exploring the electrostatic attraction of water.
- Hanging balloons using electrostatic attraction.
- Charging an electroscope by conduction.
- Charging an electroscope by induction.
- Investigating charging by induction.
- Using a Van der Graaff generator to make a fluorescent tube glow.
- Discussion on how tall buildings may be protected from lightning.
- Explaining why the inside of a car is safe in a storm.

- Designing a poster on safety in storms.
- Designing a model chimney filter.
- Mind map about the uses and hazards of electrostatics.

Resources

http://www.school-for-champions.com/science/electrical-charges.htm
http://facstaff.gpc.edu/~pgore/Physicalscience/electric-charge.html

Where next?

The next section considers electric forces and fields. This extends the work in this section by considering why charges attract or repel in terms of electric fields.

Answers to review questions

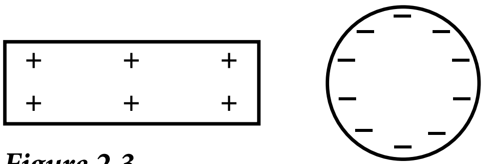
1. When there is moisture in the air, as there is on a damp day, the charged water molecules quickly remove charge from a charged object.
2. Most objects we meet in daily life appear to be uncharged because the positive and negative charges balance out – there are equal numbers of both.
3. 

   Figure 2.3
4. A plastic comb that has been rubbed will become electrostatically charged and so will attract small pieces of paper.
5. a) Plastic objects frequently become covered with dust because they may be slightly charged and thus dust is attracted to them by electrostatic attraction.
   b) By rubbing such objects with a duster one may in fact increase the charge on the object, which will, in turn, attract more dust.
6. The very fine charged droplets are attracted to the surface of the car, which is charged in the opposite way to the droplets of paint. The droplets of paint will spread themselves evenly over the surface of the car.
7. a) By rubbing an inflated balloon on your clothing, you charge that surface of the balloon, which can then stick on the ceiling.
   b) The balloon eventually drops off the ceiling because the charge on its surface will leak away to the surrounding air.
8. The distribution of charge on a sphere is uniform.
9. A lightning conductor is designed to conduct a lightning strike safely to earth so that it does not damage the building. It has a sharp point at its tip which collects the charge as shown in Figure 2.4.

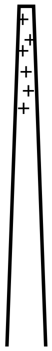


Figure 2.4

10. a) Some uses of electrostatics are: chimney filters, paint sprays, photocopiers.
    b) Some hazards of electrostatics are: lightning, sudden discharge causing damage to delicate electronic components.
11. Some antistatic device ares: antistatic bags, antistatic clothing, antistatic mats, antistatic wrist straps.

2.2 Electric forces and fields

This section should fill approximately **5 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Define an electric field.
- Represent diagrammatically the electric field lines around and between two points.
- Distinguish between the electric field inside, outside and between surfaces of a spherical metallic conductor.
- State Coulomb's law.
- Compare Coulomb's law and Newton's law of universal gravitation.
- Calculate the force acting on a charge due to two other charges placed on the same plane (line of action).
- Calculate the force between three charges placed in a line.
- Calculate the electric field strength at a point due to charges placed in a line and at right angles.

Starting off

This section does not contain as many practical activities as the last section. Students will need to be able to manipulate formulae and change the subject of an equation. Begin with a short quiz that checks that they are able to do this – use equations from Unit 1 such as $F = ma$, or $I = MR^2$. Ask students to explain the steps for rearranging an equation in their own words.

Teaching notes

Explain the concept of an electric field carefully. Activity 2.14 gives students an opportunity to consolidate their understanding by explaining given field plots. Note that this section has links to Section 4.2, so students need to understand it thoroughly to support later learning.

Activity 2.15 gives students a chance to see if they can apply their knowledge to a new situation. This is a valuable skill and should be encouraged wherever possible throughout the course.

Electric field strength is defined by a mathematical relationship between the force experienced by an electric charge in the field and the size of the charge. Remind students how to rearrange the equation using the triangle in Figure 2.5.

Ask students to explain the various stages of the worked examples in their own words. You could give them the problem without the working to see how far they can progress, and use the given working as a scaffold for their learning as necessary.

We then move on to consider the force between charges, which is summarised in Coulomb's law. Again, students are invited to make links with other learning

Activity 2.14: Answer

Students' explanation

Activity 2.15: Answer

Students' explanation

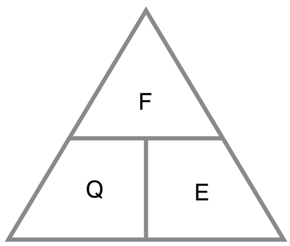


Figure 2.5

Activity 2.16: Answer

For example:

- Both inverse square relationship
- Newton's law attraction between masses, Coulomb's law attraction between charges
- Coulomb's law constant on denominator, Newton's law constant on numerator

in Activity 2.16 by comparing Coulomb's law to Newton's law of universal gravitation, which they met in Section 1.4. Making these links can help students to remember the formulae. Again, it would be valuable to ask students to explain the steps in the worked examples in their own words.

Activity 2.17 requires students to explain why the results in the worked examples demonstrate the inverse square relationship.

Activity 2.17: Answer

The key to this is that the distances are 1 m and 2 m, respectively, and the charges are the same, so one would expect the inverse square relationship to lead to one result being $\frac{1}{4}$ of the value of the other. If you divide 3.15×10^{11} by 7.875×10^{10} you find that the answer is 4, so 7.875×10^{10} is indeed $\frac{1}{4}$ of 3.15×10^{11}.

When we consider more than two charges, the key to solving the problems is a good diagram showing both size and direction of all the forces acting. Make sure that the students can follow the working in worked example 2.7.

SA = starter activity MA = main activity CA = concluding activity	
1. What is an electric field?	
SA	With a partner, summarise Student Book pages 60–61.
MA	Activity 2.14 with a partner.
CA	Review questions 1–3 to be tackled with a partner.
2. Explaining field patterns	
SA	With a partner, discuss how charges are distributed on the surface of a spherical conductor. Feed back ideas.
MA	Activity 2.15 with a partner.
CA	Research electric shielding with a partner.
3. Electric field strength	
SA	Feed back research from end of last lesson.
MA	Work with a partner to tackle examples of electric field strength calculations.
CA	Tackle review questions 4–7 with a partner.
4. Coulomb's law (1)	
SA	Activity 2.16 with a partner.
MA	Worked examples 2.5 and 2.6 to be tackled with a partner before solutions are revealed.
CA	Activity 2.17 with a partner.
5. Coulomb's law (2)	
SA	Worked example 2.7 to be tackled with a partner. Feed back ideas for approach to solution before given solution is revealed.
MA	With a partner, summarise page 66 of the Student Book.
CA	Review questions 8–9 to be tackled with a partner.

Activities

- Explaining field plots.
- Explaining field patterns.

- Comparing Coulomb's law and Newton's law of universal gravitation.
- Explaining how the results of calculations demonstrate the inverse square relationship.

Resources

http://library.thinkquest.org/10796/ch12/ch12.htm

http://www.colorado.edu/physics/2000/waves_particles/wavpart3.htm

Where next?

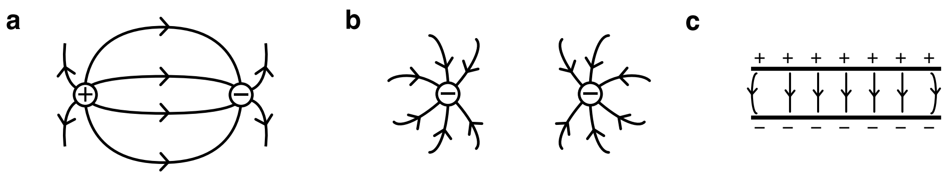
This section leads on to a consideration of electric potential in Section 2.3 and also links to Section 4.2.

Answers to review questions

1. The term 'electric field' means the region in which an electric charge will experience a force as a result of other electric charges being present.
2. The electric field around a a positive charge (a) and a negative charge (b) is shown below.

The arrows indicate the direction of a force on a positive charge.

3. The electric field around a positive and a negative charge (a), around two negative charges (b) and between two oppositely charged flat metal plates (c) is shown below.



4. The unit we use to measure electric charge is the coulomb. Its correct abbreviation is C.
5. $E = \frac{F}{Q}$ so $F = EQ = 18 \times 2 = 36$ N
6. The force would act in the opposite direction.
7. $E = \frac{F}{Q}$ $Q = \frac{F}{E} = \frac{12}{48} = 0.25$ C
8. $F = \frac{kQ_1 Q^2}{r^2} = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \times 3 \times \frac{2}{5^2} = 2.16 \times 10^9$ N
9. $F = \frac{kQ_1 Q^2}{r^2} = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \times 3 \times 10^{-12} \times 2 \times \frac{10^{-6}}{5^2} = 2.16 \times 10^{-10}$ N

This section should fill approximately **4 periods** of teaching time.

2.3 Electric potential

Learning Competencies

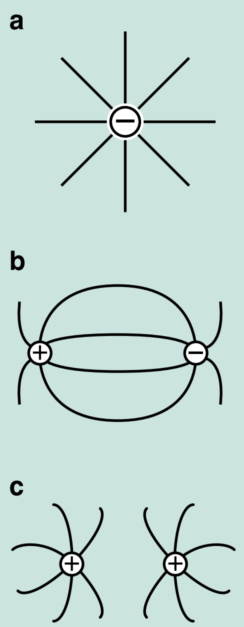
By the end of this section students should be able to:

- Define electric potential and its SI unit.
- Distinguish between absolute potential and potential difference.
- Show that 1 N/C = 1 V/m.
- Explain equipotential lines and surfaces.
- Draw equipotential lines and surfaces in an electric field.
- Define the term electric potential energy.

Starting off

This relatively short section introduces the important concept of electric potential and equipotential lines and surfaces. You need to ensure that students are confident with the concept of an electric field exerting a force on charged objects before beginning this section. You could give a short quiz to check that they are able to work out the force on various charges and the electric field strength equation. Base the questions on the worked examples in the last section.

Activity 2.18: Answer



Teaching notes

The section begins by defining electric potential at a point. It is worth stressing that the electric potential at a point is measured relative to that at infinity, as this concept is needed when we move on to show the difference between absolute potential and potential difference. Students need to understand the concept of potential difference when they study electric circuits in the next unit, so this is an important step in their learning and should not be rushed.

Work through the equivalence of 1 N/C and 1 V/m carefully. If you can get students to explain the steps in their own words they will be consolidating their understanding of the underlying concepts more thoroughly than they will by simply reading the text. As always, students need to be actively involved in their learning in order to ensure depth of understanding.

We move on now to consider equipotential lines and surfaces. It might be worth using analogies with which students are familiar here: for example, contour lines on maps show lines of equal altitude, isobars on weather maps show lines of equal pressure. This may aid students' understanding and help them to complete Activity 2.18, which requires them to draw equipotentials. Note that they have already met such diagrams in the last section: here we simply explain the precise nature of the diagrams more formally.

Before considering electric potential energy, revise potential energy that a body possesses because of its position. Give a few quick examples: for instance, what potential energy does a piece of chalk of mass 0.001 kg have when it is on a desk that is 1 m high? (PE = $mgh = 0.001 \times 9.81 \times 1 = 0.0098$ J).

Then consider electric potential energy and remind students about the principle of conservation of energy, i.e. that energy cannot be created or destroyed, simply converted from one form to another. Give some simple examples such as electric energy being used in a light bulb, where it is converted to light and heat energy.

SA = starter activity MA = main activity CA = concluding activity	
1. Electric potential	
SA	Discuss with a partner what they understand by 'potential energy'. Feed back ideas.
MA	Examples of calculating electric potential to be tackled with a partner.
CA	Review answers to problems from main activity.
2. Absolute potential an d potential difference	
SA	Discuss meaning of term 'absolute' with a partner. Feed back ideas.
MA	Produce a poster showing why 1 V/m = 1 N/C with a partner.
CA	Evaluate posters in small groups.
3. Equipotential lines and surfaces	
SA	With a partner, list as many words as possible that use 'equi'. Examples 'equilateral', equidistant, equiangular, equimolecular
MA	Activity 2.18 with a partner.
CA	Review question 4–5 to be tackled with a partner.
4. Electric potential energy	
SA	Experiment with compressing a spring. Discuss with a partner.
MA	Give examples of energy conversions in a small group.
CA	Review question 6 to be tackled with a partner.

Activities

- Drawing equipotentials.

Resources

http://www.rwc.uc.edu/koehler/biophys/4b.html

http://www.physicsclassroom.com/Class/circuits/u9l1b.cfm

Where next?

The next section considers capacitors and capacitance. Students will need the concept of potential difference when considering capacitors.

Answers to review questions

1. Electric potential at a point in space is potential energy divided by the charge that is associated with a static (does not vary with time) electric field. Its SI unit is the Volt.

2. To define absolute potential you need a reference point (for example, infinity). Then you can say that:

   electric potential at a point = work done per unit mass in bringing a small object from infinity to a point in an electric field.

   To define electric potential difference between two points *P* and *Q*, you need to assume the absolute electric potential at *P* is V_P and the absolute electric potential at *Q* is V_Q. Then the electric potential difference is $V_P - V_Q$

3. You can show that two quantities are equivalent by using their units.

   From the definition of *V* we can find its units in terms of N, m and C.

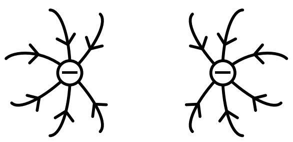
   $$V = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r}$$

   We know that the units for the constant term are N m^2 C^{-2}. The units for $\frac{q}{r}$ are C m^{-1}. So the units for *V* are N m^2 C^{-2} C m^{-1}.

   This can be simplified, using the laws of indices, to N m C^{-1}.

   If we divide this by m, to give V/m, we get N/C. So 1 V/m = 1 N/C.

4. Equipotential lines are lines showing where the electric potential is the same value. Equipotential surfaces are surfaces that have the same electric potential.

5. 

6. Electric potential energy is the energy a charge possesses because it is in the region of other charges.

This section should fill approximately **4 periods** of teaching time.

2.4 Capacitors and capacitances

Learning Competencies

By the end of this section students should be able to:

- Describe the structure of a simple capacitor.
- Define the term capacitance and its SI unit.
- Apply the definition of capacitance to solve numerical problems.
- Use the circuit symbol to represent a capacitor.
- Explain the charging and discharging of a capacitor.
- Define the term dielectric and explain what is meant by a dielectric material.
- Identify combination of capacitors in series, parallel and series–parallel.
- Explain the effect of inserting dielectric in the gap between the plates of a parallel plate capacitor.

- Derive an expression for the effective capacitance of capacitors connected in series and parallel.
- Draw an electric circuit diagram for a simple capacitor, series and parallel connections of two or more capacitors using symbols.
- Solve problems on combination of capacitors.
- Define parallel plate capacitor.
- Describe the factors that affect the capacitance of a parallel plate capacitor.
- Calculate the capacitance of a parallel plate capacitor.
- Find an expression for the electric potential energy stored in a capacitor.
- Calculate the energy stored in a capacitor using one of three possible formulae.
- State some uses of capacitors in everyday life.

Starting off

This section links to the next unit on current electricity. You may wish to cover some of that content before attempting this section; some of the explanations require a knowledge of Ohm's law, which is covered in Section 3.2, and there are parallels in, for example, the formulae for combinations of capacitors and the formulae for combinations of resistors (Section 3.3).

If you can get hold of some large capacitors from old TV power supplies, or a selection of capacitors from an electrical supplier, show these to the students. See if anyone knows what they are or where they might be used.

Teaching notes

This section begins by explaining what a capacitor is and the basic structure of a capacitor. It then moves on to consider capacitance and its SI unit. Make sure that students are comfortable with rearranging the equation linking capacitance, charge and potential difference between its terminals. Give plenty of practice based on the worked examples in the Students' Book. Remind students how to use the triangle in Figure 2.6 if they need it to help them change the subject of the equation.

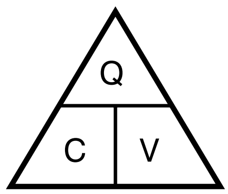
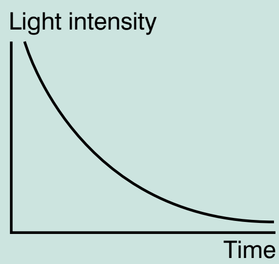


Figure 2.6

Activity 2.19: Answer



The section then moves on to consider the use of capacitors in electrical circuits. This links to the next unit and, as noted above, you may wish to cover some of that content before the content here. Activity 2.19 gives students the opportunity to observe what happens when a capacitor is connected to a battery to charge up and then discharged through a bulb. If students can attempt to draw a graph showing light intensity versus time to record their observations, then the later theory will be easier for them to grasp.

The explanation of the charging and discharging of a capacitor requires knowledge of Ohm's law, which is covered in Section 3.2. If students have not covered this section at this point then you will need to tell them the relationship $V = IR$ where V is potential difference, I is current and R is resistance in the circuit and explain that they will find out more about this in Section 3.2.

The concept of time constant for a circuit containing a capacitor is important, as it is this that gives capacitors their usefulness in, for example, timing circuits. Timing circuits often involve a variable resistor – again, it would be useful if students had covered resistors in Unit 3 before they study this area.

This section then discusses dielectric materials and how they are used to increase the capacity of the capacitor. You could perhaps use an analogy of putting a sponge in glass – the sponge will soak up liquid so that the total volume of liquid in the full glass is greater than that in the full glass without the sponge. Try demonstrating this and ask students to compare the two volumes!

Activity 2.20: Answer

Students' own results.

Most of the remainder of this section is fairly mathematical. Students will need to understand reciprocals and how to add fractions with different denominators. We consider combining capacitors in series and parallel circuits (combining resistors in series and parallel is covered in Section 3.3). Begin this section by letting students attempt Activity 2.20, which involves them charging and discharging series and parallel combinations of resistors. Give them plenty of opportunity to experiment and discuss their observations before you introduce the equations. When you do introduce the equations, work through the worked example carefully and ensure that the students understand the steps involved (ask them to explain them in their own words). Give further examples based on this worked example as necessary.

Activity 2.20: Answer

Students' own observations.

Before studying the section on factors that affect the capacitance of a parallel plate capacitor, see if students can come up with some possible variables that will change the capacitance. You could guide them by using pieces of card in pairs to represent the plates of a capacitor. For example, show them a model of a capacitor with two pieces of card, dimensions 10 cm × 5 cm, and ask them whether they think such a 'capacitor' would have greater capacitance if the cards were 2 cm apart or 5 cm apart. Then use two pieces of card dimensions 15 cm × 7 cm, and ask which of the two 'capacitors' will have greatest capacitance when the plates are same distance apart: the one with 10 × 5 plates or the one with 15 × 7 plates (think about amount of charge stored on plates). Students should see that capacitance is directly proportional to area (larger area gives more surface to store charge) and inversely proportional to distance between plates (smaller distance means more charge can be stored). Activity 2.21 gives students an opportunity to explore real capacitors.

Students may like to do some research on various values of ε (dielectric constant) for different materials, such as air, silicon and water.

The final mathematical section concerns the electric potential energy stored on a capacitor. Make sure that students remember the definition of electric potential energy from the last section. Work through the explanation of the reason for the formula being $E = \frac{1}{2}QV = \frac{1}{2}CV^2$ carefully, asking questions as you go to check understanding.

The section ends with a consideration of where capacitors are used in everyday life.

SA = starter activity MA = main activity CA = concluding activity	
1. Capacitors	
SA	Discuss with a partner why a larger sphere will have a larger capacitance. Feed back ideas.
MA	Activity 2.19 in a small group.
CA	Review questions 1–3 to be tackled with a partner.
2. Capacitor circuits	
SA	Discuss with a partner the meaning of the terms 'series' and 'parallel'. Feed back ideas.
MA	Activity 2.20 in a small group.
CA	Review questions 4–5 to be tackled with a partner.
3. Factors that affect capacitance	
SA	Discuss in a small group why capacitance is directly proportional to area but inversely proportional to distance between plates.
MA	Activity 2.21 in small groups.
CA	Review questions 6–11 with a partner.
4. Uses of capacitors	
SA	With a partner discuss what quantity capacitors store (energy). Feed back ideas.
MA	In a small group, research applications of capacitors. Produce a poster to summarise your findings.
CA	End of unit questions to be tackled with a partner.

Activities

- Charging and discharging capacitors.
- Charging and discharging series and parallel combinations of capacitors.

Resources

http://academic.greensboroday.org/~regesterj/potl/Electronics/Capacitors/caps.htm

http://Level1.physics.dur.ac.uk/skills/capacitors.php

Where next?

This section has close links with Unit 3 as described above. Students will also study circuits in Unit 5, Introduction to electronics.

Answers to review questions

1. A capacitor is a small device designed to store more charge at a lower potential. The commonest way of doing this is to use two parallel plates, a tiny distance apart and separated by an insulator (which may be air or may be a dielectric material).
2. If a charge Q results in a rise of V in the potential, we define the capacitance of the sphere by:

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

This is the charge needed for each volt rise in the body's potential. The units will be coulombs per volt, C V^{-1}, which we call farads, F.

3. a) $Q = CV = 2 \times 10^{-6} \times 6 = 0.000012$ C
   b) $E = \frac{1}{2} QV = \frac{1}{2} \times 0.000012 \times 6 = 0.000036$ J
   c) The energy has come from the electric potential energy as the charge is increased from 0 to 0.000012 C.
   d) If the capacitor is then discharged, the energy is transformed into other forms by the component through which the capacitor is discharged; for example, if the capacitor is discharged through a bulb then the energy is transformed into light and heat.

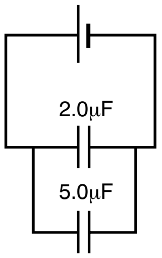


Figure 2.10

4. a) The capacitance = 2.0 μF + 5.0 μF = 7.0 μF (see Figure 2.10).
   b) The capacitance = $\frac{1}{2.0\ \mu F} + \frac{1}{5.0\ \mu F} = \frac{10}{7\ \mu F}$ (see Figure 2.11).

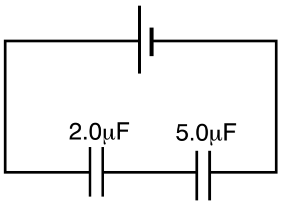


Figure 2.11

5. When a capacitor discharges through a resistor (or a bulb), the capacitor acts like a battery to drive a current through the resistor, but unlike a battery its voltage drops rapidly as its charge drains away. Think of a capacitor charged up to a voltage V_o, which is then emptied through a resistor R. When it is first connected, the discharging current is determined entirely by the resistor (since $I = V/R$ for it) – the higher the value of the resistor, the more slowly the capacitor will empty.

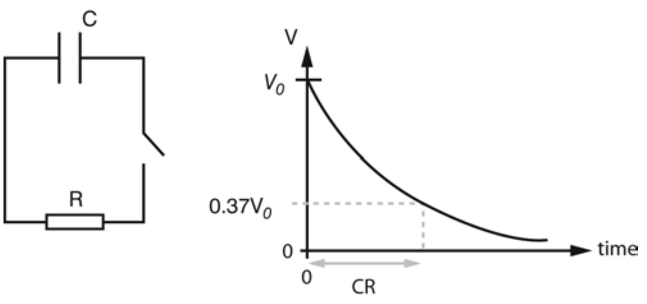


Figure 2.12

Figure 2.12 indicates how the charge remaining on the capacitor will decrease with time; the vertical axis actually shows the voltage across its plates, but this also provides a measure of the charge left.

As the capacitor empties, so the voltage across its plates drops. This decreasing voltage across the resistor R results in a reducing discharge current, so the capacitor empties ever more slowly. The resulting curve is what we call exponential decay.

We can work out how long it takes for the voltage to drop to 0.37 of its starting value (by which time the capacitor has almost two-thirds emptied). We do this by multiplying C by R. This gives what we call the time constant of the circuit.

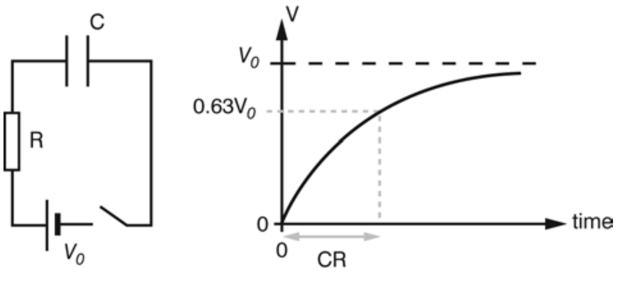


Figure 2.13

When a capacitor is charged through a resistor we have the opposite to the discharge situation. Here the capacitor charges rapidly at the start, but this then continues at an ever-declining rate. It is a kind of 'upside down' exponential curve. When the voltage between the plates of the capacitor equals that of the battery, the charging ceases (see Figure 2.13).

This time when the time constant has elapsed the capacitor is almost two-thirds full. Such a circuit can be used as the basis for a timing circuit. When the voltage across the capacitor reaches a certain value, it causes something else to occur – a light to come on, for instance. If a control is provided by which you can adjust the time delay, you will be altering a variable resistor to change the value of R.

6. A dielectric is the electrically insulating material between the metallic plates of a capacitor. The advantage of using a dielectric is that it stops the two charged plates coming into contact with each other.
7. A dielectric increases the capacitance of the capacitor (so a greater charge can be stored at a given voltage).
8. A parallel plate capacitor has two plates that are parallel to each other. If a capacitor has two plates each of area A separated by a distance d, then it is possible to calculate what its capacitance C will be by using the relationship:

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

   The symbol ε is a constant, which varies according to the dielectric that is used to separate the plates.

   The capacitance depends on the dielectric, the area of the plates and the distance between them.
9. $5 \times 10^{-6} = 7.1 \times 10^{-12}\ \text{F m}^{-1} \frac{A}{0.4} \times 10^{-3}$ so $A = 5 \times 10^{-6} \text{ x } 0.4 \times \frac{10^{-3}}{7.1}$

   $\times 10^{-12}\ \text{F m}^{-1} = 281.7\ \text{m}^2$

10. Energy $= \frac{1}{2}QV$
    $= \frac{1}{2}CV^2$

11.

Energy (J)	C (F)	V (v)
?	100×10^{-6}	22.5

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

$= \frac{1}{2}\,100 \times 10^{-6} \times (22.5)^2$

$= 0.025$ J

Answers to end of unit questions

1. Take a bar of Perspex and pivot it, for example by suspending it by a nylon thread. Charge the suspended bar by rubbing it. Bring a second charged Perspex rod up to the first one, and the first one will swing away.

   Now charge the bar of Perspex again. Bring a charged rod of Polythene up to the suspended rod, and you will see the suspended rod move towards it. The bar of Perspex and the rod of Polythene have opposite charges.
2. The metal exterior of the car will conduct any static charge from lightning safely to Earth so that it will not touch you.
3. a) $F = QE = 4 \times 5 = 20$ N

   b) Coulomb's law states that the force between two point charges is inversely proportional to the square of the distance between them.

c) Both Coulomb's law and Newton's law of universal gravitation are inverse square relationships.

4. An equipotential is a line along which all the points have the same electric potential.

5. a) A capacitor is a small device which is used to store more charge at a lower potential.

   b) Some uses of capacitors in everyday life include in a camera flash, to provide a break in a direct current circuit, to allow alternate currents to pass, to link two stages of an amplifier and as the basis for a timing circuit.

   c) In series total capacitance = 3.33 μF whereas in parallel

   total capacitance = 15 μF so parallel arrangement gives higher capacitance.

   d) Capacitance is inversely related to distance between plates, so if distance doubles capacitance will halve in value if all other factors are constant. So capacitance of *A* is half capacitance of *B*.

6. a) $E = \frac{v}{d}$

$= \frac{30}{0.02}$

$= 1500 \text{ vm}^{-1}$

$F = EQ$

$= 1500 \times 1.5 \times 10^{-19}$

$= 2.25 \times 10^{-16} \text{ N}$

   b) $a = \frac{F}{M}$

$= \frac{2.25 \times 10^{-16}}{9.1 \times 10^{-31}}$

$= 2.47 \times 10^{-14} \text{ mls}$

   c) If positive plate is the lower one, the electron will accelerate downwards.

   d) $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$

$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$

$= \frac{0.1}{5 \times 10^{6}}$

$= 2 \times 10^{-8} \text{ s}$

Current electricity

Unit 3

Learning Competencies for Unit 3

By the end of this unit students should be able to:

- Define electric current and its SI unit.
- Explain the flow of electric charges in a metallic conductor.
- Calculate the number of electrons that pass a point at a given length of time when the current in the wire is known.
- Describe factors affecting the resistance of a conductor.
- Write the relationship between resistance R, resistivity ρ, length l and cross-sectional area A of a conductor.
- Calculate the resistance of a conductor using the formula $R = \rho l/A$.
- Find the relationship between resistivity and conductivity.
- Construct and draw an electric circuit consisting of a source, connecting wires, resistors, a switch and a bulb using their symbols.
- Explain why an ammeter should be connected in series with a resistor in a circuit.
- Explain why a voltmeter should be connected in parallel across a resistor in a circuit.
- Do experiments using an ammeter and a voltmeter to investigate the relationship between current and p.d. for metallic conductors at constant temperature.
- Identify combinations of resistors in series, parallel and series–parallel connection.
- Derive an expression for the effective resistance of resistors connected in series.
- Derive an expression for the effective resistance of resistors connected in parallel.
- Calculate the effective resistance of resistors connected in series.
- Calculate the effective resistance of resistors connected in parallel.
- Calculate the current through each resistor in simple series, parallel and series–parallel combinations.
- Calculate the voltage drop across each resistor in simple series, parallel and series–parallel connections.
- Define the electromotive force of a cell.
- Distinguish between e.m.f. and terminal p.d. of a cell.
- Write the relationship between e.m.f., p.d., current and internal resistance in a circuit.
- Use the equation $V = E - Ir$ to solve problems in a circuit.
- Identify cell combinations in series and parallel.
- Compare the e.m.f. of combinations of cells in series and parallel.

This unit should fill approximately **14 periods** of teaching time.

- Define electrical energy and power in an electrical circuit.
- Find the relationship between KWh and joule.
- Use $P = VI = \frac{V^2}{R} = I^2R$ to solve problems in electric circuits.
- Use $W = VIt = I^2Rt = \frac{V^2}{R}$ to calculate electric energy dissipated in an electric circuit.
- Calculate cost of electrical energy expressed in KWh.
- Understand the dangers of mains electricity.
- Have some awareness of safety features incorporated in mains electrical installations.
- Understand the nature of the generation and supply of electricity in Ethiopia.
- Consider employment prospects in Ethiopia's electricity industry.

This section should fill approximately **2 periods** of teaching time.

3.1 Electric current

Learning Competencies

By the end of this section students should be able to:

- Define electric current and its SI unit.
- Explain the flow of electric charges in a metallic conductor.
- Calculate the number of electrons that pass a point at a given length of time when the current in the wire is known.

Starting off

It is important that students realise that electric current is closely related to the static electric charges they met in Unit 2 – electric current is what happens when these charges move.

If you have access to a Van de Graaff generator, you can introduce the idea of current very dramatically. Figure 3.1 below (part a) shows a girl with long hair, standing on a polythene bowl, being slowly charged up by a Van de Graaff generator. The electric charges slowly trickle up her arm, spread over the surface of her body and cause her hair to rise (every single one of those charges is repelling all the rest). She has been filled up with charge by means of this gentle trickle, this tiny electric current, which continued to flow for a minute or so.

In (b) she starts to shake hands with another person who is standing on the floor. In an instant, all that charge rapidly flows down her arm, jumps the air gap to the

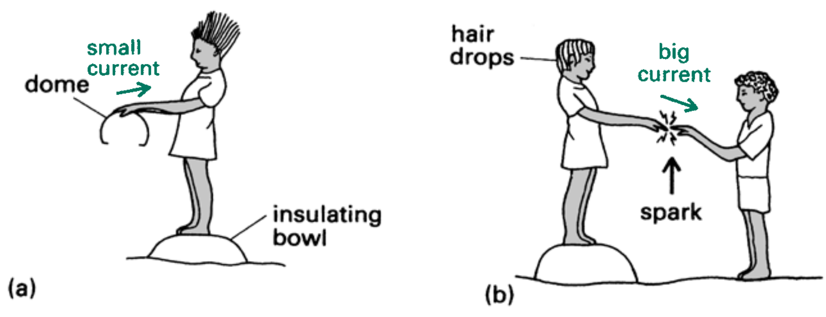


__Figure 3.1__ (a) The girl is slowly charged up by a small current. (b) She is rapidly emptied of charge.

other person and escapes down to earth. She has emptied of charge by means of a large electric current lasting for a very short time. It is the size of this current that determines the severity of the shock; she did not notice the small current that filled her up, but the rapid emptying gave a short, sharp shock.

Teaching notes

Students should be able to construct a galvanometer to detect when an electric current is flowing.

Introduce the units used in studying electric current – the amp and the volt. Some investigation/private research could be set for the students to discover the people behind the unit names.

Introduce the concept of 'conventional current' carefully. This is the convention for showing the flow of electricity in a circuit, which was established when it was assumed that charge flowed round a circuit from the positive to the negative pole of a cell. Although it is now known that the flow of charge is actually a flow of electrons in the opposite direction (from the negative to the positive pole) the convention of showing the flow of positive charge from positive to negative is used on diagrams.

The activity 'investigating the direction of current flow' should fix in students' minds the idea that current does move, and that the way in which the circuit is connected is important.

In the activity 'testing conductivity in different materials' students will see when electric current flows through a material because the light bulb becomes illuminated, showing that electric current is flowing. Electric current flows through materials that are good 'conductors' of electricity. These materials, mostly metals, possess electrons, which are only weakly attached to their atoms and are thus free to move. If a supply of energy is applied to a conductor, electric charge flows through it forming an electric current. Students will also see that some materials do not conduct electricity at all. They will see that these are used as 'insulators'.

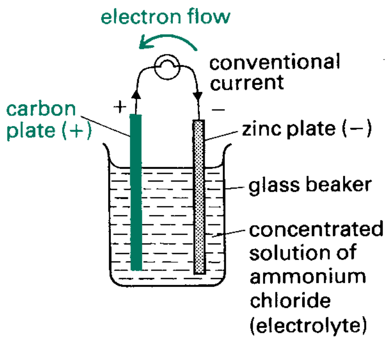


Figure 3.2

A cell provides energy to make current flow in a circuit because the chemicals within the cell produce a potential difference between its positive and negative poles. This potential difference (p.d.) causes current to flow if a circuit is connected between the poles of the cell. The students will see from the fruit cell activity that using different combinations of metals as electrodes will produce a different p.d.

Summary of cell types

A **primary cell** produces electricity as a result of chemical action in the cell and is usually irreversible.

A **secondary cell** is 'charged' by passing current through it in the opposite direction to that taken when it is discharging. The actions in this cell (an example is the lead–acid accumulator) are reversible.

There is also the electrolytic cell which does not produce electricity but, when its electrodes are connected to a source of direct current, will decompose an electrolyte (electrolysis). It can be used to plate one electrode with ions of the electrolyte (electroplating).

Make sure the students are clear on the differences between the types of cell.

The specific uses of the thermocouple thermometer could be studied, and the Seebeck effect studied. http://www.thermoelectrics.com/introduction.htm

SA = starter activity MA = main activity CA = concluding activity	
1. Electric current	
SA	Activity 3.1 in small groups.
MA	Activity 3.2 in small groups.
CA	Write a report on the activities in this lesson with a partner.
2. Cells and thermocouples	
SA	Activity 3.3 in small groups.
MA	Activity 3.4 in small groups.
CA	Activity 3.5 in small groups. Review questions to be tackled with a partner.

Activities

- Constructing a galvanometer.
- Testing conductivity in different materials.
- Making an electrochemical cell.
- Investigating the direction of current flow.
- Making a thermocouple thermometer.

Resources

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elecur.html

http://science.howstuffworks.com/electricity1.htm (has some adverts)

www.mpoweruk.com/chemistries.htm

www.allaboutcircuits.com/vol_1/chpt_9/5.html

Where next

More work could be done on the 'fruit cell' – linking the size of the voltage produced by particular metals to their position in the electrochemical series.

Students could experiment using other equipment and solutions in place of the juice in the fruit.

Students might be interested to hear about the strange phenomenon of superconduction. If the resistance of metals goes up when you heat them, then it must get less when you cool them. At very low temperatures, within a few degrees of absolute zero (–273°C), some metals develop a fascinating property: their resistance drops to nothing. They become superconducting. The resistance is not simply very small; it is literally nil. If a current once starts in such a circuit it will continue to flow, even though there is no battery. An application of this is seen in the memories of some large computers. A vast number of tiny circuit loops, immersed in liquid helium at 4 K, can store such currents indefinitely.

Answers to review questions

1. a) 3 C
   b) 36 C
   c) 360 C
2. 0.2 s
3. 300 s (5 minutes)
4. a) 1.9×10^{20}
   b) 1.0×10^{-5} kg (0.010 g)
5. Coulomb, measures charge
6. You would expect same e.m.f. but lifetime of smaller one would be shorter.
7. A primary cell uses the chemicals in it to supply electrical energy; a secondary cell has to be charged up first.
8. a) 30 °C
   b) 110 °C
   c) −10°C
9. a) Heat conduction is fast in the small thermocouple junction; heat has further to travel in the larger mercury-in-glass thermometer.
   b) Heat conduction is fast in the metal from which the thermocouple junction is made; heat passes more slowly through the glass – which is an insulator – of a mercury-in-glass thermometer.

   Both these factors allow the thermocouple junction measuring probe to respond more quickly than a mercury-in-glass thermometer.
10. As a result of its atomic structure, an uncharged metal wire contains conduction electrons (one or two electrons in an uncharged metal atom are free to move within the structure of the metal). When a cell is connected to a metal wire, these electrons move from the negative terminal of the cell to the positive terminal, forming an electric current.

3.2 Ohm's Law and electrical resistance

This section should fill approximately **3 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Describe factors affecting the resistance of a conductor.
- Write the relationship between resistance R, resistivity ρ, length l and cross-sectional area A of a conductor.
- Calculate the resistance of a conductor using the formula $R = \rho l/A$.
- Find the relationship between resistivity and conductivity.
- Construct and draw an electric circuit consisting of a source, connecting wires, resistors, a switch and a bulb using their symbols.
- Explain why an ammeter should be connected in series with a resistor in a circuit.
- Explain why a voltmeter should be connected in parallel across a resistor in a circuit.
- Do experiments using an ammeter and a voltmeter to investigate the relationship between current and p.d. for metallic conductors at constant temperature.

Starting off

The construction and study of electric circuits is important in this section. Students will need to remember that electric current will flow around a circuit only if the circuit is complete.

It will be particularly helpful if you have sufficient equipment – cells, resistors, light bulbs, connecting wires, and possibly ammeters and voltmeters – to allow students to get some first-hand experience with electric circuits.

Teaching notes

Use the voltmeter and ammeter in the first activity (using a resistor not a light bulb) to find results that demonstrate Ohm's law. Make sure that you tell the students that you will be looking in more detail at the way the ammeter and voltmeter are used later in this section. Stress the importance of Ohm's law in the many calculations that arise in studying electric circuits.

You will be using a variable resistor in this activity and students might be interested to learn more about this piece of equipment.

The current goes into a coil of bare resistance wire and escapes via the slider.

Moving the slider to the right in Figure 3.3 would introduce a greater length of the resistance wire into the circuit, which would mean that there would be more ohms of resistance.

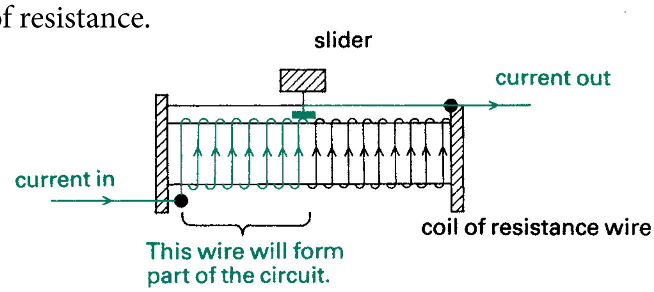


Figure 3.3 *How a variable resistor works*

Introduce the unit of measurement of resistance, the ohm. Some investigation/private research could be set for the students to discover the man behind the unit name.

Demonstrate the effect of heat on resistance of a conductor. 'Repeat' the activity in which Ohm's law was discovered, but this time using a light bulb as the resistor. Show the students what happens to the ammeter reading as the bulb glows. Discuss the reason for poor electrical conduction at high temperatures. (You might need to remind students that the light from a 'conventional' light bulb arises from the fine piece of wire (the filament) within the glass bulb becoming hot and glowing white hot. You can introduce calculations using the formula $\Delta R = \alpha R_0 \Delta\theta$.

Demonstrate the effect of length and cross-sectional area on conduction (Activity 3). Use the analogy of a large flow of water through a wide pipe compared with a small flow through a narrow pipe. Introduce calculations using the formula $R = \frac{\rho l}{A}$.

Use the concepts of resistivity and conductivity.

Make sure students are confident with the basic symbols used in drawing electric circuits – the cell, the resistor, variable resistor, light bulb, ammeter, voltmeter. Ask them to draw circuits used in this section.

Discuss the correct position of an ammeter. Demonstrate that the ammeter has the same reading at all points in a series circuit.

Demonstrate the correct position for a voltmeter. Encourage the students to consider what the voltmeter is doing (make sure they don't get the idea that it is measuring volts flowing through it!): it is 'sampling' the potential at two points in the circuit and displaying the difference in potential between the two points.

SA = starter activity MA = main activity CA = concluding activity	
1. Resistance	
SA	With a partner, discuss the meaning of 'resistance'. Feed back ideas.
MA	In a small group, measure the resistance of a variety of resistors.
CA	With a partner, make a poster about Ohm's law.
2. Factors affecting resistance	
SA	Ohm's law calculations to be tackled with a partner.
MA	In a small group, explore the effect of heat on resistance.
CA	Write a report on the investigation. Does a bulb obey Ohm's law? Discuss with a partner.
3. Resistivity and conductors	
SA	With a partner, discuss how resistance, resistivity, length and cross–sectional area of a conductor could be related. Feed back ideas.
MA	With a partner, summarise pages 97–100 of the Student Book.
CA	Review questions to be tackled with a partner.

Activities

- Investigate resistance of a resistor – vary the current (arrive at Ohm's law) (need to use voltmeter correctly here).
- Investigate resistance of a resistor – vary the temperature (light bulb).
- Investigate resistance of resistor – vary length and cross-sectional area.
- Construct a range of electrical circuits.
- Draw electric circuits using symbols.
- Use an ammeter to measure current (at various points in the circuit).
- Use a voltmeter to measure p.d.

Resources

www.physics.uoguelph.ca/tutorials/ohm/Q.ohm.intro.html
www.gcse.com/circuit_symbols.htm

Where next

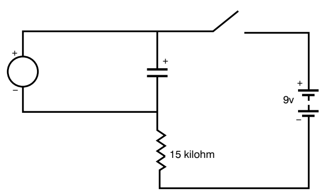


Figure 3.4

You can demonstrate how the capacitor stores and releases charge if it seems relevant. Take a 9 volt battery plus connectors, a 470 μF electrolytic capacitor, a 15 kilohm resistor, a switch, a voltmeter plus connectors, a timer measuring in seconds and some graph paper.

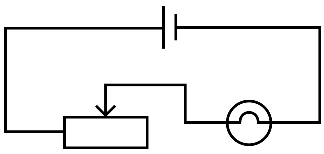
Connect the circuit as shown in Figure 3.4, being careful to connect the capacitor the correct way round. If the voltage reading is not zero, it shows that the capacitor retains charge from a previous application. This charge will need to be discharged. To do this, touch both leads of the capacitor with the ends of a connecting lead at the same time. This will allow the charge to equalise between the two plates of the capacitor. Close the switch and record the voltage reading every 5 seconds for 70 seconds. Plot a graph of voltage against time. It should form a rising exponential curve. Test the voltage of the battery and compare it with the maximum voltage reached by the capacitor – the two figures should be the same. It could be interesting to repeat this for different values of capacitor.

Answers to review questions

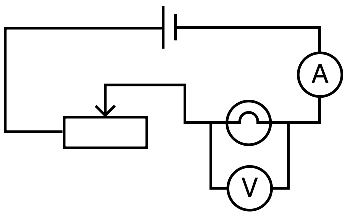
1. 0.5 A
2. a) 8 Ω

   b) The current would initially be more than 0.3 A (Resistance stays the same, voltage increases greatly from 2.4 to either 110 or 220 V. From Ohm's Law $I = \frac{V}{R}$ if there is a large voltage increase, there is a large increase in current.

   c) The bulb would go out very quickly. This is because the large current would cause the wire in the bulb to heat up to a very high temperature, causing it to break. This is what happens inside a fuse (see Section 3.6)
3. 0.06 Ω
4. 18.7 Ω
5. a)



b)



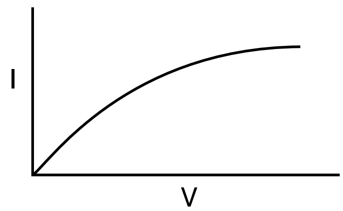
c) i) Make a table with two columns. Label the first 'voltage', the second 'current'.

ii) Connect the circuit shown in b (above) and take readings from the voltmeter and ammeter, recording them in the table.

iii) Adjust the variable resistor and take readings from the voltmeter and ammeter, recording them in the table.

iv) Repeat step (iii) for a range of readings.

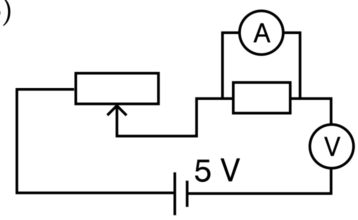
v) Use the readings from the table to plot a graph of current against voltage. The graph will be of this shape:



d) The graph above shows that the resistance of the bulb increases at higher voltages. To demonstrate Ohm's Law, replace the bulb with a resistor and repeat the steps in c (i to v) above.

6. a) In the diagram, the voltmeter is connected across the cell, it should be connected across the resistor.

   b)



7. A cell, consisting of two electrodes separated by an electrolyte, generates an electromotive force. A battery is a group of separate cells.

3.3 Combinations of resistors

This section should fill approximately **3 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Identify combinations of resistors in series, parallel and series–parallel connection.
- Derive an expression for the effective resistance of resistors connected in series.
- Derive an expression for the effective resistance of resistors connected in parallel.
- Calculate the effective resistance of resistors connected in series.
- Calculate the effective resistance of resistors connected in parallel.
- Calculate the current through each resistor in simple series, parallel and series–parallel combinations.
- Calculate the voltage drop across each resistor in simple series, parallel and series–parallel connections.

Starting off

Discuss the way in which electric circuits in Sections 3.1 and 3.2 have been connected. Introduce the idea that this way is called 'in series' and that there is another important way of connecting components in a circuit that they are about to learn.

Teaching notes

Series circuit – make sure students can see how current decreases as the number of light bulbs connected in a series circuit increases (the lights become dimmer; also see the ammeter reading). Use analogy of runners having to queue up to go through narrow gates.

Make sure students realise what happens if one of the bulbs is removed – no current flows in any part of the circuit. (Analogy of runners being faced with a wall built across the track, or of a path where a bridge over a river is removed.)

Measure current and also p.d. across all *resistors* (not bulbs, see Section 3.2) and show the students that the total resistance in the circuit is the sum of the individual resistances. $R = R_1 + R_2 + R_3 + ... + R_n$.

Make sure that students see that the current is the same at all points in the circuit. Demonstrate that the sum of the p.d. across each individual resistor equals the p.d. across the cell, (V) $V = V_1 + V_2 + V_3 + ... + V_n$

Parallel circuit – make sure students can see how additional lights connected in parallel appear to each glow as brightly as one on its own. Use analogy of runners having several gates to use – there is no queuing up so less slowing down.

Make sure students realise what happens if one of the bulbs connected in parallel is removed – remaining bulbs stay lit.

Measure current through each resistor (resistor, not bulb see Section 3.2) (I_1, I_2, ... I_n) and current through the unsplit part of the circuit (I). Discover that $I = I_1 + I_2 + ... + I_n$.

Measure the p.d. across each resistor. Discover that the p.d. is the same across each resistor. $V = V_1 = V_2 = V_3 \ldots = V_n = V$

Using Ohm's law to calculate the current through each resistor:

Current through resistor 1 = … current through resistor 2 =

current through resistor 3 = ... current through resistor n =
Therefore, considering total current in circuit, I = sum of current flowing through each resistor. Therefore = + + + ... + and as $V = V_1 = V_2 = V_3$ etc. = + + ... +
Make sure students know that circuits can have both series and parallel elements. Demonstrate such a circuit and make sure students can draw a circuit diagram.

SA = starter activity MA = main activity CA = concluding activity	
1. Series and parallel circuits	
SA	With a partner, write down all you can remember about capacitors in series and parallel. Feed back ideas.
MA	Activity 3.6 in small groups.
CA	With a partner, discuss how resistors in combination behave compared to how capacitors in combination behave.
2. The voltage drop across resistors in parallel	
SA	Worked example 3.12 to be tackled with a partner. Feed back ideas on solution before given solution revealed.
MA	In a small group investigate the statement 'if resistors are connected in parallel, they all have the same voltage drop across them'.
CA	With a partner, write a report on the investigation. Do your results support the statement?
3. Combining resistors	
SA	Worked example 3.13 and 3.14 to be tackled with a partner. Feed back ideas on solution before given solution revealed.
MA	With a partner, make a poster to summarise the three lessons in this topic.
CA	Review questions to be tackled with a partner.

Activities

- Connect resistors in a range of series circuits; study current and p.d. at various points.
- Connect resistors in a range of parallel circuits; study current and p.d. at various points.
- Show how more complex circuits can include a variety of series and parallel components; suggest uses.

Resources

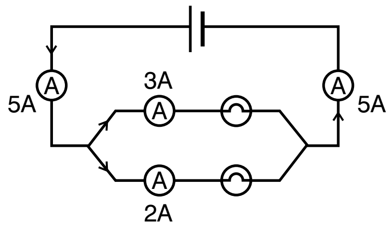
http://physics.bu.edu/py106/notes/Circuits.html

Where next

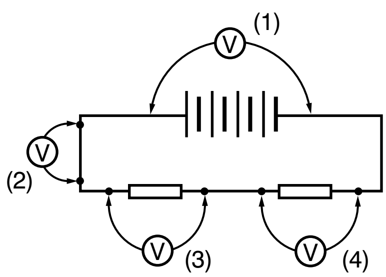
Find circuits with practical applications which use both series and parallel elements. Discuss these with the students. If there is time, introduce Kirchhoff's laws.

With lamps connected in series, if one bulb fails, the circuit is broken and all the lights go out. This problem is avoided if the lamps are connected in parallel instead

You can check the currents by placing ammeters in the circuit as shown.



The readings next to the ammeters are a possible set of values that you might obtain. When the current gets to the fork in the circuit, if the two branches are identical the flow will split up evenly. With the circuit as drawn, the upper branch must provide the easier route for the charge to flow through, which is why more of the current takes that path. Whatever way it splits up, though, notice that the two currents in the separate branches add up to the current approaching the junction. Each second 5 coulombs of charge arrive there: 3 coulombs take one route, so the other 2 coulombs must take the other route. This is Kirchhoff's current law.
Set up a circuit like Figure 3.6 below. The resistors may be light bulbs, lengths of resistance wire, variable resistors or whatever you have handy. You do not need four voltmeters; one will do, moved to each of the four locations in turn.



See what your circuit gives, but one possible set of readings are these: (1) 6 V; (2) 0 V; (3) 2 V; (4) 4 V. Your readings will differ, but the two points you should agree on are these:

1. There is no voltage drop down a conducting lead.

2. The voltage drops across each resistor in series add up to the voltage of the battery.

This is known as *Kirchhoff's voltage law*.

Answers to review questions

1. a) 0.7 A

   b) 0.5 A

   c) 0.7 A

   The bulb shown by the arrow will be brightest, this is because it has the largest current passing through it.

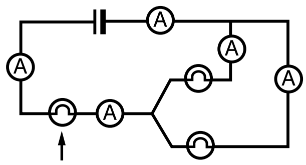


Figure 3.5 *The current splits at the junction in the circuit*

2. a) 4 A

   b) 6 A

   Each bulb has a difference resistance. More current will pass through a bulb which has a small resistance than will flow through a bulb with a high resistance.

3. c) 2.5 A

   d) 5 A

   The bulbs through which a current of 5 A passes will be brighter than those through which a current of 2.5 A passes.

4.

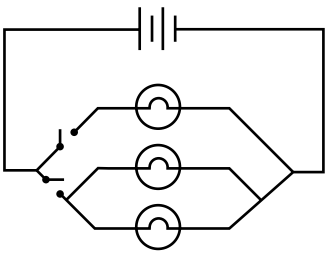


Figure 3.6 *Investigating voltage drops in a series circuit*

5. a) 2 Ω

   b) 3 Ω

   c) 2 A

6. 3 Ω

7. 20 Ω; 2.5 A

8. a) 6 Ω

   b) 2 A

9. (*Question 10 in the Students' Book)*

   a) 150 Ω

   b) 0.02 A = 20 mA

   c) 1 V

3.4 E.m.f. and internal resistance of a cell

This section should fill approximately **3 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Define the electromotive force of a cell.
- Distinguish between e.m.f. and terminal p.d. of a cell.
- Write the relationship between e.m.f., p.d., current and internal resistance in a circuit.
- Use the equation $V = E - Ir$ to solve problems in a circuit.
- Identify cell combinations in series and parallel.
- Compare the e.m.f. of combinations of cells in series and parallel.

Starting off

Remind students about electromotive force (e.m.f., introduced in Section 3.1). Remind students that a voltmeter measures the potential between two points.

Teaching notes

a Test the p.d. across the terminals of a cell.

b Connect the cell into a circuit and test the p.d. across the cell.

Show the pupils that the reading taken in **b** is lower than that in **a**. Encourage students to think about what is happening in **a** and **b**. In **a** there is no flow of electric current, while in **b**, the cell is driving current through a circuit. In Section 3.2 students have seen and measured the p.d. across resistors. Encourage them to realise that there is a resistance *inside* the cell that is causing the reading in **b** to be lower than that in **a**. The resistance inside the cell is known as internal resistance and is shown using the variable r. Internal resistance should be taken into account when performing calculations in a circuit.

Show that the e.m.f. (E) of a cell equals the p.d. across the *total* resistance in the circuit (total p.d. in the circuit = p.d. across the cell's internal resistance r plus p.d. across any external resistor R). OR E = p.d. across cell + p.d. across resistor, and using Ohm's law $V = IR$:

$E = Ir + IR$, which can be rearranged to give (for example) voltage (V) across resistor $V = E - Ir$

Demonstrate to students (and then let them try themselves if possible) what happens if more than one cell is linked together in a circuit. Try several arrangements.

1. Connect two cells positive to negative in series with a light bulb. Connect one or two more cells (again positive to negative) in the circuit and make sure students realise the bulb glows more brightly.
2. Using the circuit from 1, connect one or more of the cells positive to positive and let the students see the light glowing less brightly. Explain that this is because the cells are trying to push the current against each other and will cancel each other out.

3. Experiment with cells connected in parallel and see what happens to the brightness of the light bulb. The students will see that the light glows as brightly, however many cells are connected.

SA = starter activity MA = main activity CA = concluding activity	
1. Electromotive force and terminal voltage	
SA	With a partner, write a definition of electromotive force. Feed back ideas.
MA	Activity 3.7 in a small group.
CA	Discuss results of activity 3.7 in small group.
2. Emf, current and internal resistance	
SA	With a partner, discuss the meaning of the term ‘internal resistance’. Feed back ideas.
MA	In a small group, consider Figure 3.46 and try and derive an expression for E, the cell’s emf, in terms of I, V, R and r.
CA	Worked example 3.15 to be tackled with a partner. Feed back ideas on solution before given solution revealed.
3. Combinations of cells	
SA	With a partner, discuss Figure 3.47. What do you think the total emf would be in each case if one cell has an emf of 1.5 V?
MA	Activity 3.8 in small group.
CA	Review questions to be tackled with a partner.

Activities

- Measure the e.m.f. and the terminal p.d. of a cell.
- Connect cells together in series and in parallel, and measure the voltage of the resulting battery of cells.

Resources

http://science.uwaterloo.ca/~cchieh/cact/c123/emf.html
http://fizzics.co.uk/emf.aspx
www.batteryuniversity.com/partone-24.htm

Where next

When connecting cells in parallel and discovering that the light bulb in the circuit glows as brightly however many cells are connected (step 3 above), students will wonder what difference the number of cells makes. The answer is that the bulb will burn for longer when several cells are connected in parallel than if a single cell is used.

Answers to review questions

1. Think of electric current as a flow of positive charges around a circuit. These are ‘pushed’ from the ‘+’ terminal of a cell, around the circuit and ‘pulled towards’ the ‘–’ terminal of the other cell.

   a) If the ‘+’ terminals of both cells were connected together, they would be ‘pushing’ against each other and no charges would flow around the circuit.
   b) An ammeter is specially designed to allow current to flow very easily though it in one direction, and if it flows the other way, the current ‘twists’ the

ammeter in the wrong direction and damages it. To stop this happening, one terminal of the ammeter is marked with a '+' to show which terminal should be connected to the '+' side of the cell.

2. 0.6 A
3. a) 1 A b) 0.6 A
4. a) Where the voltmeter is connected in the diagram is effectively the same as connecting it between A and B, as there is no resistance between the connection points at A or B.
   b) 2 A c) 3 V
5. a) 5 A b) 60 V

3.5 Electric energy and power

This section should fill approximately **2 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Define electrical energy and power in an electrical circuit.
- Find the relationship between KWh and joule.
- Use $P = VI = \frac{V^2}{R} = I^2R$ to solve problems in electric circuits.
- Use $W = VIt = I^2Rt = \frac{V^2}{R}$ to calculate electric energy dissipated in an electric circuit.
- Calculate cost of electrical energy expressed in KWh.

Starting off

It will stimulate debate if students share their ideas about which electrical appliances use most electricity.

Teaching notes

Forget the usual meanings of the word 'power': they might confuse. The meaning of power here is: *The rate at which work is being done, or the rate at which energy is being supplied or converted.* Put another way, power is anything that can be measured in the units joules per second (J/s), known as watts. Ask students to list (from highest consumption to lowest) such appliances as – sewing machine, heater, air conditioner, electric drill, food mixer, light bulb, computer, television, refrigerator, vacuum cleaner, floor polisher – and then find out the actual power ratings and see how they compare to initial assumptions. Using data for supply voltage and power ratings discovered above, discover the current drawn by various appliances. Find the cost of electricity per unit and calculate the cost of running several of the appliances studied above.

SA = starter activity MA = main activity CA = concluding activity	
1. Electrical energy and power	
SA	With a partner, attempt to define electrical energy and power. Feed back ideas.
MA	Worked examples 3.16–3.19 to be tackled with a partner. Feed back ideas on solution before given solution revealed.

CA	With a partner, discuss which appliances should be investigated in Activity 3.9. Carry out the activity at home.
2. Cost of electrical energy	
SA	Discuss results of activity 3.9 with a Partner. Work out how much each appliance costs to run for 1 hour.
MA	Worked examples 3.20–3.23 to be tackled with a partner. Feed back ideas on solution before given solution revealed.
CA	Review questions to be tackled with a partner.

Activities

Research electrical appliances at home and in school. Observe the power ratings associated with them. (Could try finding out how power ratings have changed – e.g. light bulbs, efficiencies.) Look at electricity bills.

Resources

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elepow.html

www.facstaff.bucknell.edu/mastascu/elessonshtml/Basic/Basic6PE.html

Where next

Introduce the concept of efficiency. If possible, find equivalent appliances with different power ratings – one example could be the 'old fashioned' tungsten filament light bulb compared with the compact fluorescent light bulb – and discuss the value of using appliances which do a comparable job but use less power. If possible, students could find out more about James Prescott Joule and James Watt.

Answers to review questions

1. Students' own answers.

Energy requirement	Possible energy sources	Possible economies
Lighting	electricity, candles, electric torch	low energy light bulbs, making the best use of daylight
Heat	fire, electricity	improving insulation, wearing more clothes to keep warm
TV, computer, games	electricity	using the equipment less and switching off when not using
Cooking	electricity, gas, fire	covering cooking pots while cooking

2. Students' own answers.

Energy requirement	Possible energy sources	Possible economies
Lighting	electricity	low energy lighting, making sure the school is built with big windows to make the most of the natural light
Heating	gas, electricity	improving insulation, wearing more clothes
Cooling	electricity (fans or air conditioning)	making sure the building is designed so that it doesn't get too hot

3. a) 5 A b) 150 W c) 2.5 A d) 75 W e) 37.5 W

The voltage supplied to both circuits is the same. The current flowing round the second circuit is half that flowing round the first circuit. The heat produced in the two 6 Ω resistors in the second circuit combined is therefore half that produced in the single 6 Ω resistor in the first circuit and the heat produced in one of the two resistors in the second circuit is thus one quarter of that produced by the resistor in the first circuit.

3.6 Electric installation and safety rules

This section should fill approximately **2 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Understand the dangers of mains electricity.
- Have some awareness of safety features incorporated in mains electrical installations.
- Understand the nature of the generation and supply of electricity in Ethiopia.
- Consider employment prospects in Ethiopia's electricity industry.

Starting off

Remind students that the work they did in Sections 3.1 – 3.4 was concerned with small voltage direct current supplied by cells and batteries of cells. The electricity considered in Section 3.5 was mains electricity, supplied by Ethiopia's power stations. This is at a high voltage and is therefore potentially very dangerous, hence the need for safety devices.

Teaching notes

Discuss the importance of earthing electrical equipment. Demonstrate the action of a fuse (allowing the students to do this themselves if possible). After the students have researched into the safety features in Ethiopia's electrical supply, discuss specific safety features used in Ethiopia's electricity system. (Three pin plugs incorporating an earth wire.) After the students have researched the methods of power generation used in Ethiopia (hydro, solar, fossil fuel) discuss the advantages and disadvantages of these methods.

Method	Advantage	Disadvantage
Hydro	Constant supply, provided no shortage of rainfall	Only possible near river – need power lines to distribute to other places; power lines are expensive to build and power is lost in distribution.
Solar	Conditions in Ethiopia are suitable	Only available during daylight; battery storage would be necessary at night.
Fossil fuel	Can locate power station near demand	Expensive (imported) fuel required, which contributes to manmade global warming.

SA = starter activity MA = main activity CA = concluding activity	
1. Electrical safety	
SA	Activity 3.10 in small group.
MA	Engineering project on page 116 of Student Book in small groups.
CA	Review questions to be tackled with a partner. End of unit questions to be tackled with a partner.

Activities

- Testing the action of a fuse.
- Researching safety features.
- Researching the sources of power generation in Ethiopia.

Resources

http://waltainfo.com/EEPCO/about.htm

http://ethioelectricagency.org/about.html

(solar) www.eia.doe.gov/kids/energy.cfm?page=solar_home-basics

(solar) www.solar4schools.co.uk/parents/Solar-Explained

(hydro) www.darvill.clara.net/altenerg/hydro.htm

(wind) www.sciencenewsforkids.org/articles/20050309/Feature1.asp

(wind) www.alliantenergykids.com/EnergyandTheEnvironment/RenewableEnergy/022397

(wind) www.eia.doe.gov/kids/energy.cfm?page=wind_home-basics

(fuse) www.explainthatstuff.com/fuses.html (has some adverts)

(domestic electricity safety features) www.furryelephant.com/content/electricity/domestic-electricity/

Where next

Remind students of the conversion of energy from one form to another. Introduce the concept of regenerative braking (the process of converting kinetic energy into a form of energy that can be used or stored, rather than dissipating it as heat). Discuss the hybrid motor engineering project – in particular the way the 'electric brakes' in the car convert energy by recharging the battery. Also, the conversion of energy into rotational energy in the fly wheel.

If time permits, investigate the way in which electricity can be produced from wind (Unit 5 will introduce the generation of electricity from light [solar power]).

An electric motor consists of a coil of wire that can spin on an axle in a magnetic field. If electricity is supplied to the coil of wire, it spins, turning the axle, which can then be used to power other machines. If, instead, the axle is turned, the coil of wire turns in the magnetic field and electricity is generated in the coil.

In this experiment wind power (from a hair dryer) turns a propeller attached to the axle of an electric motor and electricity is generated by the electric motor at different wind speeds.

Take a small motor (for example 1.5 v 200 mA) with 2 mm axle diameter, a propeller to push fit onto 2 mm axle, a voltmeter or multimeter, 2 crocodile clip leads, a hair dryer or other air blower with at least three different air speeds Insert the axle of the electric motor into the hole in the centre of the propeller. Ensure it is held firmly. Attach crocodile clip leads to the connections on the electric motor. Attach the other ends of the crocodile clip leads to a multimeter (or voltmeter). Switch the hair dryer to a slow speed and record the voltage reading in the table.

Air speed	Voltage reading
slow	
medium	
fast	

Adjust the setting of the hair dryer and record the voltage in the table. A higher voltage will be recorded when a faster wind speed is used. This follows from Faraday's law of electromagnetic induction.

An electric motor can therefore also act as a generator. The energy to turn the axle of a generator can come from many sources in addition to wind. Many power stations use the steam generated from the heat of either burning fossil fuels (fossil fuel power) or from decaying nuclear fuels (nuclear power). The energy from falling water is also used to rotate turbines that power generators (hydro power).

There are places in which the ability of a generator to act in opposite directions is very useful. If there is a reservoir at the top of a mountain and there is a lake at the bottom, water can be stored in the reservoir at the top and used to run the generators when electricity is needed. When demand for electricity is low, electricity can be used to run the generator as a pump, which raises the water to the reservoir at the top of the hill.

For an example of one such system, in Scotland, follow this link:
www.scottishpower.com/uploads/CruachanPowerStation.pdf

Answers to review questions

1. a) The kettle is earthed so that if a fault develops any dangerous large current would run harmlessly to earth.

   b) The fuse breaks the curcuit if the current is such that the circuit overheats.

2. a) i) MCBs are used instead of fuses in some appliances.

      ii) An ECLB is used instead of a fuse in a domestic electricity supply board.

   b) i) MCBs cut off the power if there is a fault which causes the appliance to overheat. They can be re-set when the appliance cools down.

      ii) ECLBs cut off the supply very quickly if a fault occurs. They are also useful to prevent injury when using electrical equipment outdoors since they will cut off the power supply quickly if the power cable is cut accidentally.

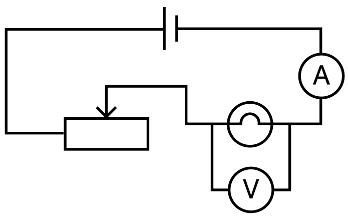
Answers to End of Unit Questions

1. 9 A
2. 19 Ω
3. a) The ammeter should be in series not in parallel.

   b) 4 Ω 1.5 A

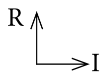
   c) 0 V

   d) almost 0 A (resistance of voltmeter is very high)
4. a)

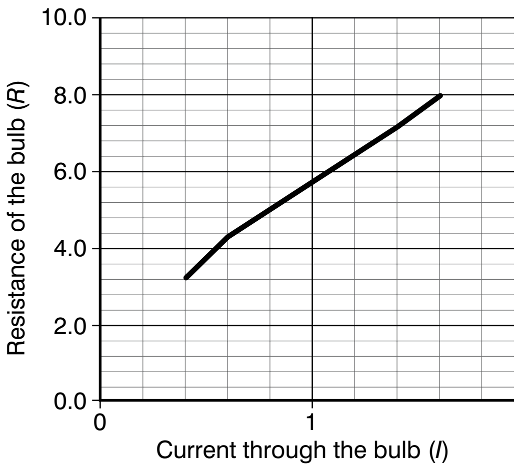


b)

Current	0.4	0.6	0.8	1.0	1.2	1.4	1.6
p.d.	1.4	2.6	3.9	5.5	7.4	9.7	12.6
R	3.5	4.3	4.9	5.5	6.2	6.9	7.9

c) Use the following points to plot on ordinary graph paper 

(0.4, 3.5) (0.6, 4.3) (0.8, 4.9) (1.0, 5.5) (1.2, 6.2) (1.4, 6.9) (1.6, 7.9)

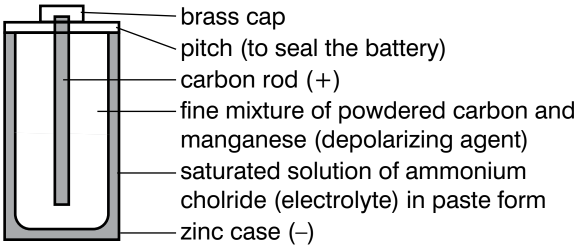


The bulb's resistance increases as the current increases. This is because it becomes hotter. When the current is zero, the bulb cools down, but still has a positive value for resistance, so the graph will not go through the origin.

d) about 2 Ω

5. 1.5 Ω

6.



The brass cap protects the carbon rod. The manganese dioxide converts the hydrogen that builds up as a result of polarisation to water.

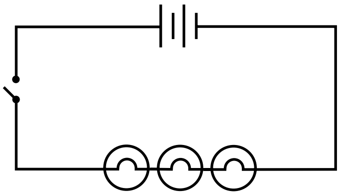
7. 0.06 Ω

8. a) 12 V

b) 180 C

9. The units are not $\frac{R}{l}$ but $R \times l$ i.e. Ω m.

10.



It does not matter where the switch is positioned. The components are all in series so the current passes through each in turn.

11. a) 3 A

b) 39 V

c) 13 Ω

12. 3 A, 5 A

13. a) 1 A, 2 A, 3 A

b) 6 A

c) 1 Ω

d) $\frac{1}{R} = \frac{1}{2} + \frac{1}{6} + \frac{1}{3}$

$= \frac{3+1+2}{6} = \frac{6}{6} = 1\ \Omega$ – the same result

14. a) 0.5 A, 3.75 V

b) 8 A, 0 V

Electromagnetism

Unit 4

This unit should fill approximately **20 periods** of teaching time.

Learning Competencies for Unit 4

By the end of this unit students should be able to:

- Investigate the domain theory of magnetism.
- Describe a magnetic field.
- Perform and describe an experiment to demonstrate the existence of a magnetic field around a current-carrying wire.
- Sketch the resulting magnetic field lines pattern of a current-carrying wire.
- Apply the right-hand rule to determine the direction of magnetic field lines around a straight current-carrying wire.
- Calculate the magnetic field strength at a point due to a straight current-carrying wire.
- Sketch the magnetic field lines pattern of a current loop.
- Sketch the magnetic field lines pattern of a solenoid.
- Specify the polarity of a solenoid using the right-hand rule.
- Calculate the magnetic field strength at the centre of a solenoid.
- Describe the factors on which the force on a moving charge in a magnetic field depend.
- Demonstrate the relation $B = \frac{mv}{qR}$ from the fact that the centripetal force is provided by the magnetic force.
- Calculate the magnetic force acting on a moving charge in a uniform magnetic field.
- Determine the direction of a force acting on a moving charge using the left-hand rule.
- Demonstrate the existence of a force on a straight current-carrying conductor placed in a magnetic field.
- Derive the expression $F = BIl\sin\theta$ from $F = qvB\sin\theta$.
- Apply the left-hand rule to determine what will happen when current flows perpendicular to a uniform magnetic field.
- Calculate the magnitude and direction of force between two parallel current-carrying conductors in a uniform magnetic field.
- Define the SI unit ampere.
- Draw a diagram to show the forces acting on a rectangular current-carrying wire in a uniform magnetic field.
- Draw diagrams to show the action of a force on a simple d.c. motor and a moving coil galvonometer.

- Define magnetic flux and its SI unit.
- State Faraday's law of induction.
- Perform simple experiments that demonstrate an induced e.m.f. caused by changing magnetic flux.
- State Lenz's law.
- Indicate the direction of induced currents, given the direction of motion of the conductor and the direction of a magnetic field.
- Describe the factors that affect the magnitude of induced e.m.f. in a conductor.
- Describe the link between electricity and magnetism.
- Apply Faraday's law to calculate the magnitude of induced e.m.f.
- Define inductance and its SI unit.
- Distinguish between self- and mutual inductance.
- Apply the definition of inductance to solve simple numerical problems.
- Explain the action of the simple a.c. generator.
- Compare the actions of d.c. and a.c. generators.
- Draw a diagram of a transformer.
- Give a simple explanation of the principles on which a transformer operates.
- Identify that, for an ideal transformer, $P_{out} = P_{in}$.
- Show that, for an ideal transformer, $V_s/V_p = N_s/N_p$.
- Apply the transformer formulae to solve simple problems.

4.1 Magnetism

This section should fill approximately **6 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Investigate the domain theory of magnetism.

Starting off

Students learnt about the magnetic force in Grade 9. Activity 4.1 gives them the opportunity to revisit this. Move on to discuss the Earth's magnetic field and arrange for the students to carry out Activity 4.2 in small groups outside.

Activity 4.1: Answer

Students should find that like poles repel and opposite poles attract.

Activity 4.2: Answer

Students' own results.

Teaching notes

This section centres on magnetic domains. To help students to understand the first section explaining the nature of magnetic domains, you could ask a group of students to stand up and face a partner. This would be the analogy for

Figure 4.1**a**). Now ask the students to turn so that they all face in the same direction (i.e. they are facing the back of the person in front of them). This is the analogy for Figure 4.1**b**).

Activity 4.3: Answer

Students' own results.

Activity 4.4: Answer

Students' own results.

Activity 4.5: Answer

Students' own results.

Activity 4.6: Answer

Students' own results.

Activity 4.3 should be done in small groups if possible. Tell the students to take care with the iron filings as they will stain clothing. Encourage students to discuss their observations in their small groups and then bring the class back together to discuss the results. Finally students should be given the opportunity to explain the results to a partner in their own words in order to consolidate understanding.

Point out to students that a magnet may become weaker over time, as explained in the Students' Book. Activity 4.4 requires Bunsen burners and associated safety precautions. Do make sure that students are aware of these before the activity begins. Ask the students why the second (unheated) nail should be put on the bar magnet for the same length of time as the first nail. This concept, of a fair test, is an important one for students to grasp and should be practised at every opportunity in order to develop competent experimental scientists.

As with the previous activity, give the students the opportunity to discuss, and attempt to explain, their observations in their small groups, before bringing the class back together to talk about the results.

The section moves on to discuss magnetic shielding. You may want to give students the opportunity to do some independent research into magnetic shielding and where it is used in real life before they carry out Activity 4.5 and Activity 4.6 in small groups. Before they attempt Activity 4.6, ask students for ideas about how they can make this a fair test. For example, if the paper cup had thicker paper than the plastic cup had plastic, would the test be fair? If not, why not? (It would not be fair because the results could be influenced by the extra thickness of paper rather than the nature of the materials themselves.)

Activities

- The force between two bar magnets.
- Using a compass.
- Investigating domains, magnetisation and demagnetisation.
- Magnetisation by heating and cooling.
- Magnetic shielding.
- Investigating which material makes the best magnetic shield.

Resources

http://www.school-for-champions.com/science/magnetism.htm

http://library.thinkquest.org/11924/emagnet.html

Where next?

The next section considers the magnetic field. It considers the magnetic fields that are generated by electric currents. Students will need the skills learnt in this section to carry out the activities.

SA = starter activity MA = main activity CA = concluding activity	
1. The magnetic force	
SA	Activity 4.1 with a partner.
MA	Activity 4.2 in a small group.
CA	Review question 1 to be tackled with a partner.
2. What are magnetic domains?	
SA	Small groups of 6 students act as 'human domains'. Arms spread wide, left hand 'north' and right hand 'south'. Arrange themselves as in Figure 4.2 a and b in Student Book.
MA	Activity 4.3 in a small group.
CA	Try to explain results of activity 4.3 to a partner. Review questions 2–3 to be tackled with a partner.
3. Magnetisation by heating and cooling	
SA	In a small group, discuss pages 122–123 of Student Book.
MA	Activity 4.4 in small groups.
CA	Review questions 4–5 to be tackled with a partner.
4. Magnetic shielding	
SA	In a small group, think of situations where magnetic shielding may be used. Feed back ideas.
MA	Activity 4.5 in small groups. Activity 4.6 in small groups.
CA	Review question 6 to be tackled with a partner.

Answers to review questions

1. A compass needle is like a small suspended bar magnet. Its north seeking pole will point to the Earth's north pole.

2. a) Imagine a piece of steel to be made up of a huge number of invisibly small magnets. In an ordinary unmagnetised piece of steel, the little magnets are there, but they are in clusters rather like you would get if you threw a large number of small bar magnets into a box. The 'N' end of one magnet is up against the 'S' end of another, and the two effectively cancel each other out (see Figure 4.1**a**). These are magnetic domains.

   b) Figure 4.1**b**) shows the steel when it is fully magnetised. There are a large number of north poles at one end of the bar, and the same number of south poles at the other.

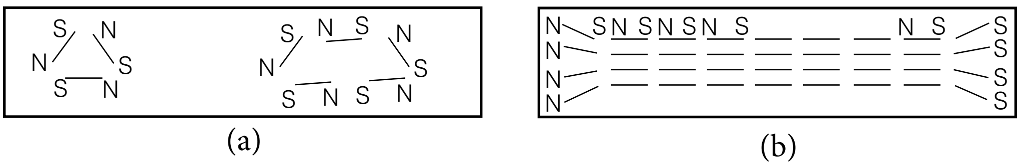


Figure 4.1

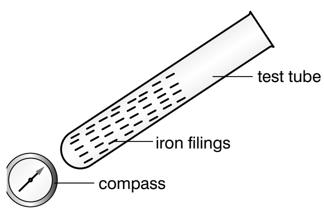


Figure 4.2

3. Fill a test tube two-thirds full with iron filings or shredded steel wool and bring the end of the tube towards first the north end of a compass needle and then the south end as shown in Figure 4.2.

   Record the maximum angle to which the needle is deflected (see Figure 4.3).

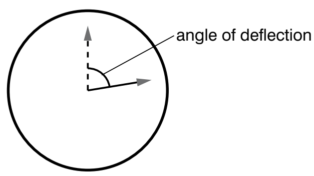


Figure 4.3

Now stroke the tube 50 times with a permanent magnet and repeat the procedure. Record the results.

Finally, shake the tube vigorously for one minute (make sure the tube is firmly sealed otherwise the iron filings will go everywhere)! Record the results.

4. The tiny magnets, or domains, of the nail, are the individual atoms that make up the nail. These atoms will be moving slightly from a given position, and as the nail is heated they will move more and more. By heating the nail until it is red hot, you cause all the domains to jumble up. As the nail cools on a permanent magnet, the jumbled-up domains line up again and the nail becomes magnetised again.
5. Place the nail on a permanent magnet. The permanent magnet will cause the domains to line up so that the nail becomes magnetised.
6. Cut the bottoms from two paper cups of different sizes, two plastic cups of different sizes and two tin cans of different sizes.

   Place a compass on a table and record the direction of magnetic north. Now place two bar magnets 7 cm to the east and west of the compass so that the north pole of one faces the south pole of the other, as shown in Figure 4.4. Record the angle of deflection.

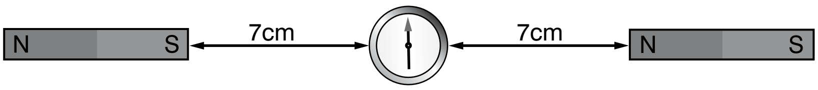


Figure 4.4

Now remove the magnets and place a tin can over the compass. Put the magnets back in the same position as shown in Figure 4.5.

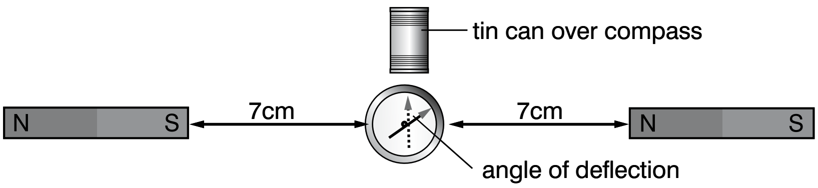


Figure 4.5

Record the angle of deflection. Remove the magnets and place a second can over the first so that the compass is now shielded by two cans. Replace the magnets. Record the angle of deflection.

Repeat this procedure using first the plastic cups and then the paper cups. Place your results in a table like this:

Shielding material	Angle of deflection of compass
No shield	
One tin can	
Two tin cans	
One plastic cup	
Two plastic cups	
One paper cup	
Two paper cups	

The best magnetic shield is the combination with the smallest angle of deflection of the compass.

4.2 Concepts of magnetic field

This section should fill approximately **3 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Describe a magnetic field.
- Perform and describe an experiment to demonstrate the existence of a magnetic field around a current-carrying wire.
- Sketch the resulting magnetic field lines pattern of a current-carrying wire.
- Apply the right-hand rule to determine the direction of magnetic field lines around a straight current-carrying wire.
- Calculate the magnetic field strength at a point due to a straight current-carrying wire.
- Sketch the magnetic field lines pattern of a current loop.
- Sketch the magnetic field lines pattern of a solenoid.
- Specify the polarity of a solenoid using the right-hand rule.
- Calculate the magnetic field strength at the centre of a solenoid.

Starting off

Remind students about their learning in Section 2.2 about electric fields. Give a short quiz to make sure that this learning is brought to the front of students' minds as there are parallels between electric and magnetic fields which they will need to appreciate later in the unit. You could use Activity 2.2 as the basis for this quiz

Teaching notes

The section begins by answering the question 'What is a magnetic field?'. Activity 4.7 gives students an opportunity to observe a magnetic field – that of a bar magnet. Activity 4.8 extends this to three dimensions.

We move on to consider magnetic fields that exist around electric currents. Activity 4.9 requires students to use compasses to plot the magnetic field around a current-carrying wire. This is an important concept, so allow plenty of time for this activity and for discussion of the results.

The right-hand rule needs to be explained carefully. Go through the worked example to make sure students understand how to use the rule. Give further examples and ask students to predict the direction of the field lines.

We now consider magnetic field strength, given the symbol B. The first arrangement we consider is a simple current $F1$ carrying wire. The relationship $F = BIL$ is important and students should have opportunities to work with it, as in the worked example 4.2. Check that all students are comfortable with the

Activity 4.7: Answer

Students' own results.

Activity 4.8: Answer

Students' own results.

Activity 4.9: Answer

Students' own results.

mathematical manipulation of the equation to each of the variables the subject: if necessary, work through the rearrangement to make B, then I, then L the subjects in turn, so that students get used to the process. Give further practice using examples like the worked example as necessary – at this stage the numbers do not need to be complicated, it is the process of manipulation of the equation that is important.

Activity 4.10: Answer

Students' own results.

Activity 4.10 gives students an opportunity to plot the magnetic field of a current loop. It would be worth promoting discussion on the similarities and differences between this field and the field the students plotted in Activity 4.9. Activity 4.10 gives a good introduction to the next section, which is the magnetic field of a solenoid, which is basically several loops of current.

A solenoid is an electromagnet – it is magnetic when a current flows through its coils but not when the current is switched off.

Solenoids are used in practical applications: for example, at certain stages of a cycle in a washing machine, the solenoid attached to a spring turns on a tap to admit more water.

The strength of a magnetic field in a solenoid includes a term μ_0 – the permeability of free space. Students should not worry too much about precisely what this means at this stage – the value will always be given in questions requiring calculations to be carried out.

Work through the worked example carefully and note that the answer has been given in terms of π, as π appears in the defined value of the permeability of free space. Give further examples as necessary until students are comfortable with the formula and can manipulate it to change the subject as required.

SA = starter activity MA = main activity CA = concluding activity	
1. Magnetic fields	
SA	With a partner, students discuss what they think a magnetic field is. Feed back ideas.
MA	Activity 4.7 in small groups. Activity 4.8 in small groups.
CA	Write a report on the activities.
2. Magnetic fields around a current-carrying wire	
SA	With a partner discuss 'what is an electric current?'. Feed back ideas.
MA	Activity 4.9 in small groups.
CA	Review questions 1–4 to be tackled with a partner.
3. Magnetic field of a current loop	
SA	In a small group, discuss what factors affect the strength of a magnetic field around a current loop. Feed back ideas.
MA	Activity 4.10 in a small group.
CA	Review questions 5–6 to be tackled with a partner.

Activities

- Magnetic fields in two dimensions.
- Magnetic fields in three dimensions.
- Plotting the magnetic field lines around a current-carrying wire.
- Finding the magnetic field of a current loop.

Resources

http://hyperphysics.phy–astr.gsu.edu/hbase/magnetic/magcon.html
http://www.studyphysics.ca/2007/30/06_forces_fields/18_apply_mag.pdf

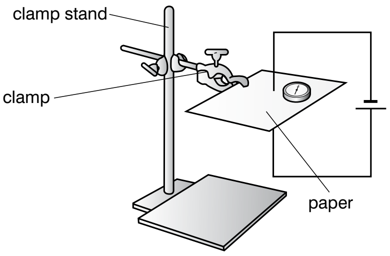
Where next?

The next section considers the magnetic force. It shows how the force on a magnetic field has practical applications in devices such as motors.

Answers to review questions

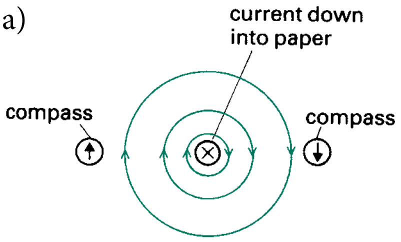
1 a) A magnetic field is a region in which a magnetic force may be exerted. Put a compass down in a magnetic field and it will experience a force making it set in a particular direction.

b) Set up the apparatus as shown in the diagram.

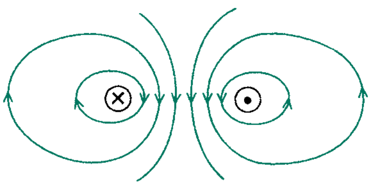


Switch on the current and then use a compass to plot the field lines.

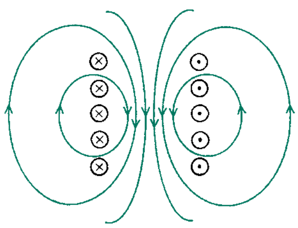
2. a)



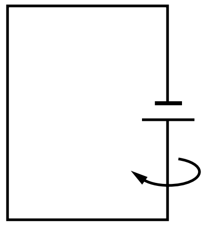
b)



c)

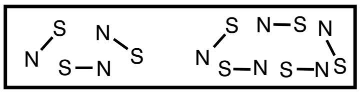


3.

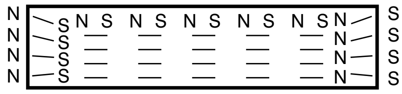


4. $F = BIL$ so $B = \dfrac{F}{IL} = \dfrac{36}{6 \times 3} = 2\ \text{T}$

5. a)



b)



6. $B = \mu_0 NI = 4\pi \times 10^{-7}\ \text{H m}^{-1} \times 5000 \times 5 = 0.01\ \pi\ \ \text{T}$

This section should fill approximately **6 periods** of teaching time.

4.3 Magnetic force

Learning Competencies

By the end of this section students should be able to:

- Describe the factors on which the force on a moving charge in a magnetic field depend.
- Demonstrate the relation $B = \dfrac{mv}{qR}$ from the fact that the centripetal force is provided by the magnetic force.
- Calculate the magnetic force acting on a moving charge in a uniform magnetic field.
- Determine the direction of a force acting on a moving charge using left-hand rule.
- Demonstrate the existence of a force on a straight current-carrying conductor placed in a magnetic field.
- Derive the expression $F = BIl\sin\theta$ from $F = qvB\sin\theta$.
- Apply the left-hand rule to determine what will happen when current flows perpendicular to a uniform magnetic field.
- Calculate the magnitude and direction of force between two parallel current-carrying conductors in a uniform magnetic field.
- Define the SI unit ampere.
- Draw a diagram to show the forces acting on a rectangular current-carrying wire in a uniform magnetic field.
- Draw diagrams to show the action of a force on a simple d.c. motor and a moving coil galvonometer.

Starting off

The first two sections of this section require students to remember prior learning: first of all $F = BIL$ from the last section, and then the equation for centripetal force, $F = \dfrac{mv^2}{R}$. Make sure that these two equations are in the front of students' minds by asking questions to draw these equations from them – you could do this in the form of a quiz. For example, what is the equation to find the force on a current-carrying wire? What is the equation for the centripetal force?

Teaching notes

The first section describes the factors that affect the force on a single charge moving in a magnetic field of strength B. The force depends on the strength of the magnetic field, B, the size of the charge, q, and the velocity, v. This is summarised in the equation $F = Bqv$.

We then move on to consider the centripetal force experienced by a charge in a magnetic field, which will move in a circular path (this is used in equipment such as mass spectrometers, which are used to identify chemicals in samples). Activity 4.11 requires students to work with a partner to derive the expression

$$B = \frac{mv}{qR}.$$

Work through the worked example slowly, asking students to explain each step in their own words. You may prefer to set the problem without the solution and see how students go about solving it. This is useful formative assessment.

Activity 4.12 gives students the opportunity to explore the motor effect. Give plenty of time for this and, if possible, allow the students to work in groups so that they can discuss their observations. Encourage them to try and explain what they see in their group before bringing the whole class back together to discuss the explanation given in the Students' Book.

Fleming's left-hand rule should be explained carefully. Make sure that students do not confuse it with the right-hand rule introduced earlier!

We now revisit a current-carrying conductor and discuss how the force varies according to the angle between the wire and the field.

Activity 4.13 gives students the opportunity to derive the expression $F = qvB\sin\theta$

We now consider the force between two parallel current-carrying conductors. In Activity 4.14 students are given the opportunity to observe this force. This is an important step as the unit of current, the ampere, is defined using this technique.

From parallel current-carrying conductors we move on to a rectangular current-carrying wire. Again, do not rush this section as students need to have a thorough understanding of this in order to understand how the electric motor works.

The section finishes by considering how the apparatus for a motor can be adapted to measure current in the moving coil galvanometer.

Activity 4.11: Answer

Start by equating $F = \frac{mv^2}{R}$ and $F = Bqv$

to give $\frac{mv^2}{R} = Bqv$

We can divide each side by v to give

$\frac{mv}{R} = Bq$

Finally we divide each side by q to give $\frac{mv}{qR} = B$ as required.

Activity 4.12: Answer

Students' own results.

Activity 4.13: Answer

Start with $F = Bqv$ and $F = BIL$

This means $Bqv = BIL$

We can therefore replace the 'BIL' part of $F = BIL\sin\theta$ with Bqv to give

$F = qvB\sin\theta$ as required.

Activity 4.14: Answer

Students' own results.

SA = starter activity MA = main activity CA = concluding activity	
1. Magnetic fields and the centripetal force	
SA	With a partner, write down the centripetal force equation and the equation for the force on a moving charged particle.
MA	Activity 4.11 with a partner.
CA	Review questions 1–2 to be tackled with a partner.
2. The motor effect	
SA	With a partner, discuss what 'motor' means. Feed back ideas.
MA	Activity 4.12 in small groups.
CA	Review questions 3–4 to be tackled with a partner.

3. The force on a current–carrying conductor	
SA	With a partner, discuss the factors that determine the force on a current–carrying wire. Feed back ideas.
MA	Activity 4.13 with a partner.
CA	Review question 5 to be tackled with a partner.
4. The force between two current–carrying conductors	
SA	With a partner, write a definition of the ampere. Feed back ideas.
MA	Activity 4.14 in a small group.
CA	Review questions 6–7 to be tackled with a partner.
5. The electric motor	
SA	With a partner, discuss and summarise Student Book pages 136–137.
MA	With a partner, produce a poster to explain how an electric motor works.
CA	Review questions 8–9 to be tackled with a partner.
6. The moving coil galvonometer	
SA	With a partner, write a list of uses of a galvanometer. Feed back ideas.
MA	With a partner, produce a presentation to explain how a moving coil galvanometer works.
CA	Review question 10 to be tackled with a partner.

Activities

- Deriving $B = \frac{mv}{qR}$
- Demonstrating the motor effect
- Deriving $F = qvB\sin\theta$ from $F = BIL\sin\theta$
- Demonstrating the force between two parallel current-carrying conductors.

Resources

http://hyperphysics.phy_astr.gsu.edu/hbase/magnetic/magfor.html

http://www.ricat.edu/~yhn/phys226/Ch21A.pdf

Where next?

The next section extends the work in this section by considering electromagnetic induction. We look at transformers and students are given the opportunity to build an a.c. motor.

Answers to review questions

1. The factors on which the force on a moving charge in a magnetic field depend are: the size of the magnetic field, the size of the charge, q, and its velocity, v. Therefore, for a single charge, the force is given by

   $F = Bqv$

2. A particle of mass m carries a charge q and is travelling with a velocity v. It enters a region where there is a perpendicular magnetic field of flux density B.

   a) $F = Bqv$

b) The path of the particle due to this force will be a circle because when you apply Fleming's left-hand rule, the deflection of the particle is such that its path is a circle.

c) $F = Bqv = \frac{mv^2}{r}$

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

Divide both sides by v

$Bq = \frac{mv}{r}$

Multiply both sides by r

$Bqr = mv$

Divide both sides by Bq

$r = = \frac{mv}{Bq}$

d) $r = \frac{9.1 \times 10^{-31}\ \text{kg} \times 4.5 \times 10^{7}\ \text{m s}^{-1}}{0.02 \times -1.6 \times 10^{-19}\ \text{C}} = 0.0128\ \text{m}$

3. The arrows on magnetic lines of force show the direction of the force experienced by the north pole of a magnet. The south pole of the magnet will be pushed the opposite way.

   Figure 4.12**a** shows the magnetic field due to the current. When the current flows, both magnets will be pushed downwards. The magnets are usually fixed in position. By Newton's third law, if they are being pushed down, the current in the wire will experience an equal sized push upwards (see Figure 4.12**b**)). This is the motor effect.

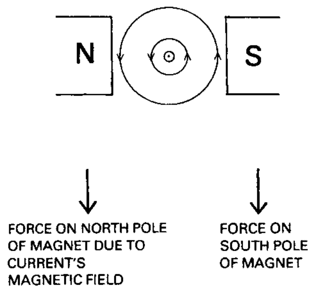


Figure 4.12

4. The Flemings right-hand rule is used to predict the direction of the movement produced by the motor effect (see Figure 4.13). Hold the thumb and first two fingers of your left hand at right angles to each other. If the First finger points along the magnetic Field and the second finger shows the Conventional Current, then the THumb points in the direction of the Thrust (movement).

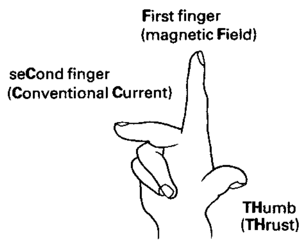


Figure 4.13

5. The factors that determine the size of a force on a current-carrying conductor are:
   - the current
   - the length of the wire
   - the strength of the magnet.
6. Two parallel wires each carrying a current will interact with each other. If the currents are both flowing the same way they attract one another; with currents going opposite ways they repel (see Figure 4.14).

   The current in one wire creates a magnetic field that extends out to where the second wire is. The current in this second wire then experiences a force due to the motor effect.

   Set up the equipment so that current flows as in Figure 4.14. First have the current in each wire flowing in the same direction and then reverse the direction of one of the currents.

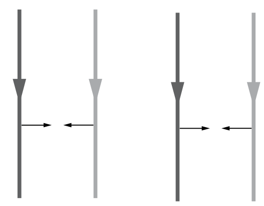


Figure 4.14

7. If one ampere is flowing in each of two parallel wires 1 m apart in a vacuum then the force on each wire due to the other will be exactly 2×10^{-7} N on every metre length.
8. a) $F = BIAN$ where F = force, B = magnetic field strength, I = current, A = area of coil N = number of turns

   b) $F = 0.2\ \text{T} \times 1\ \text{A} \times 0.025\ \text{m}^2 \times 100 = 0.5\ \text{N}$
9. The left-hand rule will predict the directions of the forces, as shown in Figure 4.15.

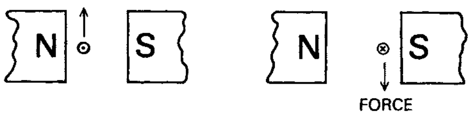


Figure 4.15

Figure 4.16 shows a coil carrying a current in a magnetic field. Figure 4.17 analyses the same coil by using Fleming's left-hand rule. It starts as in **a**, the forces causing it to rotate. After a quarter of a turn **b** the forces acting on the wires might distort the coil, but they will no longer turn it. If you pushed the coil round a bit more, the forces on the coil would simply return it to the upright position **c**.

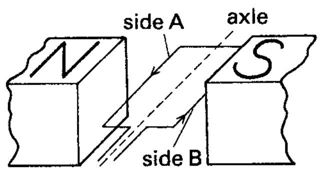


Figure 4.16

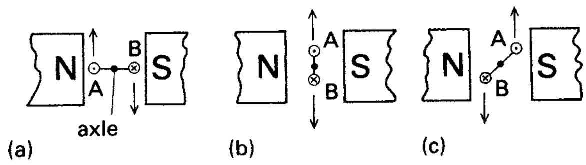


Figure 4.17

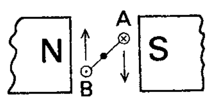


Figure 4.18

If by the time the coil reached the position in **c** the battery leads to it could be reversed, so the current flowed the other way, the situation would become that shown in Figure 4.18 and the coil would continue to rotate.

To lead the current into the coil, and to reverse its direction automatically at the right moment, the coil ends up in two segments of metal called a split-ring commutator (see Figure 4.19). The two wires from the battery end in brushes, which press against each of the segments of the commutator.

In cheap motors these brushes may be strips of springy metal, but in better ones they are usually blocks of carbon pressed against the commutator by springs. Sparking at the brushes tends to cause burns on the material used: with ordinary metals this is liable to lead to non-conducting corrosion, but carbon will oxidise to carbon dioxide gas, which will still leave a clean surface. Such brushes will need replacement from time to time as they wear down and burn away.

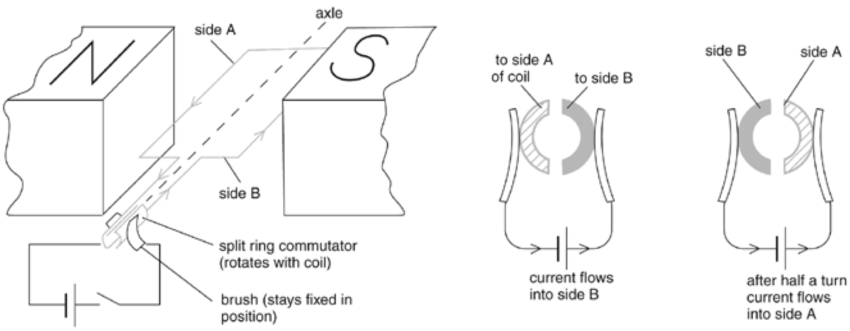


Figure 4.19

10. The greater the current flowing around the coil of an electric motor, the more strongly it will try to turn. This suggests a way to measure the size of a current: let it flow through a motor, and make the coil try to turn while it is held back by a spring. The bigger the current, the further the coil will manage to stretch the spring.

    This is the basis of the moving-coil galvanometer. (The coil of the instrument is shown in Figure 4.20.) The current can be fed into the coil and out again via the hairsprings at top and bottom; no commutator is needed because the rotation of the coil is restricted to just a fraction of a turn.

    Figure 4.20 shows a view of the complete arrangement from above. The coil can rotate inside the gap of a steel horseshoe magnet, which has curved pole pieces. The soft iron cylinder which sits in the middle of the coil (but does not rotate with it) itself gets turned into a magnet because of the presence of the permanent magnet; one of its effects is to increase the strength of the field within the gap.

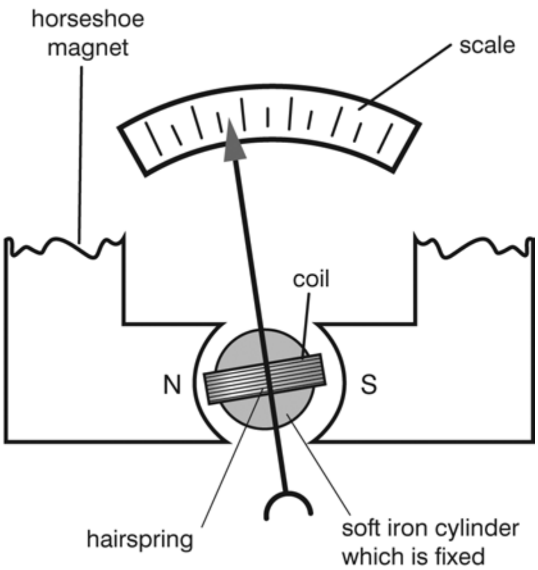


Figure 4.20

    Its other effect is to give the instrument a linear scale. In the gap there is a radial field, so as the coil rotates within the gap it always stays along the field lines. The torque remains proportional to the current.

    A galvanometer thus measures an electric current. The greater the current round the coil, the more marked the motor effect is and the further the hairsprings are wound up.

    A typical instrument is so sensitive that its pointer will be moved to the end of the scale by a current of perhaps 5×10^{-3} A; we say that it has a full-scale deflection of 5 mA. Even though copper is used for the windings of its coil, it consists of such a long length of so very thin wire that it may have a resistance as high as 50 ohms or more.

This section should fill approximately **7 periods** of teaching time.

4.4 Electromagnetic induction

Learning Competencies

By the end of this section students should be able to:

- Define magnetic flux and its SI unit.
- State Faraday's law of induction.
- Perform simple experiments that demonstrate an induced e.m.f. caused by changing magnetic flux.
- State Lenz's law.
- Indicate the direction of induced currents, given the direction of motion of the conductor and the direction of a magnetic field.
- Describe the factors that affect the magnitude of induced e.m.f. in a conductor.
- Describe the link between electricity and magnetism.
- Apply Faraday's law to calculate the magnitude of induced e.m.f.
- Define inductance and its SI unit.
- Distinguish between self- and mutual inductance.
- Apply the definition of inductance to solve simple numerical problems.
- Explain the action of the simple a.c. generator.
- Compare the actions of d.c. and a.c. generators.
- Draw a diagram of a transformer.
- Give a simple explanation of the principles on which a transformer operates.
- Identify that, for an ideal transformer, $P_{out} = P_{in}$.
- Show that, for an ideal transformer, $V_s / V_p = N_s / N_p$.
- Apply the transformer formulae to solve simple problems.

Starting off

Begin by considering magnetic flux and its relation to magnetic field strength. Go through the worked example in the Students' Book carefully. Show the students a loop of wire as shown in Figure 4.49 on page 142 of the Students' Book (but do not let the students have the book open at this point). Do the students think a current can flow in the wire? Discuss.

Activity 4.15: Answer

Students' own results.

Teaching notes

Now let the students open their Students' Books and work through the explanation of electromagnetic induction. Activity 4.15 gives students an opportunity to observe the dynamo effect. As always, they should work in small groups and discuss their observations before you bring the class back together to talk about the activity.

We now move on to discuss the two laws of electromagnetic induction: Faraday's law and Lenz's law. Read through the theory section covering Faraday's law carefully with the students and ask questions to check understanding. You may want to do Activity 4.16 as a class demonstration but involve the students as much as possible, and certainly they should be encouraged to attempt to explain the observations.

Discuss the theory section on Lenz's law. Ask the students to give you the answers to the questions before the answers are given in the text. Students should always be encouraged to think through an argument for themselves and not simply receive it passively from the teacher or Students' Book.

When considering the section on applying Lenz's law to a solenoid, it would be a good idea to demonstrate the text using a solenoid connected to a sensitive ammeter and a magnet and inserting the magnet into the solenoid. It is always helpful to use visual aids where possible.

Activity 4.17 is an opportunity for students to see Lenz's law in action. If possible this activity should be done in small groups and students should be encouraged to discuss their observations with their peers.

Activity 4.18 and Activity 4.19 are opportunities for students to see how magnets can be used to produce movement.

Activities 4.20 and 4.21 are opportunities for students to consolidate their learning. First they design a poster to summarise their learning. Then they consider the relationship between the motor effect and dynamo effect. Making such links assists students to remember the content of the lessons and helps them to see learning as a continuum rather than as separate blocks that bear no relation to one another.

We move on to consider inductors. It would be useful to set up a circuit containing an inductor so that you can demonstrate the text. You should plan to set up the circuit shown in Figure 4.53 on page 147 of the Students' Book so that students can relate the theory to their own observations.

When considering the time constant in an inductor circuit, remind students about their learning in Section 2.4, where we covered the time constant in a circuit containing a capacitor.

It is important that students can distinguish between self-inductance and mutual inductance, so work through these two sections carefully, asking questions to test understanding. Work through the worked example – as before, you may wish to set the problem and ask students to attempt it before using the given solution.

We move on to consider a simple a.c. generator. This extends the work in the previous section, where students learnt about the simple motor. Make sure that students appreciate the difference: this time the coil has to be turned rather than turning by the motor effect.

Activity 4.22 will test students' understanding of the theory as they are required to use the information given to build their own simple generator. Activity 4.23 requires them to work in a small group to compare the actions of a.c. generators and simple motors.

The section then moves on to consider transformers, which are an important part of the electricity supply network. Transformers are a practical application of the dynamo effect.

Activity 4.16: Answer

Students' own observations.

Activity 4.17: Answer

Students' own observations.

Activity 4.18: Answer

Students' own observations.

Activity 4.19: Answer

Students' own observations.

Activity 4.20: Answer

Should include some practical examples of the dynamo effect from everyday life (e.g. bicycle lights powered by the motion of the wheel).

Activity 4.21: Answer

Right-hand rule.

Activity 4.22: Answer

Students' own results.

Activity 4.23: Answer

d.c. generator	a.c. generator
Turns half a turn by motor effect then would stop unless battery leads could be reversed	Coil is turned rather than turning by motor effect
Split ring commutator reverses direction of current automatically	Slip rings connect to outside circuit

Activity 4.24: Answer

Students' own results.

Activity 4.25: Answer

A non-zero current is produced for an instant.

Activity 4.26: Answer

Students' own results.

Activity 4.27: Answer

They need to know that $P = VI$ (which they met in Section 3.5).

Then since $V_{out} \times 3_{out} = V_{in} \times I_{in}$

$P_{out} = P_{in}$

Activity 4.28: Answer

Students' own results.

When considering step-up and step-down transformers, give students plenty of practice in using the equations. Use the worked example given as the basis for your own examples; as always, you should ask the students to explain the steps required in their own words to assess understanding.

Activity 4.24 requires a flyback transformer from an old TV. A useful background website is http://en.wikipedia.org/wiki/Flyback_transformer.

Activity 4.25 is a group discussion activity that will test students' understanding. Students are then invited to carry out some research on one of the given applications.

Activity 4.26 is an opportunity for students to explore transient electric currents.

We then consider the ideal transformer equation. As always, question the students as you work through the text to check understanding.

Activity 4.27 tests understanding by requiring students to show that for an ideal transformer, $P_{out} = P_{in}$.

Work through the worked example in the usual way and give further examples based on this as necessary.

Activity 4.28 requires students to build either a toothpick motor or a cork motor. You will find details about how to do this at http://www.ceressoft.org/Files/emotors.htm. This activity should be carried out in small groups. Note that students may need to look at Section 5.4 for information about the photo transistor circuit.

SA = starter activity MA = main activity CA = concluding activity	
1. Faraday's law	
SA	Activity 4.15 in a small group.
MA	Activity 4.16 in a small group.
CA	Review questions 1–3 to be tackled with a partner.
2. Lenz's law (1)	
SA	Activity 4.17 in a small group.
MA	Activity 4.18 in a small group. Activity 4.19 in a small group.
CA	Review questions 4–8 to be tackled with a partner.
3. Lenz's law (2)	
SA	With a partner, write down Lenz's law.
MA	Activity 4.20 in a small group.
CA	Activity 4.21 in a small group.

4. A simple a.c. generator	
SA	In a small group, discuss and summarise Student Book pages 146–147.
MA	Activity 4.22 in a small group.
CA	Activity 4.23 in a small group.
5. Transformers (1)	
SA	Activity 4.24 in a small group.
MA	Activity 4.25 in a small group.
CA	Review questions 9–14 to be tackled with a partner.
6. Transformers (2)	
SA	With a partner, discuss how transformers are used in everyday life. Feed back ideas.
MA	Activity 4.26 in a small group.
CA	Review question 15 to be tackled with a partner.
7. Build an a.c. motor	
SA	Activity 4.27 with a partner.
MA	Activity 4.28 in a small group.
CA	End of unit questions to be tackled with a partner.

Activities

- Demonstrating the dynamo effect.
- Faraday's law.
- Lenz's law in action.
- Magnets producing movement.
- Factors that affect the magnitude of an induced current in a conductor.
- The relationship between the motor effect and the dynamo effect.
- Build a simple a.c. generator.
- Compare the actions of a.c. and d.c. generators.
- A flyback transformer.
- Lenz and Faraday and decaying fields.
- Transient electric current.
- Power in the ideal transformer equation.
- Build an a.c. motor.

Resources

http://www.mgnet.fsu.edu/education/tutorials/java/electromagneticinduction/index.html

http://www.cyberphysics.co.uk/topics/magnetism/electro/EMI.htm

Where next?

Unit 6 considers electromagnetic waves. Students will need to recall Faraday's law. In Unit 6, we bring together ideas about electric fields from Unit 2 and magnetic fields from this unit and consider how they interact in electromagnetic radiation.

Answers to review questions

1. magnetic flux = magnetic flux density (magnetic field strength) × area. Its SI unit is T m^2.
2. The size of the e.m.f. in volts is proportional to the rate at which the conductor is cutting through flux lines.
3. Wind about 1000 turns of wire around the copper pipe that is about 1 m long and attach the turns of wire to a light bulb as shown in Figure 4.45 on page 139 of the Students' Book. Drop the magnet through the pipe. The bulb should light.
4. The direction of the induced current is such as to oppose the change that is causing it.
5. Use Fleming's left-hand rule.
6. The factors that affect the magnitude of induced e.m.f. in a conductor are: the rate at which the conductor is cutting through flux lines, the strength of the magnetic field, the number of turns if the e.m.f. is induced in a solenoid.
7. When a wire is moved through a magnetic field, a current is generated by the dynamo effect.
8. Faraday's law can be used to calculate the magnitude of induced e.m.f.
9. Inductance is defined as the property in an electrical circuit where a change in the electric current through that circuit induces an e.m.f. that opposes the change in current. Its SI unit is the henry.
10. Self-inductance occurs when a current is first switched on in a coil and the build-up of the magnetic flux induces a voltage in the coil that opposes the battery in the circuit to delay the build-up of current. Mutual inductance occurs when a changing current in one coil induces a voltage in a neighbouring coil.
11. It is difficult to generate a continuous current by swinging a wire in a magnetic field. Whichever way you move the wire you soon come out of the magnetic field, which means the wire is no longer cutting through flux lines.

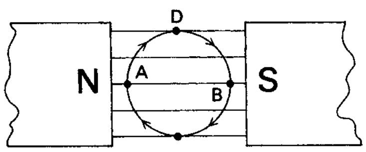


Figure 4.21

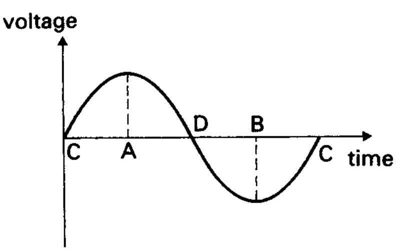


Figure 4.22

Figure 4.21 shows an end-on view of such a wire.

The wire is going round at a steady speed, so it is cutting the lines of force at a maximum rate at points A and B: at these moments the voltage induced in the wire is at its greatest, one way round at A and the other way round at B.

At stages C and D in the rotation, although the wire is moving, no lines of force are being cut, so at those instants the voltage is zero. The graph in Figure 4.22 shows what will happen in the course of one complete revolution, starting at C.

Suppose you have not a single wire but a rectangular coil, which may be rotated about an axle. As the left-hand side moves up through the magnetic field the right-hand side will move down. Although they are opposite ways round, the two combine to pump current round the coil rather than cancelling each other.

A practical arrangement by which the coil may be rotated and yet joined to a circuit is shown in Figure 4.23.

The connection to the outside circuit is made by sliding brush contacts and a pair of slip rings. The two slip rings are joined to the coil; they are metal rings with the axle at the centre, and they spin round with the coil.

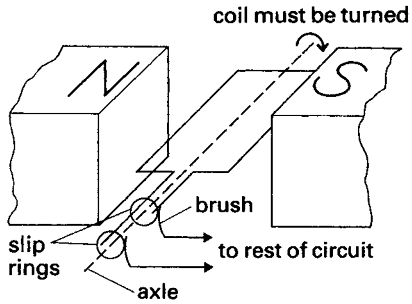


Figure 4.23

12.

d.c. generator	a.c. generator
Turns half a turn by motor effect then would stop unless battery leads could be reversed	Coil is turned rather than turning by motor effect
Split ring commutator reverses direction of current automatically	Slip rings connect to outside circuit

13.

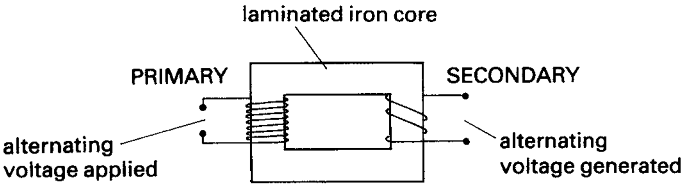


Figure 4.24

14. The alternating voltage applied to the input drives a current round the primary to magnetise the core. As the state of magnetisation of the core changes, an alternating voltage will be induced in the secondary. There is no reason why these two voltages should be the same size, and the main purpose of transformers is to change the size of a voltage.

    The one shown in Figure 4.25 is a step-down transformer: it steps the voltage down so that low voltage equipment can be run from the mains.

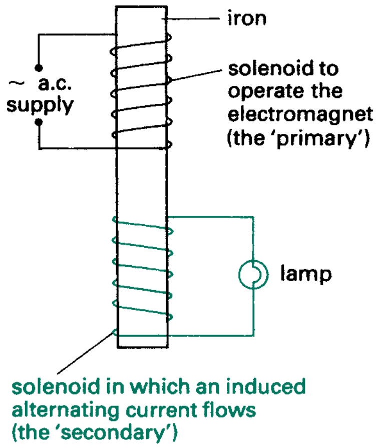


Figure 4.25

15. $V_{out} \times I_{out} = V_{in} \times I_{in}$

$$\frac{I_{in}}{I_{out}} = \frac{V_{out}}{V_{in}} = \frac{N_s}{N_p}$$

where V_{out} is the alternating voltage produced in the secondary coil, and V_{in} is the alternating voltage that is applied to the primary coil, for N_s and N_p.

Answers to end of unit questions

1. You use a magnetic shield to protect sensitive equipment such as electronic circuits from magnetic fields.
2. A material that is a good magnetic conductor will form a more effective magnetic shield by limiting the amount of penetration to the equipment being shielded.
3. When a nail becomes magnetized, the domains of magnetic clusters are broken up and rearranged into lines.

4. a) $\frac{F}{IL} = B$ where F is force, B is magnetic field strength, I is current and L is length.

   b) $B = \frac{15}{(3 \times 2.5)} = \frac{15}{7.5} = 2\ \text{N}$

5. Right hand rule

6. The motor effect is the movement that occurs when a current-carrying wire is placed in a magnetic field.

7. $B = \mu_0 NI$ so you need to know permittivity of free space, number of turns in solenoid and current.

8. The iron core in a solenoid becomes magnetised as a result of the current passing through the solenoid coil, increasing the magnetic field strength due to the coil alone.

9. $B = \frac{mv}{qR}$

   Where B = magnetic field strength
   m = mass of particle
   v = velocity of particle
   q = charge of particle
   R = radius of path

10. a) $Bqv = \frac{mv^2}{R}$

$$q = \frac{mv}{BR}$$

$$\frac{q}{m} = \frac{v}{BR}$$

   b) $\frac{1}{2}mv^2 = qV$

$$v^2 = \frac{2qV}{m}$$

$$v = \sqrt{\frac{2qV}{m}}$$

   c) $\frac{q}{m} = \sqrt{\frac{2qV}{m}} \times \frac{I}{BR}$

$$\frac{q^2}{m^2} = \frac{2qV}{m\,B^2R^2}$$

$$\frac{q^2}{m^2} \times m = \frac{2qVm}{m\,B^2R^2}$$

$$\frac{q^2}{mq} = \frac{2qV}{qB^2R^2}$$

$$\frac{q}{m} = \frac{2V}{B^2R^2}$$

d) $\frac{q}{m} = \frac{2V}{B^2R^2}$

$R^2 = \frac{2Vm}{qB^2}$

$R = \sqrt{\frac{2Vm}{qB^2}}$

$= \sqrt{\frac{2 \times 3000 \times (35 \times 1.67 \times 10^{-27})}{1.6 \times 10^{-19} \times (3.0)^2}}$

$= \sqrt{\frac{3.507 \times 10^{-22}}{1.44 \times 10^{-18}}}$

$= \sqrt{2.44 \times 10^{-4}}$

$= 0.016$ m

11. The motor effect is the effect the force experienced by a current-carrying conductor in a magnetic field.

12. Faraday's law of induction states that the size of the induced e.m.f. in volts is proportional to the rate at which the conductor is cutting through flux lines.

13. $\varepsilon = \frac{\Delta Ø}{\Delta t}$

$= \frac{6Tm^2}{I}$

$= 6$ V

14. $\varepsilon ind\ L = \frac{\Delta I}{\Delta t}$

$= 3 \times 10^{-3} \times \frac{3}{2}$

$= 4.5 \times 10^{-3}$ V

15. $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

16. a) A transformer requires a constantly changing magnetic field to operate. This is obtained from an alternating supply.

b) If connected to a battery, the magnetic field will be constant and so the transformer would not operate.

Introduction to electronics

Unit 5

Learning Competencies for Unit 5

By the end of this unit students should be able to:

- Define the term electronics.
- State the importance of electronics in your daily life.
- State what is meant by thermionic emission.
- Describe the behaviour of vacuum tubes.
- Describe the function of a cathode ray tube.
- Describe the uses of a cathode ray tube.
- Represent both d.c. and a.c. on current–time or voltage–time graphs.
- Use the current–time or voltage–time graphs to find the period and frequency of alternating currents or voltages.
- Distinguish between conductors, semiconductors and insulators.
- Give examples of semiconductor elements.
- Distinguish between instrinsic and extrinsic semiconductors.
- Describe a semiconductor in terms of charge carriers and resistance.
- Explain doping to produce the two types of semiconductors.
- Indentify semiconductors as *p*-type and *n*-type.
- Describe the mode of conduction by the majority and minority carriers.
- Define the term diode and show its circuit symbol.
- Draw a current versus voltage characteristics (graph) to show the behaviour of the *p-n* junction.
- Describe how a semiconductor diode can be used in a half-wave rectification.
- Sketch voltage–time graphs to compute the variation of voltage with time before and after rectification.
- Distinguish between direct current from batteries and rectified alternating current by consideration of their voltage–time graphs.
- Show the circuit symbols of semiconductor devices such as thermistor, LED, LDR and transistors.
- Distinguish between p-n-p and n-p-n transistors.
- Identify the base, emitter and collector of a transistor.
- Use the following terms correctly: forward biased and reverse biased.
- Describe the behaviour of semiconductor devices such as thermistor, LED, LDR, photodiode and transistors.
- Use the circuit symbols for the gates.
- Draw the truth tables for the different logic gates and for a combination of logic gates.
- Explain the action of logic gates: NOT, OR, AND, NOR, NAND.

This unit should fill approximately **11 periods** of teaching time.

5.1 Vacuum tube devices

This section should fill approximately **3 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Define the term electronics.
- State the importance of electronics in their daily life.
- State what is meant by thermionic emission.
- Describe the behaviour of vacuum tubes.
- Describe the function of a cathode ray tube.
- Describe the uses of a cathode ray tube.
- Represent both d.c. and a.c. on current–time or voltage–time graphs.
- Use the current–time or voltage–time graphs to find the period and frequency of alternating currents or voltages.

Starting off

Don't worry if you don't have access to a cathode ray oscilloscope (CRO) for this section; a well-labelled diagram of a CRO would be a suitable alternative for your explanation of the structure and function of the CRO.

Don't spend too much time on the detailed structure of the CRO, it is a relatively specialised piece of equipment that students don't necessarily understand until they need to use one. Deeper study of the television tube could be more helpful, although these are becoming less common with the advent of flat-screen televisions.

Teaching notes

Teaching about thermionic emission should follow on from what the students have learned (in Unit 3) of conduction electrons.

It should be made clear to students that heating a metal with a high melting point, such as tungsten, to a very high temperature can allow electrons to escape the metal's surface, and that electrons emitted in these circumstances are said to be produced by thermionic emission.

The thin tungsten filament (C in Figure 5.1) can be raised to a high enough temperature to start thermionic emission by using a current of only a few milliamperes through a small heating wire.

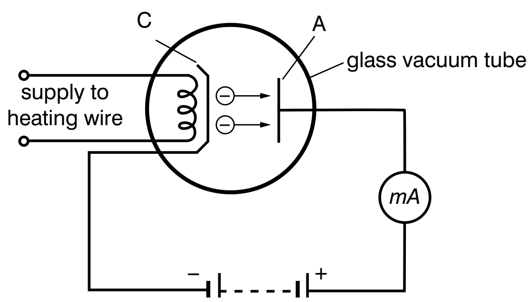


Figure 5.1 *Diode (current flowing)*

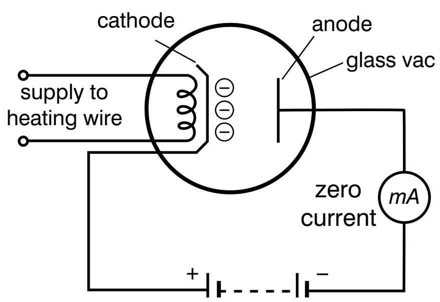


Figure 5.2 *Diode (no current)*

In Figure 5.1, the tungsten filament is placed in a vacuum tube (a glass container from which most of the air has been removed) to avoid collisions between the electrons and air particles. If another piece of metal (A) is placed in the glass container a short distance away from C the electrons that are thermionically emitted from C can be attracted to A.

This container is called a diode, as there are two pieces of metal (electrodes) inserted into it.

If electrode A is connected to the positive terminal of a battery and electrode C to the negative terminal, a current is detected with a milliammeter.

As the power supply in the diode circuit pushes electrons from negative to positive, the electrons must have travelled from the filament C (the cathode) to the other electrode A (the anode).

The electrons produced by the cathode are called cathode rays.

In Figure 5.2, the diode is connected in the reverse direction, (anode connected to the negative terminal of the power supply and cathode to positive). As current is still flowing to the heating wire, electrons are still emitted from the hot cathode, but they are not attracted to the now negatively charged 'anode' and no current flows in the diode circuit.

If the current to the heating wire is turned off there is no current in the diode circuit, as there is no thermionic emission from the cathode.

Demonstration – Maltese cross

If you have access to a Maltese cross tube, it would be very useful to demonstrate the nature of cathode rays.

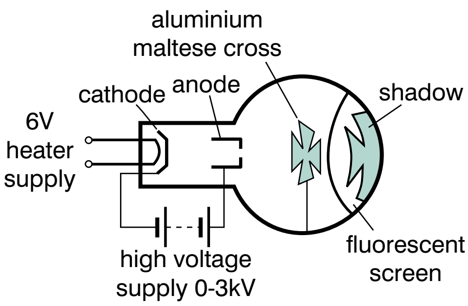


Figure 5.3 Maltese cross tube

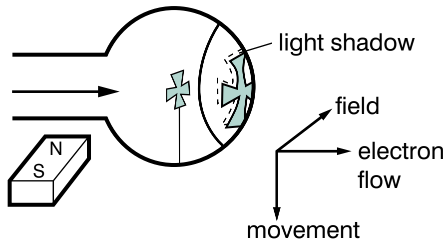


Figure 5.4 Deflection of cathode rays

The Maltese cross tube is a diode with an obstacle (the Maltese cross shape) and a fluorescent screen (Figure 5.3). When the heater supply is switched on, the filament glows and a shadow of the Maltese cross is cast on the screen. When the 3 kV diode supply is connected, electrons produced at the cathode are accelerated towards the anode (a hollow metal cylinder). The electrons pass through the anode and on towards the metal Maltese cross. The electrons that strike the Maltese cross are stopped, but those that travel past it strike the fluorescent screen, where their kinetic energy is converted to light energy (green light). The Maltese cross casts a shadow that corresponds exactly to the light shadow produced by the cathode filament alone. We can see therefore that cathode rays possess energy and travel in straight lines to produce a shadow of any obstacle in their path. If we bring a bar magnet near to the tube, the cathode ray shadow moves but the light shadow does not. This shows that cathode rays are not a form of electromagnetic radiation but move in the direction indicated by the motor rule for moving electrons.

Mention the X-ray tube – another vacuum tube device – to the students. (There is a brief description in the Students' Book.)

Introduce the students to the CRO using the diagrams and examples in the Students' Book.

Make sure students understand the use of the X and Y deflecting plates on the CRO. These allow the cathode ray beam to be deflected by varying voltages.

Make sure the students also understand the use of the controls – gain control (applied to the Y plates) and time base (applied to the X plates) – which allow voltage signals to be analysed.

Encourage the students to understand the value of the CRO in the measurement of voltage and of both direct and alternating currents.

Work through the examples in the Students' Book.

SA = starter activity MA = main activity CA = concluding activity	
1. Electronics around us	
SA	Activity 5.1 with a partner.
MA	In a small group, research uses of X–rays.
CA	Feed back research from main activity.
2. Cathode ray oscilloscope	
SA	With a partner, discuss how transformers are used in everyday life. Feed back ideas.
MA	Activity 4.26 in a small group.
CA	Review question 15 to be tackled with a partner.
3. TV picture tubes	
SA	With a partner, tackle worked examples 5.2 and 5.3. Feed back ideas before given solution is revealed.
MA	In a small group, research how a picture is produced in an older style TV. How is it produced in more modern sets?
CA	Review questions 5–6 to be tackled with a partner.

Resources

(vacuum tube) www.vacuumtubes.net/How_Vacuum_Tubes_Work.htm

thermionic emission www.st-andrews.ac.uk/~www_pa/Scots_Guide/audio/part9/page1.html

(thermionic diode) www.bookrags.com/research/diodes-wop/ (has some adverts)

(cathode rays) http://library.thinkquest.org/19662/low/eng/cathoderays.html

X-rays http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/xtube.html

(CRO) http://boson.physics.sc.edu/~hoskins/demos/cathoderay.html

(CRO) www.doctronics.co.uk/scope.htm

Where next

- The television picture tube should be studied, as this is a very important, and very familiar, vacuum tube device.

- In the CRO the electron beam is deflected by the electric field set up when a p.d. is applied to the X or Y plate, but in the television tube the electron beam is deflected by rapidly varying magnetic fields applied from coils (which receive signals from the television tuner) around the narrow part of the tube.
- As electrons are negatively charged, they are deflected by this magnetic field in the opposite direction to that predicted by Fleming's left hand rule.
- Magnetic deflection allows deflection of the beam through much bigger angles than would be given by electric deflection. This allows the tube to be much shorter than it would be if electric deflection were used.

Answers to review questions

1. a) The heater warms the cathode to encourage thermionic emission.

   b) Electrons are emitted from the cathode.

   c) Electrons are attracted to the anode.

   d) Voltages are applied to the x plates to move the beam of electrons from side to side (horizontally). Voltages are applied to the y-plates to move the beam of electrons up and down (vertically).

2. The spot on the screen of a CRO moves horizontally 2 cm in a time of 1 ms.

3. b) 3 V

   c) 4.5 V

   d) 4.5V

4. a) The voltage to be examined is connected across the y-plates of the CRO. The deflection of the beam corresponds to the voltage.

   b) The deflection of the beam produced by the voltage on the CRO responds to any changes in voltage very quickly because it is produced by a beam of electrons whose mass is very small.

   c) Virtually no current is drawn from the voltage source because it is just producing a deflection in a beam of electrons – there are no moving mechanical parts.

5. The anode gets very hot and would be in danger of melting if not specially designed. The tip is made of tungsten, which has a high melting point; the remainder of the anode is made of a block of copper, which conducts heat away. There might also be cooling fins, or the anode could be cooled by having a liquid pumped around it.

6. X-rays are used medically for investigations, and for treatment of some tumours. They are also used to check welds in pipes and to investigate the contents of cases in airport security checks. They can also be used in the laboratory to investigate the atomic structure of crystals, and in astronomy, X-rays detected from space can give useful information.

   The great danger with X-rays is that they are ionising radiation. They can cause radiation burns and damage to the DNA within cells, which can lead to tumours or sterility. The risks are greatest for those who regularly work with the equipment. To keep these to a minimum there should be adequate lead shielding (lead absorbs X-rays). The operators should not approach closer than they need to, and should stay in the vicinity no longer than necessary.

5.2 Conductors, semiconductors and insulators

This section should fill approximately **1 period** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Distinguish between conductors, semiconductors and insulators.
- Give examples of semiconductor elements.
- Distinguish between instrinsic and extrinsic semiconductors.
- Describe a semiconductor in terms of charge carriers and resistance.

Starting off

Students should be reminded of what they learnt in Unit 3 about conduction in conductors, insulators and semiconductors, and of the role played by electrons in the atomic structure of these materials.

Teaching notes

The movement of electric current through semiconductors is not straightforward, and care should be taken to make sure students grasp the details.

Students will already be aware that, when considering conduction, materials fall into three classes:

- Conductors – metals and carbon – in which atomic structure charge is carried by unfixed or 'conduction' electrons.
- Insulators – glass, plastic and most non-metals – in whose atomic structure electrons are held firmly and are largely unable to move.
- Semiconductors – such as silicon (the most important), germanium, lead sulphide, selenium and gallium arsenide – in which electric current is able to flow through the atomic structure. The mechanism of this flow is to be explained in this lesson.

Students are introduced to the structure of a semiconductor – specifically to the 'crystal lattice' made from the linked structure of semiconductor atoms, such as silicon.

By explaining this structure to the students, and introducing them to the idea that some electrons can be 'shaken free' of this structure, you should then be able to introduce the idea of the positive 'hole' left in the structure when an electron moves away.

It should then be clear that this 'hole' plays the part of a positive charge carrier into which other electrons move, freeing up further holes in the structure.

If students consider what happens when an electric field is applied to a piece of semiconductor material, it should be clear that electrons and holes move in opposite directions (electrons towards the positive pole of the power source and holes to the negative pole) and the semiconductor exhibits intrinsic conduction.

Activity 5.2 should illustrate to the class the movement of positive and negative charge carriers. In this activity, the people sitting on the row of chairs (think of them as electrons) move in one direction, while the empty chair (think of this as a positive 'hole') moves in the other.

SA = starter activity MA = main activity CA = concluding activity	
1. Conductors, semiconductors and insulators	
SA	Activity 5.2 in groups of 10.
MA	In a small group, produce a poster to summarise pages 163–165 of the Student Book.
CA	Review questions 1–3 to be tackled with a partner.

Activities

- Mysteriously moving chair activity.

Resources

(semiconductor crystal lattice) http://hyperphysics.phy-astr.gsu.edu/hbase/solids/sili.html#c4

(intrinsic semiconductor) http://hyperphysics.phy-astr.gsu.edu/hbase/solids/intrin.html

Where next

- Students are reminded that, although the semiconductors they have looked at in this lesson are able to support some electrical conduction using the movements of positive and negative charge carriers, they are not very good conductors of electricity.
- You could introduce the idea that there is a technique to improve the effectiveness of conduction in semiconductors, and that students will hear about this in the next lesson.

Answers to review questions

1. The structure of a semiconductor contains both freely moving electrons and 'holes'. If a voltage is applied to a semiconductor, it will conduct, because electrons move in one direction, and 'holes' in another, within the material.
2. At higher temperatures, more electrons in the semiconductor will have enough energy to break free, so the material conducts better.
3. In the lattice of a silicon crystal, an electron can be 'shaken free' of one silicon atom. When an electron leaves an atom in this way, the atom becomes positively charged. The effect of an electron leaving an atom is therefore to create a positive charge in the silicon crystal. This positive charge carrier is called a 'hole'.

5.3 Semiconductors (impurities, doping)

This section should fill approximately **4 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Explain doping to produce the two types of semiconductors.
- Indentify semiconductors as *p*-type and *n*-type.
- Describe the mode of conduction by the majority and minority carriers.
- Define the term diode and show its circuit symbol.
- Draw a current versus voltage characteristics (graph) to show the behaviour of the p-n junction.
- Describe how a semiconductor diode can be used in a half-wave rectification.
- Sketch voltage time graphs to compute the variation of voltage with time before and after rectification.
- Distinguish between direct current from batteries and rectified alternating current by consideration of their voltage–time graphs.
- Show the circuit symbols of semiconductor devices such as thermistor, LED, LDR and transistors.

Starting off

Students should be reminded of the nature of 'intrinsic' conduction in a semiconductor lattice – the way charge flows through a semiconductor by the movement of electrons (towards the positive pole of the power supply) leaving positive 'holes' which move in the other direction (towards the negative pole of the power supply).

Teaching notes

Compare and contrast the atomic structures of silicon (four electrons in its outer shell) with boron (three electrons in its outer shell) and arsenic (five electrons in its outer shell). Using Activity 5.3 to reinforce these facts.

Remind students that the silicon (intrinsic) semiconductor material they met in the last lesson was not a very good conductor of electricity.

Introduce the idea that, by a process known as doping, an intrinsic semiconductor can be made to conduct more effectively, becoming known as an extrinsic semiconductor.

Doping a semiconductor with a very small number of atoms of an element such as arsenic (five electrons in its outer shell) increases the number of electrons, or negative charge carriers, in the semiconductor lattice (arsenic is thus described as a donor impurity as it introduces free electrons into the lattice). This type of doped semiconductor is called *n*-type. Electrons are the majority charge carrier in an *n*-type semiconductor.

Doping a semiconductor with a very small number of atoms of an element such as boron (three electrons in its outer shell) increases the number of holes, or positive charge carriers, in the semiconductor lattice (boron is thus described as an acceptor impurity; it traps electrons when introduced into the semiconductor lattice, resulting in an increase in holes). This type of doped semiconductor is called *p*-type. 'Holes' are the majority charge carrier in a *p*-type semiconductor.

Stress the fact that atoms of elements used for doping should be approximately the same size as the semiconductor atoms. It is important not to distort the structure of the semiconductor lattice. Use Activity 5.4 to reinforce this.

Having established the structures of *p*-type and *n*-type semiconductors, introduce the concept of the *p*–*n* junction diode. (Remind students of the thermionic diode from the first section of this unit – this should help them remember that current can pass in only one direction through a diode.)

Use diagrams to show how charge carriers move when an electric field is applied.

Make sure the students understand the terms

- **forward bias** (the diode is forward biased when the *p*-type junction of the diode is connected to the positive pole of the supply voltage) and
- **reverse bias** (the diode is reverse biased when the *p*-type junction of the diode is connected to the negative pole of the supply voltage).

Use the demonstration for testing the conduction of a diode to make sure students understand the importance of the voltage characteristics of current flow through a semiconductor diode.

Stress the fact that no current will flow in the forward direction until a voltage of 0.6 V is applied, and that virtually no current flows in the reverse direction unless a very large voltage is applied, at which point the diode breaks down.

Investigating input devices

It will be useful if you are able to demonstrate the properties of a range of 'input devices' to the students. These are electronic components that detect light, moisture, heat etc. and react by changing their resistance, which produces a signal to the electronic circuit in which they are used. The choice of a particular input device depends on the function to which the circuit is to be put.

a

b

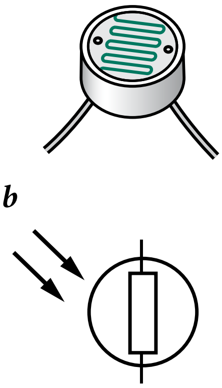


Figure 5.5
***a** LDR component*
***b** LDR symbol*

A light-dependent resistor (LDR) is used to detect light. You will need an LDR, a multimeter and a small lightproof box (large enough to cover the LDR) for this test.

Take the multimeter and set to read resistance (in kilohms). Press the probes of the multimeter firmly against the leads of the LDR, cover the LDR and take the reading on the multimeter. Remove the covering from LDR, expose to the illumination of the room and take the multimeter reading. Hold the LDR in the light from a light bulb, or the Sun, and take the multimeter reading.

You will be able to show the students that the resistance of the LDR was very high when it was covered, that it dropped to a low level when uncovered, and that it was lower still when near the light or in the sunshine.

A moisture meter is used to detect the presence of water. You will need a moisture meter, a multimeter, some water and a teat pipette for this test.

Take the multimeter and set to read resistance (in kilohms).

Press the probes of the multimeter firmly against the leads of the moisture sensor and take a reading when the sensor is dry.

Take a small amount of water into the pipette and carefully squeeze water over the metal bars of the moisture sensor and then take a reading.

You will be able to show students that the resistance of the dry moisture sensor was extremely high – its construction shows that the metal bars connected to the two leads are separated by an air gap, and air is a very poor conductor of electricity. The resistance was lower when the bars were covered with water, as water allows a small electric current to flow between the metal bars linking the two leads.

A thermistor is used to detect heat. For this test you will need a thermistor, a multimeter, a source of heat (such as a large wattage light bulb) and a source of cold (ice cube).

Take the multimeter and set to read resistance (in kilohms). Press the probes of the multimeter firmly against the leads of the thermistor and take the reading at room temperature. Take a reading while holding the thermistor close to a source of heat. Take a reading when touching the thermistor with an ice cube.

You will be able to show the students that the resistance of the thermistor dropped with increasing temperature.

In Activity 5.5, students can investigate how the voltage generated by a photovoltaic cell changes in different light levels.

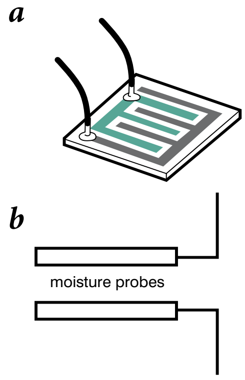


Figure 5.6
a *moisture meter component*
b *moisture meter symbol*

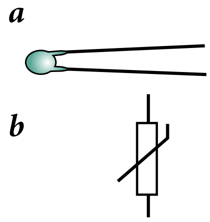


Figure 5.7
a *thermistor component*
b *thermistor symbol*

Rectification

If you are unable to illustrate output voltages referred to in this section on a CRO, you can refer to the illustrations in the Students' Book.

Make sure students understand the idea of alternating current (a.c.) and how this can be rectified (turned into direct current) using the semiconductor diode. Explain that this process is called half-wave rectification. Illustrate the fact that this process produces a rather irregular 'spurting' current using the relevant voltage–time graph.

Compare the voltage–time graph produced from an a.c. current following half-wave rectification with the direct current (d.c.) output from a battery.

Introduce the fact that a capacitor can smooth the direct current produced from half-wave rectification, and illustrate with the relevant voltage–time graph.

If time permits, discuss full wave rectification, which is described in the Students' Book.

SA = starter activity MA = main activity CA = concluding activity	
1. Doping	
SA	With a partner, summarise Student Book pages 160–167.
MA	In groups of nine, Activity 5.3.
CA	Review question 1 to be tackled with a partner.
2. Semiconductor lattices	
SA	With a partner, write down what understand by 'lattice'. Feed back ideas.
MA	Activity 5.4 with a partner.
CA	With a partner, produce a spidergram explaining how doping affects semiconductor lattices.
3. Diodes and their uses	
SA	With a partner, explore the current–voltage characteristics of the semiconductor diode.
MA	Activity 5.5 in a small group.
CA	Write a report on the activities in this lesson.

4. Rectification	
SA	With a partner, summarise Student Book pages 173–174.
MA	In a small group, explore rectification using diodes. Display outputs on a CRO screen.
CA	Review questions 2–5 to be tackled with a partner.

Activities

- Human wire activity.
- Modelling the lattice of a semiconductor activity.
- Current–voltage characteristics of semiconductor diode.
- Light into power activity.

Resources

http://www.howstuffworks.com/diode.htm

(doping, p-type, n-type, diode) http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html#c3

http://electronics.howstuffworks.com/diode1.htm (has some adverts)

(diode) http://electronics.howstuffworks.com/diode2.htm (has some adverts)

Where next

Students might think that input sensors can be used directly in electrical circuits to, for example, switch on a warning light or a motor when an LDR senses light. It is important that they discover that there are limitations to these devices, which make their use less straightforward.

For this demonstration you will need three 1.5 volt cells, two short wire connectors, three long wire connectors, one LDR, a buzzer, a table lamp and a 6 volt motor.

***Figure 5.8 a** circuit with LDR and buzzer* ***b** LDR and buzzer circuit in symbols*

Connect the equipment as shown in Figure 5.8 with the table lamp shining on the LDR. Cover and uncover the LDR.

Disconnect the buzzer and replace with the motor. Cover and uncover the LDR.

You will be able to show that the buzzer sounded when light shone on the LDR and it stopped sounding when the LDR was covered. A buzzer going off when a light goes on could make a useful alarm.

However, when the motor was connected in place of the buzzer, it did not work at all.

The problem with the simple circuit in Figure 5.8 is that the LDR still retains a relatively high resistance even when light is shining on it and, although it can be used in a circuit with a low-powered device such as buzzer or an LED, it cannot be used in this way to switch on a component such as a motor, which requires more power.

Other input devices also share this problem.

In electronics, one circuit is often used to switch on another circuit and input devices, therefore, tend to be used in this way. Students will learn about two ways in which this is done in Section 5.4:

- Transistors – varying the voltages applied to a transistor in one circuit can affect the current flowing in a separate circuit.
- Relay circuits – circuits where a sensor switches on a low-powered circuit which operates an electromagnet to close a switch in another circuit which controls more powerful components

Answers to review questions

1. a) Arsenic is an example of a donor impurity because it releases free electrons into the silicon lattice. An arsenic atom fits into the lattice in place of a silicon atom (it is a similar size and will not significantly distort in the lattice). After making four covalent bonds with the surrounding silicon atoms, the arsenic atom has one electron over. This becomes a free electron, available to conduct electricity.

   b) An n-type semiconductor has an excess of electrons, this describes a silicon lattice doped with arsenic atoms.

2. a) 1.5 A. The current will pass through the 1 Ω and 3 Ω resistors.
   It will not pass though the diode which is reversed biased in this circuit (and hence possessing infinite resistance). Current is therefore given by $I = V/R = 6/(1 + 3) = 6/4 = 1.5$A

   b) 6 A. The diode is now forward biased and the current will pass through the diode (as it requires zero voltage) rather than through the 3 Ω resistor. Current is therefore given by $I = V/R = 6/1 = 6$ A.

3. Current will only pass through a diode valve in one direction, from the hot cathode to the anode. If the polarity of the main supply is reversed, the cold anode does not emit electrons into the vacuum and so current does not flow. The diode valve therefore acts as a rectifier as it allows current to flow through it in one direction only.

4. a) p-type semiconductor material (semiconductor material such as silicon, which has been doped with an acceptor impurity such as boron) is uncharged because it is made of uncharged silicon and boron atoms – even though it has positively charged 'holes' within its structure.

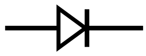
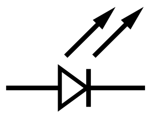
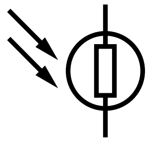
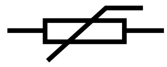
   n-type semiconductor material (semiconductor material such as silicon, which has been doped with a donor impurity such as arsenic) is uncharged because it is made of uncharged silicon and arsenic atoms – although it has additional conduction electrons within its structure.

   b) At a junction between the two types of semiconductor material, some of the free electrons in the n-type 'topple' over the edge into any nearby 'holes' in the p-type.

   c) Both materials were uncharged, but as the electrons 'topple over' the boundary, the p-type is left with an overall negative charge and the n-type with a positive charge. For silicon, a voltage of around 0.6V is created in this way.

d) For a small distance each side of the boundary (of the order of 1 μm) – a shortage of 'holes' one side and free electrons the other is created. This area is called a 'depletion zone' and it prevents any more electrons from crossing the boundary, so in that direction the diode will not conduct. In the depletion zone there are no more 'holes' in the p-type and no free electrons in the n-type, so it forms a non-conducting strip which blocks all current.

5.

Diode	Light emitting diode (LED)	Light-dependent resistor (LDR)	Thermistor
			
The semiconductor diode is formed from a layer of p-type semiconductor joined to a layer of n-type semiconductor material. It allows current to pass round a circuit in one direction only.	An LED emits light when current passes through it in the forward direction. This makes the LED a very useful component – if there is one in a circuit it is possible to see immediately if current is flowing.	A light-dependent resistor conducts electricity, but in the dark it has a very high resistance. Shining light on it appears to 'unjam' it, because its resistance falls. The brighter the light, the better it conducts.	The thermistor is a piece of semiconductor material which has a high resistance in the cold. Its resistance drops as it becomes warmer.

This section should fill approximately **3 periods** of teaching time.

5.4 Transistors (p-n-p, n-p-n)

Learning Competencies

By the end of this section students should be able to:

- Distinguish between p-n-p and n-p-n transistors.
- Identify the base, emitter and collector of a transistor.
- Use the following terms correctly: forward biased and reverse biased.
- Describe the behaviour of semiconductor devices such as thermistor, LED, LDR, photodiode and transistors.
- Use the circuit symbols for the gates.
- Draw the truth tables for the different logic gates and for a combination of logic gates.
- Explain the action of logic gates: NOT, OR, AND, NOR, NAND.

Starting off

Transistors are important components of electronic circuits because they use the input of relatively small circuits to control circuits carrying large currents.

Teaching notes

Remind students that electronic sensor cannot be used in a circuit that uses significant power (seen in 'Where next' at the end of the lesson notes for 5.3).

Introduce the idea that transistors can use the input of relatively small signals to control circuits carrying relatively large currents.

Discuss the structure of the bipolar junction transistor – refer to the diagram in the Students' Book.

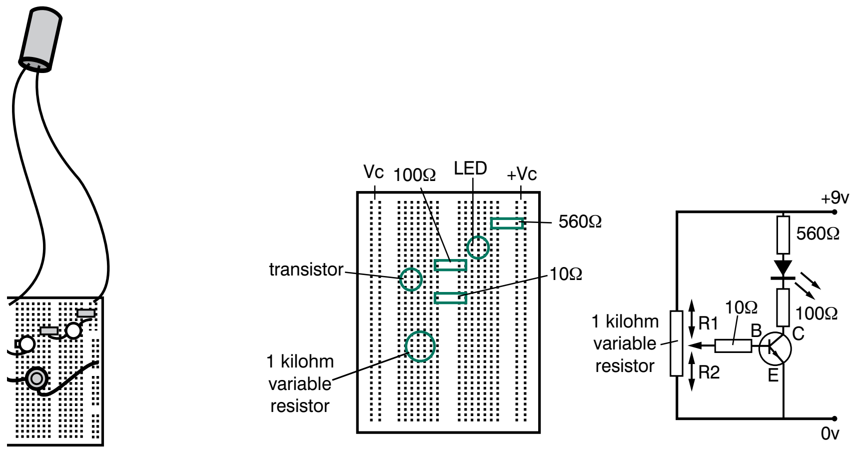
Although there are notionally two types of this transistor (n–p–n and p–n–p), both appear to have the structure of two diodes back to back. Make sure students realise that, from what they have already learned, no current should be able to flow through such a structure.

Describe the three electrodes on the n–p–n (the more usual type) of transistor – base, emitter, collector.

It would be helpful if you could now demonstrate the action of a transistor as voltage divider.

In this demonstration, you vary the voltage applied between the connections to the transistor by varying the values of resistors connected between them and show the students how this affects the ability of the transistor to conduct electricity.

You will need a transistor (a 2N3053 was used here), a 10 Ω resistor, a 100 Ω resistor, a 560 Ω resistor, a 1 kilohm variable resistor, a 5 mm LED, a 9 volt battery and snap connector, a multimeter, clip leads or connecting system such as a breadboard.



***a** equipment*   ***b** breadboard*   ***c** circuit*

Figure 5.9

Connect the equipment as shown in Figure 5.9 (make sure you have identified the base, emitter and collector wires of the transistor) with the variable resistor set at 0 (as far as possible in the anticlockwise direction). Draw the students' attention to the fact that the LED is not lit – despite the fact that a large battery appears to be connected to it! Adjust the multimeter to read voltage. Touch one probe to the base wire of the transistor and the other to the emitter wire. This voltage should read zero.

Increase the voltage applied to the base of the transistor by turning the variable resistor control in a clockwise direction, until the LED is just lit. Touch one probe of the multimeter to the base wire of the transistor and the other to the emitter wire. This voltage should read between 0.6 and 0.7 volts. This is the usual potential difference between base and emitter that is required to allow the transistor to conduct.

This demonstrates how the transistor can control the power to another circuit.

Make sure that students know that the application of around 0.6 V to the base of a transistor allows current to flow in a circuit through the transistor from collector to emitter.

In the Transistor as amplifier demonstration you can demonstrate the other use of the transistor.

Make sure that students are confident with the operation of the transistor, testing some of the circuits shown in the Students' Book, which use input devices such as the LDR, LED, thermistor and the photovoltaic cell.

Introduce the students to the logic gates shown in the Students' Book.

Construct truth tables for logic gates and combinations of logic gates.

Discuss the operation of some of the logic gate combinations in the Students' Book.

When discussing the use of logic gates, you may well need to explain the operation of a relay. If the resistance in a sensor, – such as an LDR – falls sufficiently to allow a small current to flow in a circuit in which there is an electromagnet, this electromagnet can act on a switch in a second circuit, closing it to allow a large current to flow through a device such as a motor. This combination of an electromagnet and a switch is known as a relay. Relays are important devices that allow a small current in one circuit to affect a large current in a second circuit.

SA = starter activity MA = main activity CA = concluding activity	
1. Transistors	
SA	With a partner, make a poster to explain how the bipolar transistor operates.
MA	In a small group, use a transistor as an amplifier as described on page 179–180 of the Student Book.
CA	Review question 1 to be tackled with a partner.
2. Logic gates (1)	
SA	With a partner, write down what understand by term ‘logic’. Feed back ideas.
MA	In a small group, make a poster to summarise pages 184–187 of the Student Book.
CA	Review question 2 to be tackled with a partner.
3. Logic gates (2)	
SA	Review questions 3–4 to be tackled with a partner.
MA	In a small group, produce a presentation about how logic gates are used in circuits.
CA	End of unit questions to be tackled with a partner.

Activities

- Transistor as amplifier demonstration.

Resources

(transistor) http://electronics.howstuffworks.com/diode2.htm (has some adverts)

(Boolean Logic) http://computer.howstuffworks.com/boolean.htm (has some adverts)

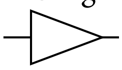
(logic gates) http://computer.howstuffworks.com/boolean1.htm (has some adverts)

Where next

Students should feel confident in examining simple electronic circuits and interpreting their function.

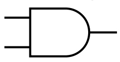
Answers to review questions

1. 6.0×10^{-4} A (0.60 mA)
2. a) NOT gate



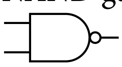
INPUT	OUTPUT
0	1
1	0

b) AND gate



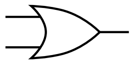
INPUT A	INPUT B	OUTPUT
0	0	0
0	1	0
1	0	0
1	1	1

c) NAND gate



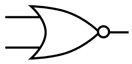
		OUTPUT
INPUT A	INPUT B	NAND
0	0	1
0	1	1
1	0	1
1	1	0

d) OR gate



INPUT A	INPUT B	OUTPUT
0	0	0
0	1	1
1	0	1
1	1	1

e) NOR gate



		OUTPUT
INPUT A	INPUT B	NOR
0	0	1
0	1	0
1	0	0
1	1	0

3. a) 1 If the output of the gate is a '1', it acts as if is part of the positive voltage line – if it is 0, it acts like part of the 0 V line, so the output needs to be a '1'.

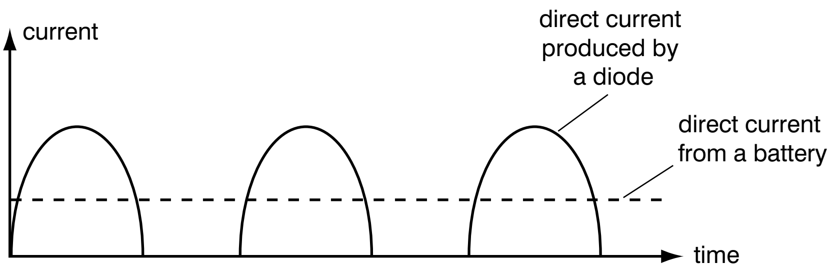
   b) 1, 1

4.

A	B	C	D	E
0	0	1	1	1
1	0	0	1	0
0	1	1	0	0
1	1	0	0	0

Answers to end of unit questions

1. 3 V
2. The boron atom makes only three covalent bonds in the silicon lattice, leaving the lattice one electron short, so there is a positive 'hole' at this point.
3. The current obtained from a battery is constant.



The current obtained from an alternating supply with a diode is constantly varying, and is zero for half the cycle (when the a.c. supply is negative).

4. n-type semiconductor material (semiconductor material such as silicon, which has been doped with a donor impurity such as arsenic) has additional conduction electrons within its structure because the arsenic atom has five electrons in its outer shell. After making four covalent bonds in the silicon lattice it has one electron over. This becomes a free electron, available to conduct electricity.

   p-type semiconductor material (semiconductor material such as silicon, which has been doped with an acceptor impurity such as boron) has positively charged 'holes' within its structure because the boron atom has three electrons in its outer shell. It makes three covalent bonds in the silicon lattice, leaving the lattice one electron short, so there is a positive hole at this point.

5. In a digital system, a voltage is either on or off. It is usual to represent ON (the full voltage) by 1 and OFF (zero voltage) by 0. Logic gates are connected between the two supply rails of an electronic circuit – one is at zero (0), the other at the supply voltage (1).

6. a) NAND gate

		OUTPUT
INPUT A	**INPUT B**	**NAND**
0	0	1
0	1	1
1	0	1
1	1	0

If both inputs are joined together, only lines 1 and 4 of the above table will be relevant. (input 0, output 1 and input 1 output 0). This is the same as the truth table for the NOT gate.

b) NOT gate

INPUT	OUTPUT
0	1
1	0

Electromagnetic waves and geometrical optics

Unit 6

This unit should fill approximately **16 periods** of teaching time.

Learning Competencies for Unit 6

By the end of this unit students should be able to:

- Explain how electromagnetic waves are produced.
- Describe the nature of electromagnetic waves.
- Compare mechanical and electromagnetic waves.
- Draw diagrams to represent transverse waves.
- Use straight lines to represent the direction of energy flow (rays).
- Identify that electromagnetic waves emitted by the Sun have a wide continuous range of frequencies (and wavelengths.)
- Explain some uses of electromagnetic radiation.
- Explain what is meant by the rectilinear propagation of light.
- State the laws of reflection.
- Perform experiments to test the laws of reflection using a plane mirror.
- Use the laws of reflection to explain how images are formed in a plane mirror.
- Find the position of a virtual image produced by a plane mirror using a ray tracing method.
- Use the laws of reflection to solve problems.
- Give examples of the uses of plane mirrors.
- Distinguish between concave and convex mirrors.
- Identify the meanings of: principal axis, principal focus, radius of curvature, magnification in relation to concave and convex mirrors.
- Distinguish between real and virtual images.
- Apply the appropriate sign convention when using mirror equations.
- Find the position and nature of the image formed by a concave and a convex mirror using the mirror equation and a ray tracing method.
- Use the relation magnification $= \frac{S_i}{S_o} = \frac{h_i}{h_o}$ to solve problems.
- Give examples of the uses of curved (concave and convex) mirrors.
- Define the term refraction.
- State the conditions in which refraction occurs.
- Define the refractive index of a material.

- Use Snell's law to solve simple problems.
- Use the formula refractive index = $\frac{\text{real depth}}{\text{apparent depth}}$ to find the refractive index of a liquid and a solid in the form of a rectangular glass block.
- Perform experiments to test the laws of refraction.
- Draw a diagram representing the passage of light rays through a rectangular glass block.
- Give examples of observations that indicate that light can be refracted.
- Identify that the passage of a ray of light through a parallel-sided transparent medium results in the lateral displacement of a ray.
- Define the critical angle θ_c.
- Explain, with the aid of a diagram, what is meant by critical angle and total internal reflection.
- Identify the conditions necessary for total internal reflection to occur.
- Perform calculations involving critical angle and total internal reflection.
- Describe how total internal reflection is used in optical fibres.
- Distinguish between convex and concave lenses.
- Identify the meaning of: principal focus, principal axis, focal point, radius of curvature, magnification in relation to converging and diverging lenses.
- Apply the appropriate sign convention when using thin lens equations.
- Find the position and nature of the image formed by a convex and concave lens using the thin lens formula and a ray tracing method.
- Define the power of a lens.
- Explain how the image is formed due to combination of thin lenses.
- Draw a ray diagram to show how images are formed by lenses in a simple microscope and a simple telescope.
- Compare and contrast the structure and functions of the human eye and the camera.
- Describe how the human eye forms an image on the retina for different object distances.
- Identify some defects of the eye and their correction with lenses.
- Explain what is meant by the dispersion of white light to produce a spectrum.
- Identify that the passage of a ray of light through a triangular transparent prism results in a deviation of a ray.

This section should fill approximately **3 periods** of teaching time.

6.1 Electromagnetic waves

Learning Competencies

By the end of this section students should be able to:

- Explain how electromagnetic waves are produced.
- Describe the nature of electromagnetic waves.
- Compare mechanical and electromagnetic waves.
- Draw diagrams to represent transverse waves.
- Use straight lines to represent the direction of energy flow (rays).
- Identify that electromagnetic waves emitted by the Sun have a wide continuous range of frequencies (and wavelengths).
- Explain some uses of electromagnetic radiation.

Starting off

Begin by ensuring that students remember previous learning about electric and magnetic fields. You could organise a quiz based on the exercises in units 2 and 4. Then show students a water wave moving in a small tank of water. You can have a shallow tank of water and start a wave by dropping a stone into the centre. Ask students to describe what they observe.

Activity 6.1: Answer

Students' own results.

Teaching notes

Make sure that students understand the diagram of a transverse wave. Explain electromagnetic waves carefully. Stress that these waves can travel through a vacuum (this is how light from the Sun reaches Earth). Organise the students into groups of about 20 to carry out Activity 6.1, which is a visual representation of an electromagnetic wave. It is important that students realise that the electric and magnetic fields are at right angles and remember how a change in the electric field will induce a change in the magnetic field.

Activity 6.2 gives students an opportunity to discuss mechanical and electromagnetic waves in a small group.

Activity 6.2: Answer

Highlight the fact that mechanical waves need a medium through which to travel but electromagnetic waves can travel through a vacuum; that mechanical waves transport energy and not material, but electromagnetic waves transport energy and momentum that can be transferred to matter with which they interact. Mechanical and electromagnetic waves have amplitude, frequency, wavelength and period.

The next section discusses the relationship between frequency, wavelength and speed. This is an important step and should not be rushed. Use the worked example as the basis for further questions for the students – you may wish to set them the problem and see how they tackle it before revealing the solution. This can give you valuable information for assessment purposes.

The electromagnetic spectrum is an important concept for students to grasp. Students need to realise that the speed of electromagnetic waves in a vacuum is 3×10^8 m/s but that they have varying wavelengths and thus frequencies, which means that they have a variety of uses (and hazards). Activity 6.3 is an opportunity for students to summarise the properties of electromagnetic radiation.

Activity 6.3: Answer

Some information is given in the text, but you may wish to use this as an opportunity to involve students in further independent research.

SA = starter activity MA = main activity CA = concluding activity	
1. Electromagnetic waves	
SA	With a partner, list examples of waves in everyday life. Feed back ideas.
MA	Activity 6.1 in groups of 20.
CA	Review questions 1–2 to be tackled with a partner.
2. Comparing mechanical and electromagnetic waves	
SA	With a partner, explain terms ‘amplitude’, ‘frequency’, ‘wavelength’. Feed back ideas.
MA	Activity 6.2 in small groups.
CA	Review questions 3–5 to be tackled with a partner.
3. Uses of electromagnetic radiation	
SA	Activity 6.3 in a small group.
MA	In a small group, produce a spidergram of the summary on pages 198–199 of the Student Book.
CA	Review questions 6–7 to be tackled with a partner.

Activities

- Modelling an electromagnetic wave.
- Compare mechanical and electromagnetic waves.
- Uses of electromagnetic radiation.

Resources

http://www.school-for-champions.com/science/emwaves.htm

http://physics.bi.edu/~duffy/PY106/EMwaves.htm

Where next?

The final two topics in this unit focus on one area of the electromagnetic spectrum – visible light. Section 6.2 concentrates on reflection of light and Section 6.3 refraction of light.

Answers to review questions

1. The vibrations in electromagnetic waves come from electric and magnetic fields. Electromagnetic waves are produced when a magnetic field and an electric field are at right angles to each other. They carry energy and momentum that may be transferred to matter with which they interact.

2. Electromagnetic waves are transverse waves. Electromagnetic waves do not need a medium through which to travel – they can travel through a vacuum.
3. Mechanical waves need a medium through which to travel but electromagnetic waves can travel through a vacuum; mechanical waves transport energy and not material, but electromagnetic waves transport energy and momentum that can be transferred to matter with which they interact. Mechanical and electromagnetic waves have amplitude, frequency, wavelength and period.
4.

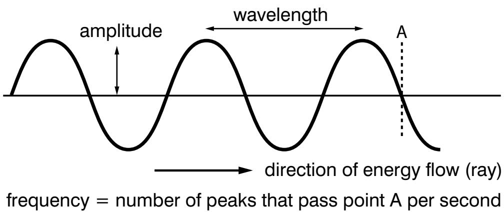


Figure 6.1

5. The frequency, wavelength and speed of a wave are related by the formula

   speed = frequency × wavelength

   In symbols this is written as

   $v = f\lambda$

   The units need to be: m/s for speed; Hertz for frequency; metres for wavelength
6. This diagram shows the electromagnetic spectrum.

γ rays	X rays	ultraviolet rays	visible light	infrared rays	microwaves	radio waves
10^{-12} m	10^{-10} m	10^{-8} m	6 x 10^{-7} m	10^{-6} m	10^{-2} m	1 m

Figure 6.2

7. $v = f\lambda$ so $f = \dfrac{v}{\lambda} = \dfrac{3 \times 10^8}{1 \times 10^{-10}} = 3 \times 10^{18}$ Hz

This section should fill approximately **6 periods** of teaching time.

6.2 Reflection of light

Learning Competencies

By the end of this section students should be able to:

- Explain what is meant by the rectilinear propagation of light.
- State the laws of reflection.
- Perform experiments to test the laws of reflection using a plane mirror.
- Use the laws of reflection to explain how images are formed in a plane mirror.
- Find the position of a virtual image produced by a plane mirror using a ray tracing method.
- Use the laws of reflection to solve problems.
- Give examples of the uses of plane mirrors.
- Distinguish between concave and convex mirrors.

- Identify the meanings of: principal axis, principal focus, radius of curvature, magnification in relation to concave and convex mirrors.
- Distinguish between real and virtual images.
- Apply the appropriate sign convention when using mirror equations.
- Find the position and nature of the image formed by a concave and a convex mirror using the mirror equation and a ray tracing method.
- Use the relation magnification $= \frac{S_i}{S_o} = \frac{h_i}{h_o}$ to solve problems.
- Give examples of the uses of curved (concave and convex) mirrors.

Starting off

This topic explores a phenomenon with which students will be very familiar from everyday life: reflection of light. Begin by drawing out this existing experience. For example, ask students how they get themselves ready for school in the morning. At some point they will probably use a mirror. Explain that 'rectilinear propagation of light' simply means light travels in straight lines!

Teaching notes

Activity 6.4 gives students an opportunity to explore reflection in a plane mirror. They then work in a small group to think about where reflection occurs in nature. This practical experience leads to a discussion of the laws of reflection. Students will need to be proficient with using protractors and understand how to measure angles. It would help students to grasp this section if you could reproduce the diagrams in the Students' Book on the board and work through the text, referring to the diagram as you go. Question students to test understanding. For example, if the angle of incidence is 40°, what would the angle of reflection be? (40° as well).

Activity 4.6 is an opportunity for students to make a simple optical instrument – a periscope. You may wish students to work with a partner to do this activity, or you may wish to set it as an assignment to be done at home.

The explanation of why you cannot see your reflection in a piece of paper brings out an important point – if light is scattered in all directions you will not get a visible image.

We move on to use the laws of reflection and a ray tracing method to explain how an image is formed in a plane mirror. Again, if you can reproduce the diagrams from the Students' Book on the board and refer to them as you work through the explanation this will be helpful for students.

You should work through the worked example carefully – again, if you provide enlarged copies of the diagrams for students and involve them in the steps this will be beneficial.

Activity 6.7 is an opportunity for students to work in a small group and see how this learning is relevant to their daily lives.

We move on now to discuss concave mirrors. If you can provide some tablespoons at this point for students to look at the images formed in them, it would be helpful. Activity 6.8 should be carried out in small groups, with students discussing their observations and trying to explain them in their own words. The magnification of images in concave mirrors explains some of their practical uses.

Activity 6.4: Answer

Students' own results.

Activity 6.5: Answer

Examples may be reflections in a lake, reflections on the bodies of insects.

Activity 6.6: Answer

Students' own results.

Activity 6.7: Answer

Examples include getting dressed, hyding, law, etc

Activity 6.8: Answer

Students' own results.

The introduction to convex mirrors points out the properties of images formed by such mirrors. Students should note Figure 6.21, which summarises the terms used in concave and convex mirrors – this vocabulary has a counterpart in concave and convex lenses, which we meet in Section 6.3.

The distinction between real and virtual images is best made using the question 'can you capture this image on a screen?'. If you can capture the image, it is real, if you cannot, it is virtual.

Activity 6.9 is similar to Activity 6.7 and gives a further opportunity for students to relate learning to everyday experience.

Activity 6.9: Answer

Students should think about shaving mirrors, driving mirrors, etc.

Activity 6.10 gives students the chance to find the focal length of a concave mirror, which leads neatly on to the section that considers the mirror equation. Make sure that students understand that virtual images are given a negative sign in the mirror equation. Work through the worked example carefully – as usual you may wish to set the problem and see how the students tackle it before discussing the given solution. Give plenty of practice using your own examples based on the one given.

Activity 6.10: Answer

Students' own results.

The ray tracing method should be explained carefully. Ask students to explain in their own words how to use this method to check understanding. They will need this understanding when we consider the technique in relation to lenses in Section 6.3.

The section ends by considering the magnification relationship for mirrors. See whether students can come up with the relationship for themselves before showing them the formula: talk about the image height and object height and how they might give an idea of magnification, for example.

SA = starter activity MA = main activity CA = concluding activity	
1. Reflection of light	
SA	With a partner, list examples of reflection in everyday life. Feed back ideas.
MA	Activity 6.4 in a small group.
CA	Activity 6.5 in a small group.
2. Laws of reflection	
SA	Discuss review question 1 with a partner. Feed back ideas.
MA	Activity 6.6 with a partner.
CA	With a partner, make a poster about the laws of reflection.
3. Images in plane mirrors	
SA	Worked example 6.2 individually, before given solution revealed.
MA	Activity 6.7 in a small group.
CA	Feed back from the activities in the lesson. What went well? What would you do differently?
4. Concave and convex mirrors (1)	
SA	Review questions 2–6 to be tackled with a partner.
MA	Activity 6.8 in small group.
CA	Activity 6.9 in small group.
5. Concave and convex mirrors (2)	
SA	Feed back ideas from Activity 6.9.
MA	Activity 6.10 in small group.
CA	Review the activity.

6. Equations for mirrors	
SA	Worked example 6.3 to be tackled with a partner.
MA	With a partner, make a poster to summarise Student Book pages 208–209.
CA	Review questions 7–12 to be tackled with a partner.

Activities

- Investigating the reflection of light.
- Natural examples of reflection.
- Making a simple periscope.
- The uses of plane mirrors.
- Investigating the behaviour of a concave mirror.
- The uses of concave and convex mirrors.
- Determining the focal length of a concave mirror.

Resources

http://www.tutorvista.com/content/physics/physics-ii/light-reflection/light-reflectionindex.php

http://www.csun.edu/~psk17793/S9CP/S9%20Reflection_of_light.htm

Where next?

The next section uses some of the ideas introduced here and applies them to lenses.

Answers to review questions

1. Rectilinear propagation of light simply means that light waves travel in straight lines.
2. The angle of reflection is equal to the angle of incidence. The reflected ray lies in the plane which contains the incident ray and the normal.
3. Set up the apparatus as shown in figure 6.3.

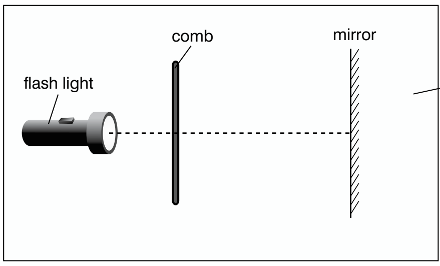


Figure 6.3

   Break every other tooth of the comb. Draw the rays that appear to be coming from the mirror on the paper.

4. Consider the mirror shown here, with the object at point O.

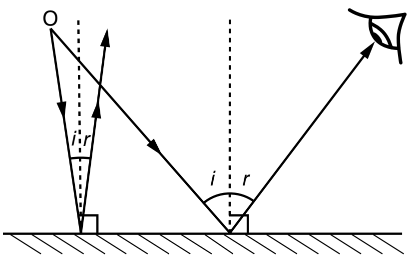


Figure 6.4

   The first law tells us that the angle of incidence is equal to the angle of reflection, so in the diagram $i = r$.

Now trace the reflected rays beyond the mirror using dotted lines as shown on the right.

The point where the dotted lines meet is the position of the image, I.

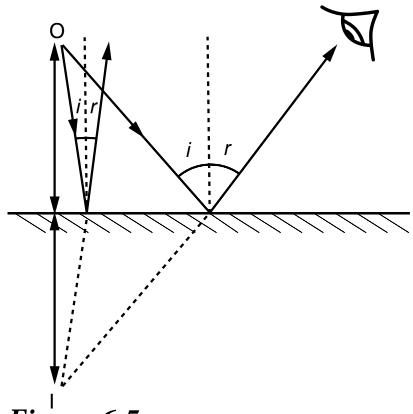


Figure 6.5

5.

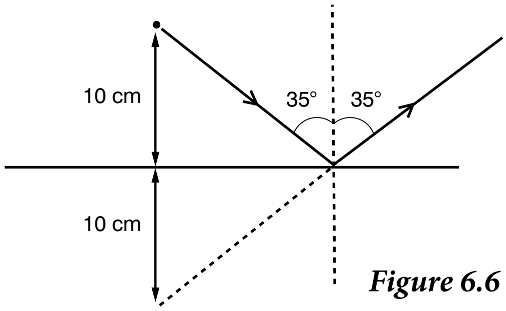


Figure 6.6

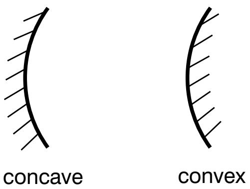


Figure 6.7

6. Examples of the uses of plane mirrors include checking that clothing is tidy, that hair is tidy, making a room look bigger by reflecting light.
7. Figure 6.7 shows the difference between concave and convex mirrors.
8.

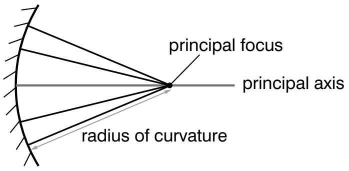


Figure 6.8

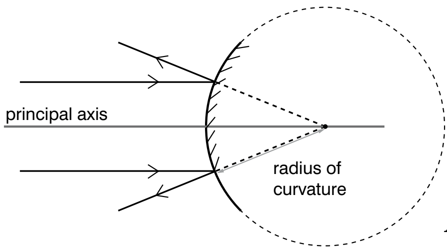


Figure 6.9

9. Magnification is defined as the height of the image divided by the height of the object. It is just a number, and will have no units. We can calculate it will as follows:

   Magnification = $\frac{v}{u}$ where v = height of image and u = height of object

10. Real images may be captured on a screen but virtual images cannot be captured on a screen.
11. The notation used is:

    f = the focal length of the mirror.

    u = the distance from the object to the centre of the mirror.

    v = the distance from the centre of the mirror to where the image is formed.

The connection between them is:

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

If the image is virtual then we use a negative sign for the distances.

12. a) $\frac{1}{20} + \frac{1}{v} = \frac{1}{f}$

$\frac{1}{15} - \frac{1}{20} = \frac{1}{v}$ so v = 60 cm image is real and 60 cm from mirror

$\frac{1}{15} + \frac{1}{v} = \frac{1}{f}$

$\frac{1}{8} - \frac{1}{15} = \frac{1}{v}$ so v = 17.1 cm image is real and 17.1 cm from mirror

b)

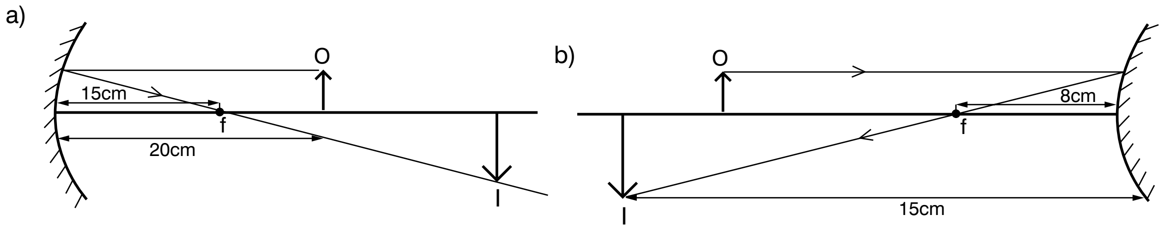


Figure 6.10

6.3 Refraction of light

This section should fill approximately **7 periods** of teaching time.

Learning Competencies

By the end of this section students should be able to:

- Define the term refraction.
- State the conditions in which refraction occurs.
- Define the refractive index of a material.
- Use Snell's law to solve simple problems.
- Use the formula refractive index = $\frac{\text{real depth}}{\text{apparent depth}}$ to find the refractive index of a liquid and a solid in the form of a rectangular glass block.
- Perform experiments to test the laws of refraction.
- Draw a diagram representing the passage of light rays through a rectangular glass block.
- Give examples of observations that indicate that light can be refracted.
- Identify that the passage of a ray of light through a parallel-sided transparent medium results in the lateral displacement of a ray.
- Define the critical angle θ_c.
- Explain, with the aid of a diagram, what is meant by critical angle and total internal reflection.
- Identify the conditions necessary for total internal reflection to occur.
- Perform calculations involving critical angle and total internal reflection.
- Describe how total internal reflection is used in optical fibres.

- Distinguish between convex and concave lenses.
- Identify the meaning of: principal focus, principal axis, focal point, radius of curvature, magnification in relation to converging and diverging lenses.
- Apply the appropriate sign convention when using thin lens equations.
- Find the position and nature of the image formed by a convex and concave lens using the thin lens formula and a ray tracing method.
- Define the power of a lens.
- Explain how the image is formed due to combination of thin lenses.
- Draw a ray diagram to show how images are formed by lenses in a simple microscope and a simple telescope.
- Compare and contrast the structure and functions of the human eye and the camera.
- Describe how the human eye forms an image on the retina for different object distances.
- Identify some defects of the eye and their correction with lenses.
- Explain what is meant by the dispersion of white light to produce a spectrum.
- Identify that the passage of a ray of light through a triangular transparent prism results in a deviation of a ray.

Starting off

This section builds on ideas we met in Section 6.2. By devising a quiz, check that students can recall the difference between concave and convex mirrors and the terms used when considering concave and convex mirrors (e.g. principal axis, principal focus, radius of curvature and magnification). Check that they can recall the mirror equation and the sign convention used with this equation.

Activity 6.11: Answer

Straw or stick looks 'bent'.

Teaching notes

The section begins by looking at a simple example of refraction. Students are given the opportunity to set the situation up for themselves in Activity 6.11. They should be given time to discuss their observations in small groups. At this stage you should remind students about the word 'normal', which they met in Section 6.2 when considering the laws of reflection. Its meaning here is the same as before. Take time to discuss the section on consequences of refraction and see whether students can add to the list of examples given in the text.

Snell's law requires students to have an understanding of sines of angles. Make sure that students are comfortable with this mathematical concept before studying the physics. It is important to show students how their study of mathematics has applications in other subjects such as this so that they see the value of mathematical study, even if they are not natural mathematicians!

It would be good to set the problem in the worked example and see how students tackle it before discussing the given solution, but you should prompt them to draw a diagram so that they can see what is going on.

Activity 6.12 is an opportunity for students to apply their learning to a new situation. Students should discuss the questions thoroughly and record some hypotheses about what will happen before testing their ideas using apparatus.

At this point you could demonstrate refraction of water waves: take a shallow tank of water and put a block of glass into the water. Set up some water waves and ask students to describe what happens to the waves in the different depths of water.

Activity 6.13 is an opportunity for students to observe the refraction of a light ray through a glass block. The block should be sized so that it fits neatly into the centre of a piece of paper and the angle of incidence should be such that it is easy to measure using a standard protractor. You may wish to reduce the light levels in the classroom for this activity so that the light beam is easier for students to see. Activity 6.14 should demonstrate lateral displacement, which is discussed on page 215 in the text.

Work through the section on apparent depth carefully. If possible, have a tank of water with an object under the water that students can observe while you discuss the text. Visual aids are always useful when discussing theory such as this, and can help to hold students' interest. It is also easier to involve them in their learning since you can question them about what they observe. The activity about using

refractive index $= \frac{\text{real depth}}{\text{apparent depth}}$ to find the refractive index of the liquid should reinforce the theory.

Activity 6.15 gives students an opportunity to see where everyday observations support the theory.

Total internal reflection is a concept that has grown in importance because it has applications in fibre optics, which are used in communications, medicine and other industries. Take time to ensure that students understand what is happening. In Activity 6.16, you should add the fluorescein to the water and students should not put their hands in the water. Apply usual safety precautions for chemical use at this point. Use the worked example as the basis for further examples for your students.

You may wish to ask students to carry out some independent research into the applications of fibre optics, which can then be shared with the rest of the class. You could ask students to prepare presentations on their research, which will assist them with their language studies. They should also carry out Activity 6.17.

The section then moves on to consider lenses. There are parallels here with the previous topic when we considered concave and convex mirrors. Start by drawing a lens like the one in the Students' Book on page 219 and ask students to add the principal focus, principal axis, focal length to the diagram, using their knowledge of similar terms when considering curved mirrors. Stress the use of the term power in connection with lenses as this is the term used by opticians when prescribing lenses for glasses.

Activity 6.18 gives students an opportunity to reinforce the work done as a class by comparing lenses and mirrors. The section on magnification should also be intuitive if students remember the definition of magnification from their work on mirrors.

Activity 6.12: Answer

Speed of light will be the same in both media.

Activity 6.13: Answer

Students' own results.

Activity 6.14: Answer

Students' own results.

Activity 6.15: Answer

Students' own results.

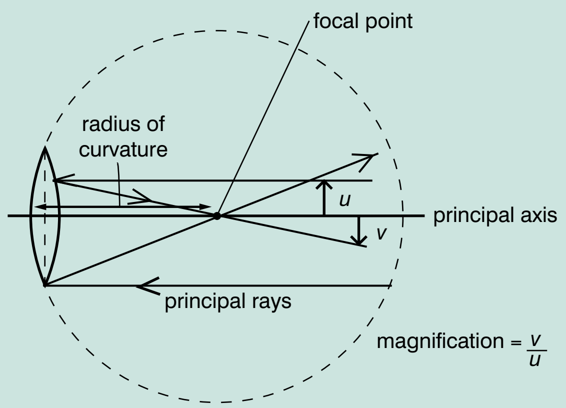
Activity 6.16: Answer

Students' own results.

Activity 6.17: Answer

Students' own results.

Activity 6.18: Answer



Activity 6.19: Answer

Students' own results.

Activity 6.19 is an opportunity for students to work in small groups and see how a lens works. You may need to darken the classroom during this activity.

Ask students to give you the mirror formula and then give the notation for the lens formula. See whether the students can see that the thin lens formula is the same as that for mirrors, with the same sign convention. This means they only have to remember one formula, which can be applied to two separate situations! Work through the worked example so that they can see the formula in action and give further examples as required.

The next section considers how to find the position and nature of an image formed by a lens using a ray tracing method. This is similar to the ray tracing method students met in Section 6.2 but you should allow plenty of time for students to work through this section. It would be helpful if you could reproduce the Students' Book diagrams on the board and refer to them as you discuss the text.

The explanation on how an image is formed due to a combination of thin lenses should be worked through carefully as it is preparation for our consideration of optical instruments. Question students to check understanding as you work through the text and encourage students to ask questions if there are any points that they do not understand fully.

Activity 6.20: Answer

Students' own results.

When considering optical instruments, if you can show students an example of the instruments, then this is beneficial. You may be able to borrow a model of a human eye from colleagues who teach Biology. Activity 6.20 is an opportunity for students to explore 'near points', while Activity 6.21 gives an opportunity for work in small groups to compare and contrast the structure and function of the human eye and the camera. Students could present their thoughts in the form of a comparison table like the one started here.

Activity 6.21: Answer

	Focusing mechanism	Image capture	Image orientation
Human eye	muscles around eye	retina	upright image
Camera	adjusting lens	film	inverted image

Activity 6.22: Answer

Students' own results.

Activity 6.23: Answer

Students' own results.

Activity 6.24: Answer

Students' own results.

The section on defects of the eye and their correction with lenses needs to be handled sensitively so that those students who have eye defects do not feel unusual in any way.

We then move on to discuss diffraction of light. As with refraction, diffraction is a phenomenon that can be observed with water waves. You could set up a shallow tank of water and show how waves are diffracted through an obstacle in the centre of the tank. Figure 6.11 shows the set up you could use.

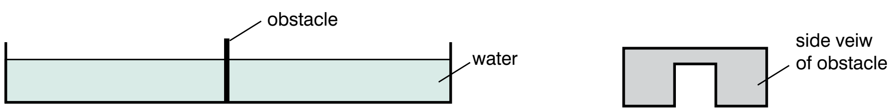


Figure 6.11

This final section of the topic is very practical. Activities 6.22, 6.23 and 6.24 all involve diffraction, and you could arrange for students to move round these activities to reduce the amount of equipment needed. For example, 20 students could start with Activity 6.21, 20 with Activity 6.22, 20 with Activity 6.23. Then they could all move on to the next activity: those who did Activity 6.21 could move to Activity 6.22, those who did Activity 6.22 could move to Activity 6.23, and those who did Activity 6.23 could move to Activity 6.21. This process could be repeated until all students have carried out the three activities.

Activity 6.25 needs to be done with all the class at once. Students should work in small groups and should try and explain their observations using their knowledge of the electromagnetic spectrum.

Bring the class back together and discuss students' explanations before working through the explanation given in the Students' Book.

Activity 6.26 involves students in building a spectroscope using a cracked CD. Make sure that students note the warning about not looking directly at the Sun, as this could cause blindness. You may like to set this activity as an assignment that can be done at home.

The final two activities, Activities 6.27 and 6.28, work as a pair and lead students to design a collector for the Sun's heat energy, which can be used to heat a small amount of water. Such technology is becoming increasingly important as the reserves of fossil fuels worldwide are depleted.

Activity 6.25: Answer

visible light has a range of wavelengths that will be refracted by different angles by the glass, thus producing the spectrum

Activity 6.26: Answer

Student's own results.

Activity 6.27: Answer

Student's own results.

Activity 6.28: Answer

Student's own results.

SA = starter activity MA = main activity CA = concluding activity	
1. Refraction	
SA	Activity 6.11 with a partner.
MA	Activity 6.12 in small group.
CA	Review questions 1–2 to be tackled with a partner.
2. The laws of refraction	
SA	With a partner, summarise Student Book page 214.
MA	Activity 6.13 with a partner. Activity 6.14 with a partner.
CA	Activity 6.15 with a partner.
3. Total internal reflection	
SA	Activity 6.16 with a partner.
MA	Activity 6.17 in small group.
CA	Review questions 3–12 to be tackled with a partner.
4. Lenses	
SA	Activity 6.18 with a partner.
MA	Activity 6.19 in small group.
CA	Review questions 13–16 to be tackled with a partner.
5. Optical instruments	
SA	With a partner, list as many pieces of equipment that use lenses as you can. Feed back ideas.
MA	Activity 6.20 in small group.
CA	Activity 6.21 in small group.

6. Diffraction	
SA	Activity 6.22 in small group.
MA	Activity 6.23 in small group. Activity 6.24 in small group.
CA	Review questions 17–21 to be tackled with a partner.
7. Dispersion of light	
SA	Activity 6.25 in small group.
MA	Activity 6.26 in small group. Activity 6.27 in small group. Activity 6.28 in small group.
CA	Review questions 22–23 to be tackled with a partner. End of unit questions to be tackled with a partner.

Activities

- Observing refraction.
- Discussion on refraction.
- Testing the laws of refraction and drawing a diagram representing the passage of light rays through a rectangular glass block.
- Using refractive index = $\frac{\text{real depth}}{\text{apparent depth}}$ to find the refractive index of a liquid.
- Observations that indicate that light can be refracted.
- Exploring increasing the angle of incidence.
- Transmission of light through a fibre optic cable.
- Comparing lenses and mirrors.
- Using a concave lens.
- Exploring 'near points'.
- Comparing and contrasting the structure and functions of the human eye and the camera.
- Diffraction of light.
- Two slit diffraction.
- Using a diffraction grating.
- Exploring dispersion of white light.
- The CD spectroscope.
- Measuring the solar constant using a Fresnel lens.
- Design a collector for the heat of the Sun.

Resources

http://www.school-for-champions.com/light-refraction.htm

http://hyperphysics.phy-astr.gsu.edu/Hbase/geoopt/refr.html

Where next?

This is the final section in the Grade 10 syllabus. You should now begin to revise the content covered in the entire grade and prepare students for their end of year examination. Base revision questions and the end of year examination questions on the exercises given in the Students' Book, because these have been designed to check that the learning competencies have been achieved.

Answers to review questions

1. Refraction is the change in the direction of travel of a light beam that occurs as the light crosses the boundary between one transparent medium and another.

2. Some materials refract light at their boundary more than others. The extent to which each one does this is measured by its refractive index, given the symbol *n*. The refractive index is a number larger than one, such that the greater the number the greater the refraction produced. Water, for example, has a refractive index of 1.33, while that of common glass is just a shade over 1.5. Figure 6.13 illustrates to scale the difference that this makes. The water has the smaller refractive index, so its surface bends the light less.

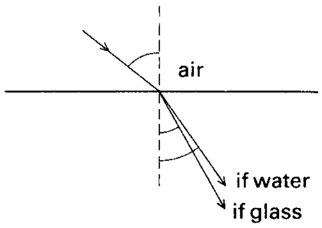


Figure 6.12

The refractive index of a medium is given by Snell's law.

3. 1.48

4. refractive index = $\frac{5\text{ cm}}{3\text{ cm}}$ = 1.67

5. Refraction occurs when a wave crosses a boundary between one medium and another.

6. Take a piece of plain paper. Set up the apparatus shown in Figure 6.13 so that a narrow beam of light is incident on one face of a rectangular glass block and is refracted as it crosses the boundary.

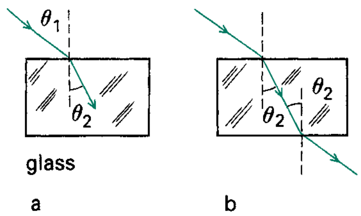


Figure 6.13

Trace round the outline of the block. Use a sharp pencil to trace the incident beam of light and the beam of light as it exits the block. Take the paper from under the block and join the two rays as shown in the right-hand diagram.

Draw on the normals for the incident beam and the exit beam. Now measure the angle of incidence and angle of refraction. Use Snell's law to find the refractive index of the block.

7. Examples of observations that indicate that light can be refracted include the apparent bending of a straw in a glass of water, stars appearing to be higher than they really are in the night sky and the shimmering effect that can be seen above a Bunsen burner flame.

8. Because the two opposite faces of the block are parallel, by geometry the light must meet the second face at the same angle, θ2, (see Figure 6.13). This means that as the light leaves the glass it is refracted by the same amount the other

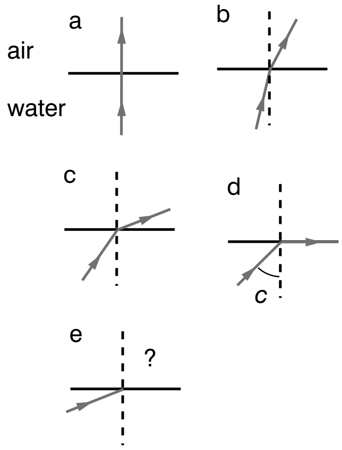


Figure 6.14

way, and so must emerge on a path parallel to its original one as shown in Figure 6.14. The sideways shift of the beam is called the lateral displacement.

The extent of the lateral displacement depends on the angle at which the light is incident on the outer surface of the glass block. At an angle of incidence of 0° (that is, when it hits the block at right angles to its surface) the lateral displacement is of course nil. As the angle of incidence increases, so does the displacement.

9. The critical angle is defined as the particular angle of incidence for which the light emerges along the surface (at an angle of refraction of 90°). The critical angle is the angle marked as c in Figure 6.14.

10. For total internal reflection to occur the angle of incidence must be greater than the critical angle.

11. At the critical angle, the angle of refraction is 90°

Using the relationship $n = \dfrac{\sin \theta_1}{\sin \theta}$ we get:

$n = \dfrac{\sin 90}{\sin c}$ but as sin 90 = 1, sin c = $\dfrac{1}{1.52}$ = 0.65789… so $c = 41°$

12. Once introduced into one end of a glass rod, the light cannot escape so long as it always hits the side walls at an angle of incidence greater than the critical angle for the material of the rod. The light is trapped in what seems like a kind of pipe with silvered walls, as shown in Figure 6.15.

Recent advances in technology have led to a whole range of applications of this effect. Individual plastic fibres can be made which, optically insulated from one another, may be enclosed side by side in a non-transparent sheath. The result is a bundle no wider than the average electrical wiring to lamps, and so flexible that it can be tied in knots without affecting its performance.

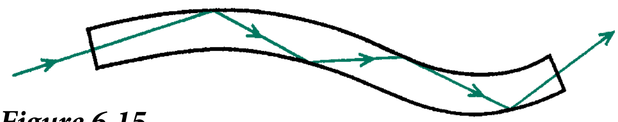


Figure 6.15

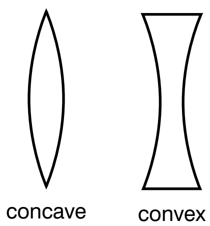


Figure 6.16

13. Figure 6.16 shows the difference between convex and concave lenses.

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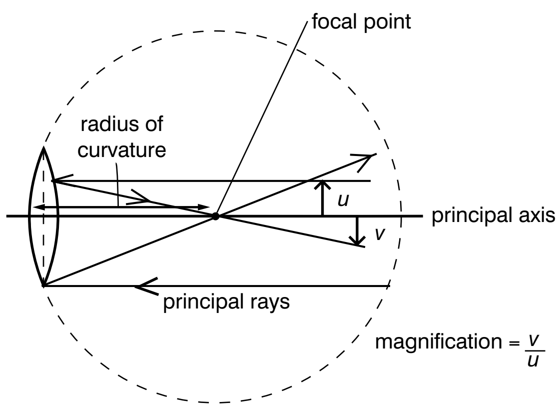


Figure 6.17

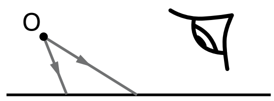
15. 

Figure 6.18

16. The power of a lens = $\frac{1}{\text{its focal length in metres}}$

so the larger numbers go with the stronger lenses. The unit of power in the optical sense will be m^{-1}, given the name dioptres. Thus a lens with a focal length of 20 cm would have a power of $\frac{1}{0.2\text{ m}}$ = 5 dioptres.

17. To view an image and make best use of the available light you need an arrangement such as that shown in Figure 6.19. It is no good putting your eye at the point 'I' itself: that would be like trying to read this print by resting your eyeball on the page! You must stand back so you can focus on it clearly.

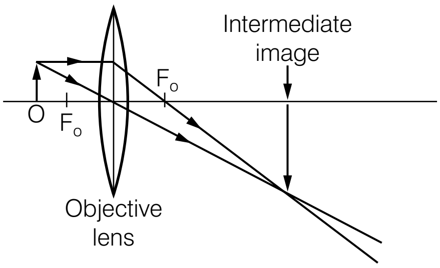


Figure 6.19

The first stage in forming an image with a combination of thin lenses can therefore be drawn like this (though the angles are much exaggerated for clarity):

The image, labelled 'intermediate image' in the drawing, is typically 10–15 cm back from the objective.

In principle you could cast this image on to a screen put there, but in practice it would be far too faint. It would be better to try to view it by placing your eye back to the right of the drawing; it does not matter how far back, so long as the image is outside your near point so you can focus on it.

In a combination of thin lenses you achieve a second stage of magnification by looking at the image not directly but through a second lens.

The intermediate image must therefore lie inside the focus f_e of the second lens. Unfortunately the two rays whose progress we have followed so far are not 'special' ones for the second lens – they will be refracted through it and help to form the virtual final image which we see, but their path is not predictable. Therefore we have had to add some construction lines to see where the image would be produced, and then draw the rays emerging from the second lens spreading out from there.

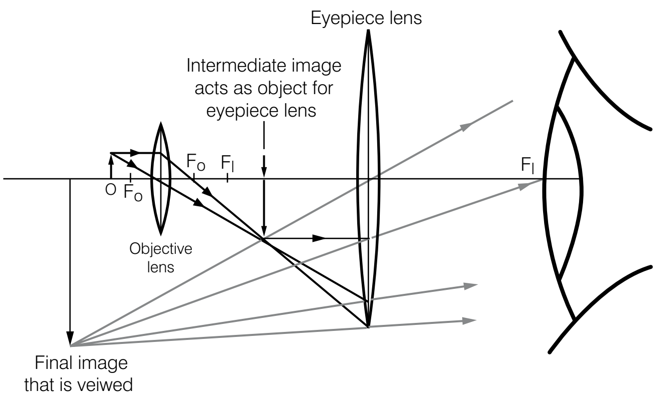


Figure 6.20

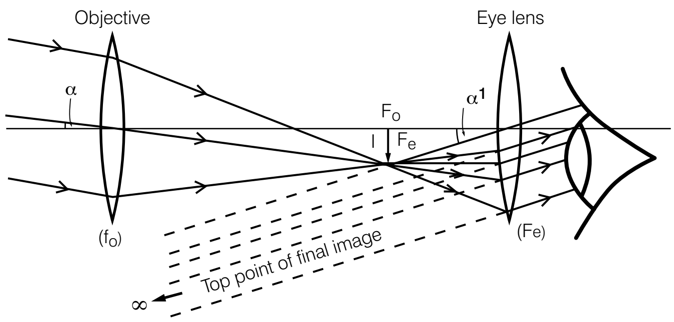


Figure 6.21

18.

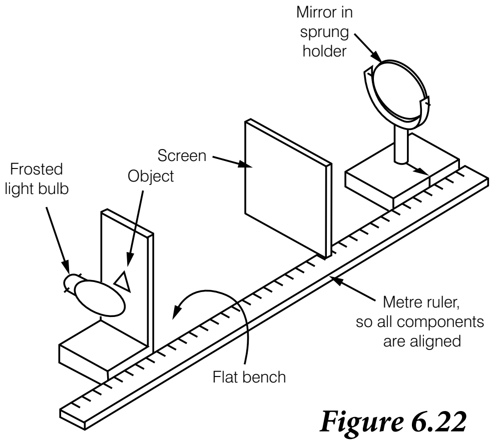


Figure 6.22

19.

	Focusing mechanism	Image capture	Image orientation
Human eye	muscles around eye	retina	upright image
Camera	adjusting lens	film	inverted image

20. You can look at close-up objects or distant ones. Unless you require spectacles, the image in both cases is clearly focused on the retina.

Most of the refraction of the light, to make it converge to a focus on the eye's retina, takes place as the light first enters the eyeball at the boundary between air and the cornea. This is where the greatest change in the speed of light occurs, and it is that speed change that causes the refraction.

The fine control of the focusing is done by the lens, but only a little of the total refraction takes place there; as the light goes between the liquid in the eye and the lens, there is only a small change in speed and therefore only a small difference in refractive index.

The eye's ability to focus on objects at varying distances is given the name accommodation. It is the ring of muscles around the lens that enables the eye to accommodate. With a distant point object the light is almost parallel, and the eye's lens focuses it back to a point on the retina. When you view a near object, the light spreading out from it and reaching your eye will be diverging strongly and yet the same lens has to focus it on the same retina. A stronger lens is needed to accomplish this second feat, and the muscles achieve this by causing the lens to bulge up into a fatter, more rounded shape.

Figure 6.23 illustrates this process in a well-adjusted eye which does not need spectacles. For simplicity, all the bending of the light is shown occurring at the lens.

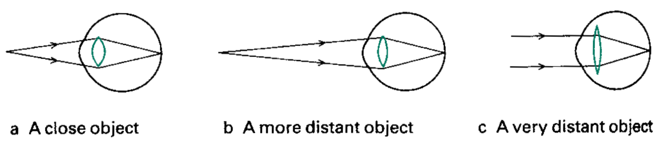


Figure 6.23

In a) the eye is focusing on a close object. The lens has to be made into a very rounded shape, to refract the light enough for it to meet on the retina. In b) the object is more distant. The light is not diverging so much, so less bending is needed to make the rays meet on the retina, and the lens is not so 'bulged up'. Finally, in c) the object is very distant. The apparently parallel rays are actually diverging from a point a long way off. Less refraction is needed and the lens is its natural shape and the muscles are relaxed.

21. **1** Short sight (*myopia*). This happens if the lens is too strong for the eye or, looked at another way, the eyeball is too long for the lens. With an object at the far point (that is, the greatest distance which can be focused clearly) the lens is fully relaxed – and for this eye the far point is not all that far away!

For objects at greater distances the lens can go no weaker, so light from them is made to meet in front of the retina and so the image is blurred.

The one compensation is that the near point will be exceptionally close.

To correct this fault, a diverging lens must be placed in front of the eye so parallel light is made to enter the eye as if it was spreading out from the eye's far point (see Figure 6.24).

2 Long sight (*hypermetropia*). This time the lens is too weak. The parallel light from distant objects would not be focused by the relaxed lens until past the retina, but they can still be seen clearly by causing the lens to bulge – thus using up some of the available accommodation already. This means that as an object approaches, the lens soon bulges to its maximum extent. Thus the near point will be an inconveniently large distance away.

This fault may be corrected with spectacles containing converging lenses, to strengthen the eyeball's optical system (see Figure 6.24).

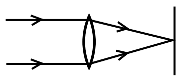
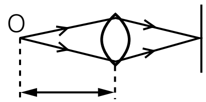
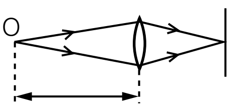
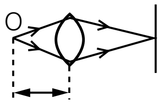
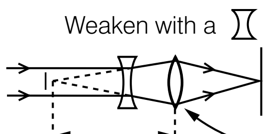
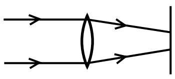
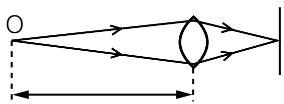
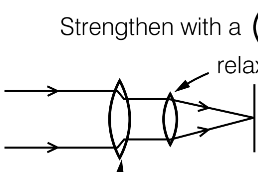
	When lens is fully relaxed	When lens is fully bulged to its strongest	The cure
Normal eye	 (still just strong enough to focus a distant point object on to the retina)	 Near point Distant ~ 250 mm	—
Short sight [The lens in the eye is too strong]	 Distance to far point (Lens won't go any weaker, so more distant objects are not focused)	 V. Close near point	Weaken with a  Far point distant. Distant object appears to be at eye's far point, so can just be focused
Long sight [The lens in the eye is too weak]	 ... too weak when fully relaxed even to focus on very distant objects. (... but you can see them clearly, nevertheless, by already bulging the lens a bit)	 V. Distant near point	Strengthen with a  This lens has already done part of necessary focusing

Figure 6.24

3 Old sight (*presbyopia*). As people age, the lens in their eye may become less supple. In that case the power of accommodation may become affected at both ends of the range – their near point is too far away, so a book has to be held at arm's length, and their far point is too close so they cannot see distant things clearly.

In that case a pair of reading spectacles with diverging lenses and a pair of general viewing spectacles with converging lenses may be needed, or else a single pair of bifocals.

4 Astigmatism. This problem arises if a person's cornea has a different curvature in the horizontal plane from that in the vertical plane. This results in two slightly different powers. Vertical lines in the field of view may be sharply focused, for instance, while horizontal lines are a bit blurred.

The remedy is a pair of spectacles fitted with cylindrical lenses, whose surfaces are each part of a cylinder rather than a sphere (see Figure 6.25). These increase the power of the eye in one plane, to bring it up to the power in the other plane.

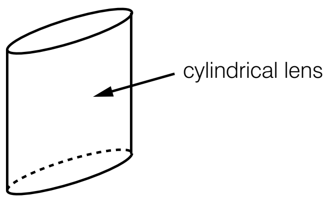


Figure 6.25

22. White light has a range of wavelengths, from blue to red. Since wavelength and speed are related by the equation $v = f\lambda$, then a range of wavelengths will produce a range of speeds since all the light has the same frequency. The amount of refraction is related to speed and so the different wavelengths in white light are refracted by different amounts to produce a spectrum. The rays are deviated by the prism.

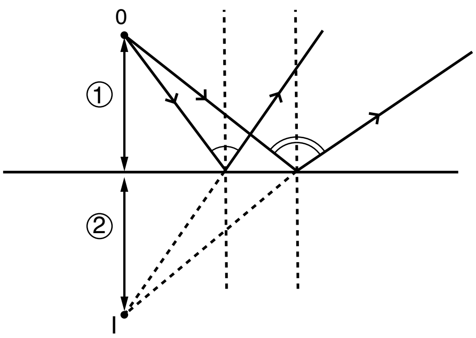
23. Refraction results in lateral displacement of the ray. The incident ray will undergo lateral displacement and so be deviated.

Answers to end of unit questions

1. In a vacuum, all electromagnetic waves travel at a speed of 3×10^8 m s^{-1}.

2. X–rays are used to take pictures of inside the body to show any bone fractures. They are absorbed more by bone (which is denser than the surrounding muscles). Infrared radiation is used in infrared cameras, which are used in rescue operations to detect the presence of bodies. Microwaves and radio waves are used for communications: for example, radio and telephone signals.

3. Set-up the apparatus as shown in the diagram. Break every other tooth of the comb. Draw the rays that appear to be coming from the mirror and the paper. Measure angles as shown.

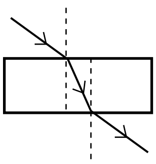


4. Magnification $= \frac{v}{u} = \frac{25}{5} = 5$

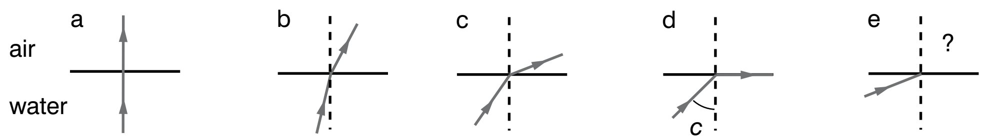
5. Examples of the uses of curved (concave and convex) mirrors are shaving mirrors and driving mirrors.

6. Whenever light crosses a boundary between the transparent media, the sines of the angles on each side of the boundary bear a constant ratio to each other

   $\frac{\sin \theta_1}{\sin \theta_2} = n$ where n is refractise index of the medium.

7. 

8. Suppose you find yourself under water with a torch that gives a narrow beam. Figure 6.14 illustrates the effect of shining the light on to the underside of the water surface at a progressively larger and larger angle (as measured to the normal). Only the path of the main beam is shown: there will always be some reflection back as well. At a particular angle of incidence (marked *c* in diagram **d** the light emerges along the surface. If you shine the light at a greater angle of incidence than this **e** then the beam will be totally internally reflected.



9. $\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$

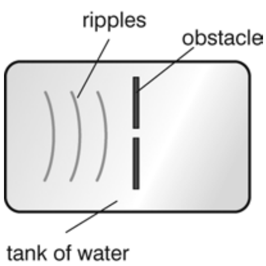
   $\frac{1}{0.04} + \frac{1}{0.06} = \frac{1}{f}$

   $\frac{1}{f} = 41.67$

   f = 0.024 m

10. Television signals need to be boosted by using satellites above the Earth to travel long distances. Satellites did not exist until the 1960s.

11. a) The diffraction of waves is a change of direction of waves as they move around obstacles.

    b) 

12. The wavelength of sound waves is a similar order to that of, for example, the width of a door. Diffraction of sound is therefore observable. However, light waves have a wavelength of the order of 6×10^{-7} m. Evereyday objects are much larger than this.

13. a) Critical angle = c

$$\sin c = \frac{1}{n}$$

$$\sin c = \frac{1}{1.33} = 0.752$$

$$c = 48.8°$$

b) $$\sin c = \frac{1}{n}$$

$$\sin c = \frac{1}{2.42} = 0.413$$

$$c = 24.4°$$

14. a) $$n = \frac{c}{v}$$

$n_A > n_B$

Since c is constant, if

$$\frac{c}{v_A} > \frac{c}{v_B}$$

$v_A < v_B$

Light travels more slowly in A

b) Since $n > 1$ then $c > v$

Therefore the speed of light in both materials must be less than that in air.

Minimum learning competencies

Grade 10

Area of Competency	Grade 10
Motion in two dimension	• Describe motion in two dimension • Define the term projectile and give common examples of projectile • Identify any projectile is moving under the influence of gravity • Describe the difference among the terms vertical, horizontal and inclined projection • Identify that projectile motion consists of two independent motions • Solve problems related to projectile motion • Identify the path followed by a projectile projected at an angle is parabolic • Define uniform circular motion, tangential velocity, centripetal acceleration, centripetal force and centrifugal force • Define rotational motion, angular displacement, angular velocity and angular acceleration • Describe the relationship between angular quantities and linear quantities • Solve problems related to uniform circular motion and rotational motion • Describe rotational with constant angular acceleration • Solve problems using equations of motion with constant angular acceleration • Define moment of inertia, torque, angular momentum and centre of gravity • State conservation of angular momentum and condition of equilibrium • Describe rotational kinetic energy in terms of moment of inertia and torque in terms of angular acceleration and moment of inertia • State laws of universal gravitation and Kepler's Laws of planetary motion. • Describe the variation of acceleration due to gravity with altitude • Solve problems related to moment of inertia of a system of particles with respect to a given axis. • Solve problems related to rotational kinetic energy, torque, angular momentum, conservation of angular momentum, conditions of equilibrium and center of gravity • Distinguish between orbital velocity and escape velocity • Describe about geostationary satellite and explain their uses • Apply the law of universal gravitation to solve common problems • Demonstrate scientific enquiry skills such as observing, predicting, comparing, communicating, problem solving, asking questions, applying concepts, analyzing

Electrostatics	• State the law of conservation of charge and law of electrostatics • Describe the charging processes and charge distribution on a conductor of different shapes • Identify that lightening is an electrostatic phenomenon and explain the role of a lightening rod • Describe about the electrostatic danger in aircraft and some applications of electrostatics • State Coulomb's law • Define the terms: electric field, electric field strength, electric field lines, test charge • Determine the magnitude and direction of force between two point charges • Identify electric field inside a conductor is zero • Define the terms: electric potential and distinguish between absolute potential and potential difference • Determine the electric potential at a given point due to a point charge and system of charges • Describe about equipotential lines and surfaces • Calculate the electric potential energy between two charges • Define the terms: capacitor, capacitance, parallel plate capacitor, dielectric • Calculate the effective capacitance of capacitors in series, parallel and in series parallel combinations • Determine the capacitance of a parallel plate capacitor with and without a dielectric and the energy stored • List some applications of capacitors • Demonstrate scientific enquiry skills such as observing, inferring, communicating, comparing, solving problem, applying concepts, relating cause and effect, asking questions, experimenting
Current electricity	• Define the terms electric current, receptivity, conductivity and resistance • Describe flow of electric charge in a metallic conductor as conventional and electron current • State Ohm's law and calculate resistance, current and voltage using Ohm's law • Solve problems related to electric current, receptivity, conductivity • Draw a simple electrical circuit with resistors in parallel and series in different position of switches • Calculate equivalent resistance, current through each resistance, current through the entire circuit and voltage drop across each resistor in any connection • Mention the merit of galvanometer, an ammeter and voltmeter and describe the connection of ammeter and voltmeter in an electric circuit • Define the terminal voltage, electromotive force (e.m.f.), internal resistance of a cell and show their relationship • Identify series and parallel connection of cells and compute the total e.m.f. of cells

	• Express electrical energy using in terms of current, voltage and resistance • Calculate electrical energy consumed, power dissipated and cost of electrical energy • Describe with the aid of diagrams for sketch, installation of household circuit • Demonstrate the scientific enquiry such as: observing, inferring, classifying, comparing, making models, measuring, asking questions, experimenting, interpreting illustration, applying concept, solving problems
Electromagnetism	• Define the magnetic field and identify that the magnetic field lines around straight current-carrying wires are concentric circles • Determine the direction of magnetic field lines around straight current loop, solenoid • Calculate the magnetic field strength at a point due to straight current-carrying wire current loop and inside a solenoid • Identify that a moving charge in a magnetic field current carrying conductor experiences a magnetic force • Describe how moving charged particles are deflected by uniform magnetic field • Solve problems on motion of charged particles in a magnetic field and current-carrying conductor in a magnetic field • Determine the magnitude and direction of a force between two parallel current carrying wires separated by a distance d • Show with the aid of diagram the direction of the forces acting on each sides of a rectangular current-carrying wire placed in a magnetic field • Determine the magnitude and direction of the torque acting on a current loop in a magnetic field • Describe how a moving coil galvanometer operates • Describe the working principle of a DC motor. • Define the terms: magnetic flux • State Faraday's Law of induction and Lenz's Law • Determine the magnitude and direction of induced e.m.f. or current using Faraday's law of induction and Lenz's law respectively • Define the terms: electromagnetic induction, inductance, self and mutual inductance • Explain the working principle of an AC and DC generator • Explain the principle of operation of transformer • Solve problems involving inductance and transformer • Demonstrate scientific enquiry skills such as: observing, inferring, comparing, making models, applying concepts, measuring, interpreting illustrations, solving problems, relating cause and effects

Introduction to Electronics	• Define the term electronics • State what is meant by harmonic emission • Describe the function of CRT and its use • Describe semiconductors in terms of charge carrier and resistance • Describe how semiconductors can be used in half wave rectification • Describe the behaviour of semiconductor devices such as thermistor, LDR, LED, photodiode, Zender diode, transistor • Demonstrate scientific enquiry skills such as classifying, comparing, relating cause and effect, interpreting illustrations, asking questions
Electromagnetic waves and geometrical optics	• Describe the circumstances in which electromagnetic waves are produced and the nature of electromagnetic waves • Identify all electromagnetic waves travel at the same speed in a vacuum • Identify that EM waves emitted by the Sun has a very wide continuous range of frequencies and therefore continuous range of wavelength • List the components of EM spectrum and describe their uses • State the laws of reflection and describe the image formation by a plane and curved mirrors with the aid of a diagram • List the nature of the image formed by a plane mirror convex mirror and identify that the nature of the image by concave mirror depend on the position of the object • Use the mirror equation to determine the nature and position of the image formed • Describe the conditions in which refraction takes place and draw a diagram representing the passage of light rays through a rectangular block • State the laws of refraction • Express Snell's law in terms of the ration of refractive indices, wavelengths and speeds • Apply the law of refraction to determine the refractive index of the medium through which light passes • Explain why a pool looks shallower than it is • Explain how total internal reflection occurs and describe its uses. • Define the terms angle of deviations and refracting angle of a prism and trace the ray through a prism • Describe the nature of image formed by thin lenses using a ray diagram • Use thin lens formula to determine the nature and position of the image formed • Apply the definition of magnification and power of a lens to determine magnification and power of a lens • Draw a ray diagram showing how images are formed by a combination of lenses in a simple microscope and simple telescope • Describe with the aid of a diagram how an image is formed in the retina of human eye and identify the types of lenses used for correction of eye defects. • Describe how dispersion of light occurs in a prism with the aid of a diagram • Explain how colours can be mixed and objects obtain their colours • Demonstrate scientific enquiry skills such as: observing, inferring, classifying, comparing, interpreting illustrations, applying concepts, problem solving, asking questions, measuring, making models, experimenting, relating cause and effect

General Objectives of Grade 10 physics

- Understand the motion of objects in horizontal, vertical, and inclined planes, and with reference to the forces acting on the objects; the laws of conservation of energy and of momentum for objects moving in one and two dimensions
- Develop basic manipulative skills in investigate motion in a plane, and solve problems involving the forces acting on an object in linear, projectile, and circular motion, with the aid of vectors, graphs, and free-body diagram.
- Understand the concepts of, electrical, gravitational, and magnetic fields; electromagnetic radiation; electromagnetic induction, and the interface between energy and matter, the common applications of electrical and electronic circuits, and the function and configuration of the components used in circuits
- Develop skills in using measuring instruments and familiar electrical devices; constructing simple electrical circuits using common tools appropriately and safely
- Appreciate the applications of electrical and electronic technologies to the community.

Unit 1: Motion in two dimensions (22 periods)

Unit Outcomes: Students will be able to:

- Describe the motion of objects in horizontal, vertical, and inclined planes, and predict and explain the motion with reference to the forces acting on the objects;
- Investigate motion in a plane, through experiments and solve problems involving the forces acting on an object in linear, projectile, and circular motion, with the aid of vectors, graphs, and free-body diagrams;
- Analyse ways in which an understanding of the dynamics of motion relates to the development and use of technological devices, including terrestrial and space vehicles, and the enhancement of recreational activities and sports equipment.

Competencies	Contents	Suggested activities
Students will be able to: • Define the term projectile • Give examples of projectiles • Distinguish between one dimensional and two dimensional motions • Identify that a projectile motion is a two dimensional motion • Define the term angle of projection (angle of elevation and depression) • Describe the effect of gravity in the motion of a projectile • Identify that the horizontal motion part is motion with a constant velocity and the vertical motion part is a uniformly accelerated motion • Write an expression for the time required to reach the maximum height of a projectile projected at an angle θ to the horizontal • Use an expression to calculate the maximum height attained by a projectile in an inclined projection • Write an expression for the total time of flight of a projectile projected at a given angle	**1. motion in two dimension** **1.1 Projectile motion** (5 periods) • Horizontal projection • Vertical projection • Inclined projection • Centre of Mass • Definition of centre of mass • Centre of mass theorem • Application problems for CM • Boat on a river with occupant walking • Satellite separating from an explosion or a rocket • uniform circular motion **1.2 Rotational kinematics** (5 periods) • Rotational variables • Angular and tangential displacement • Angular and tangential velocity • Angular and tangential acceleration • Uniform circular motion • Rotational motion with constant angular acceleration • Equations of motion with constant angular acceleration	Demonstration: The "aluminium foil cannon ball". It uses a rubber band to shoot an aluminium cannon ball out of a paper tube. Inclined plane – hitting a target. It shows independence of vertical and horizontal motions. Equipment: the same long "v" track from Newton's First Law demonstration. It should be at least a metre and a half long. Put a ball in motion down the track. Have a stop at the end. Use a short segment of track at a high angle; say 45 degrees, to impart momentum. Measure the speed of the ball on the track. Measure the height of the end of the track off the floor. Calculate the time it takes to fall. Predict where the ball will land if the stop is removed. Put a cup there to catch the ball. Repeat the demonstration perhaps with the track running over student desks. Invite students to measure and place the cup. Change the velocity of the ball. Re-measure with a different launch angle. Invite a group of students to measure the velocity and make a prediction about where to put the cup. PEER INSTRUCTION on motion in 2 dimensions Group lab – ACTIVE ASSESSMENT: Each row will have paper tube cannon. They will calibrate the cannon's initial velocity by measuring the force constant of the rubber band. Using the definition of work, and Favg they calculate the work done on the ball by the elastic. This predicts the initial velocity and also the vertical height the ball should reach. The launcher is placed in either the front desk or back desk. The instructor gives groups of 6-9 students a small basket 10-20 cm in diameter. The lab challenges student groups to calculate the angle of the launcher so that a launch will hit the basket placed in the middle of their desks. Each group gets three tries. Each group must submit a report showing their calculations and measurements that achieved the result. Individuals must write up the process and explain how to calculate range of a projectile. Activity: Independence of gravity and other forces Position a ruler or other stick on the edge of a table. place a penny on one end of the ruler and place another penny on the edge of a table near the ruler. Quickly pivot the ruler about its other end and one penny will drop straight down while the other will be hit by the ruler and move in a horizontal and vertical direction simultaneously. Listen for the clicks as each penny hits the floor. Do they hit the floor at the same or at different times? Repeat the activity using different sizes of coins and different heights. Does the motion in the vertical direction influence the motion in the horizontal direction? Discuss.

Competencies	Contents	Suggested activities
Students will be able to: • Derive an expression for the range R of a projectile projected at a given angle • Deduce the path (trajectory) of a projectile is parabolic • Show that the range occurs at an angle of 45 degrees • Solve problems involving projectile motion • Define the term centre of mass • Determine the centre of mass of regular and irregular bodies • Explain the force needed to keep an object moving in a horizontal circle (centripetal force) • Identify that a radial acceleration of a body in a uniform circular motion arises from a change in the direction of a velocity • Calculate the magnitude of the centripetal force that is needed to keep an object moving in a horizontal circle • Describe the rotational motion of a body • Describe angular displacement and tangential displacement	**1.3. Rotational dynamics** (7 periods) **1.3.1. Moment of inertia and rotational kinetic energy** **1.3.2. Torque** • Torque and angular acceleration • Angular momentum • Law of conservation of angular momentum • Conditions of equilibrium in rotational motion • Centre of gravity **1.4 Newton's law of universal gravitation** (5 periods) • Variation of g with altitude • Kepler's law of planetary motion • Motion of artificial satellites(orbital and escape velocities) • Geostationary satellites	Demonstration: A 2 m plank with four low friction wheels such as from roller bearings models a boat in water. The middle of the plank is marked on the plank and on the floor. A student, starting in the middle, walks four steps. The plank moves backwards. Marks are made of final positions. The instructor guides a calculation of the motion of the centre of mass. Demonstration: two students on platforms with wheels exchange a very heavy ball (sand filled basket ball). They analyse the event in Newtonian fashion. Now one platform has 2 or 3 students. Repeat the demonstration. Record backward motion of each sled. Demonstration of centre of mass (CM) using a tennis racket. Some lights form a band around part of the tennis racket. Use one band at a time. The instructor throws it toward the back of the class. Lights on the ends make loops in the air. Lights placed at one spot make a perfect parabola. The instructor investigates what properties this point has. He suspends the racket by a string at that point. It balances. This demonstration gives support to the CM theorem. The instructor tries again with a stick weighted heavily at one end. The CM is closer to the heavy end. Activity: centre of mass of an irregular object How can we find the centre of mass of an irregularly shaped object? Use a nail or pencil to punch three holes in the perimeter of a cardboard. Slightly enlarge these holes so the cardboard can rotate freely. Place a nail or pencil in one hole and hang a weighted piece of string from it. Swing the cardboard and when it comes to rest, draw a line on the cardboard showing the position of the string.The cardboard swing back and forth as a pendulum until the centre of mass comes to rest directly below the point of support. This position represents the state of least energy for the body, and all bodies move toward a position of minimal energy. Repeat the other two holes. Attempt to balance the cardboard at the intersection of the three lines. Demonstration: The instructor swings a pail of water horizontally at sufficient speed not to spill the water. Draw out students' ideas about circular motion. What keeps the water from spilling? Use diagrams to pull apart ideas about forces on the water. Why does the instructor lean back a bit? (bring in centre of mass arguments) Bring in Newton's laws. Why the water in the pail accelerated but its speed is not changing? Repeat the experiment with a vertical motion of the pail. Begin with a pendulum like motion then move to full rotation.

Competencies	Contents	Suggested activities
Students will be able to: • Express the measure of an angle in terms of revolutions, degrees, and radian • Define angular velocity and tangential velocity • Identify that the SI unit of angular velocity is rad/sec • Define angular and tangential acceleration. • Identify that the SI unit of angular acceleration is rad/s^2 • Show the relationship between angular displacement and tangential displacement • Show the relationship between angular velocity and tangential velocity. • Show the relationship between angular acceleration and tangential acceleration • Use the relation |a|=(a2 t +a2r)1/2 to calculate the magnitude of the total acceleration of a body in circular motion • Solve problems related to angular displacement, angular velocity, and angular acceleration • Describe rotational motion with constant angular acceleration • State the equations of motion with constant angular acceleration		Do force diagrams at the top, bottom and side points. Demo: Cut a piece of glass tubing about 15 cm in length. Heat one end in a Bunsen burner flame until the walls of the tube are smoothly rounded. Hang one end of a one-metre section of fishing line to two-holed rubber stopper and thread the other end through the tube. Tie approximately 50 grams of metal washer from the line. These washers provide the centripetal force that is exerted through the line to keep the stopper rotating in a circle. Using a stopwatch or other timing device, swing the stopper at a constant rate. Be certain to adjust the line so the distance from the top of the tube to the stopper is equal to the chosen radius, and attach a paperclip to the line above the weights to use as an indicator to check the circular motion is steady. If the clip remains stationary, the radius and speed of rotation is constant. The velocity can be computed by dividing the circumference of the circle by the period of rotation. It is easier to determine the period of rotation by measuring the time required for ten rotations and dividing by ten. Calculate the centripetal acceleration acting on the stopper. Repeat using a larger radius. Demonstration: The tool is a bicycle wheel that is filled with sand, or better, some sand mixed with metal shot. The axels have handles to hold the wheel as it rotates. The instructor gets the wheel going as fast as possible. He invites students to come up and hold the handles and attempt to twist the wheel in a vertical direction. They describe a resistance. He stops the wheel and invites others to twist in a vertical direction. Why is there no resistance when the wheel is stopped? The instructor wraps more masses onto the wheel (bicycle tire segments filled with sand, sealed at the ends.) These are taped symmetrically on the wheel. He makes the wheel spin again and invites students to try to twist it. Is it harder or easier than before? Alternately, the understanding with a demonstration of angular momentum using a weighted bicycle wheel. Have the wheel accelerated by spinning it. Connect angular momentum with linear momentum by accelerating the mounted wheel by having a weight drop and exert a torque. Demonstration: angular momentum, torque and stability Hold a coin horizontally, using thumb and first finger of one hand. Slowly move your fingers apart until the object falls. Unless you are agile enough to release both fingers from the coin at precisely the same instant the coin will flip as it falls because the last finger touching the coin acts as pivot and gravity acting at the coin's centre of mass provides an external torque to rotate the coin about this axis. As the coin falls it rotates around its centre of mass The demonstration motivates a qualitative understanding of the moment of inertia, a quantity a lot like mass but now only applicable with rotation.

Competencies	Contents	Suggested activities
Students will be able to: • Show the analogous relation between equations of uniformly accelerated rectilinear motion and rotational motion • Use equations of motion with constant angular acceleration to solve simple related problems • Define the moment of inertia of a point mass • Define rotational kinetic energy of a body • Solve simple problems related to moment of inertia and rotational kinetic energy • Define the term torque • Identify the SI unit of torque is Nm,which is not the same as Joule • Express torque in terms of moment of inertia and angular acceleration • Derive an expression for the work done by the torque • Use the formula $W=\tau\theta$ to solve problems related to work done by torque • Define the angular momentum of a particle of mass m • Write the SI unit of angular momentum • State the law of conservation of angular momentum		Demonstration: To demonstrate distribution of mass and rotational inertia. Tape cans of soup or other similar objects an equal and short distance from the centre of a metre stick, leaving room for your hand to grasp the stick at its centre. Apply torque to the stick by twisting it back and forth and note the effort required. Move the objects to the ends of the metre stick and tape them. Is it easier or more difficult to rotate the stick? Activity: to demonstrate rotational inertia Place two different sized rolls of adding machine tape or other rolled paper on the dowel. Attach heavy clips to the rolls and hold so they cannot unwind .release the rolls at the same time and note which unrolls most rapidly. Which roll has the greatest rotational inertia? Define angular momentum using the right hand rule. Show its representation as an arrow from the centre of the axis. "reality of the unseen". Angular momentum is real but it is not, itself, visible. Trying to change the direction of rotation meant applying forces to the angular momentum vector. Ask students how angular momentum helps riding a bicycle. Restate Newton's 1st law for rotation. Restate Newton's 2nd law for rotation. Define torque. Inquire why there is a distance in the definition? Define kinetic rotational energy. Show the correspondence of terms. KElinear =½ mv2=1/2 I 2 = KErot Demonstration: Use a mounted, weighted bicycle wheel and a small, light wooden pulley to supply torque to show conversion of Potential Energy into rotational Kinetic Energy. A weight suspended on a string attached to a pulley disk forces the weighted wheel to accelerate. Activity: Obtain three cans of similar size, one filled with a liquid, one filled with a solid or semi-solid, and an empty can with the ends cut out. Which can will reach the bottom first when released on a ramp at the same time? Last? Test your predictions. PEER INSTRUCTION: What happens if the mass of the wheel is increased? Why? What happens if the mass is doubled? Increase the mass of the wheel by adding sand filled segments taped on.

Competencies	Contents	Suggested activities
Students will be able to: • Solve problems using the law of conservation of angular momentum • State the first and second conditions of equilibrium • Solve problems related to conditions of equilibrium • Define the term centre of mass (centre of gravity) of a solid body • Determine the centre of gravity of a body using a plumb–line method • Define the terms: stable, unstable and neutral equilibrium • State the Newton's law of universal gravitation • Determine the magnitude of the force of attraction between two masses separated by a distance r • Calculate the value of g at any distance above the surface of the Earth • State Kepler's law of planetary motion • Use kepler's law of planetary motion to determine the period of any planet • Differentiate between orbital and escape velocity of a satellite • Determine the period of a satellite around a planet • Calculate the orbital and escape velocity of a satellite • Describe the period, position and function of a geostationary satellite		Demonstration: Converting rotational kinetic energy into electrical energy: Get the weighted wheels going to a good speed. Use a small DC electric motor with a 5-10 cm disk attached to the shaft. Have a small mirror segment attached to the disk and a light shining on the mirror to make rotations visible. Demonstrate attaching a battery to the motor. Remove the battery; attach a bulb to the output of the motor. Bring the weighted wheel to maximum speed. Touch the motor's wheel to the tyre. The light bulb will light for a while, as the wheel slows down. When it runs in reverse way, a motor is also a generators. PEER Instruction: What kinds of energy transformations are involved? If the light bulb were not screwed in, what would the interaction with the motor and tyre? Do the experiment. Collect literature about satellites from newspapers, libraries and catalogues. Ask students to write an essay about the history of satellites, dates for the launching of the satellites into space and time spent in space. The Mousetrap car. Using power from one mousetrap students design a mousetrap car to go the furthest distance. They can choose any number of wheels and any size of the wheels. The world record is 180 m.

Assessment

The teacher should assess each student's work continuously over the whole unit and compare it with the following description, based on the competencies, to determine whether the student has achieved the minimum required level.

Students at minimum requirement level

A student working at the minimum requirement level will be able to: analyse and predict, in quantitative terms, and explain the motion of objects in horizontal, vertical, and inclined projections; analyse and predict, in quantitative terms, and explain the motion of a projectile with respect to the horizontal and vertical components of its motion; analyse and predict, in quantitative terms, and explain uniform circular motion in the horizontal and vertical planes with reference to the forces involved; describe Newton's law of universal gravitation, apply it quantitatively, and use it to explain planetary and satellite motion.

Students above minimum requirement level

Students working above the minimum requirement level should be praised and their achievements recognised. They should be encouraged to continue working hard and not become complacent.

Students below minimum requirement level

Students working below the minimum requirement level will require extra help if they are to catch up with rest of the class. They should be given extra attention in class and additional lesson time during breaks or at the end of the day.

Unit 2: Electrostatics (19 periods)

Unit outcomes: Students will be able to:

- Demonstrate the principles of static electricity;
- Gain knowledge and understandings in static electric charge, electric field and force, electric potential capacitors and energy stored in capacitors
- Develop skills in performing electrostatic experiments, and solving problems related to charges at rest
- Appreciate the workings of some equipments which operate on the basis of electrostatic charges
- Describe and apply models of static electricity.

Competencies	Contents	Suggested activities
Students will be able to: • State the law of conservation of charge • Describe and explain the charging processes: charging by rubbing, conduction, and induction • Perform an experiment to charge an electroscope by conduction, induction • Describe the distribution of charge on a conductor of variable shape • Explain how lightning is formed • Describe the use of lightning rod • Describe the working principle of some equipments which operate on the principles of electrostatic charge • Describe the electrostatic hazards and useful application of electrostatics • State coulomb's law • Compare coulomb's law and Newton's law of universal gravitation • Compute the force acting on a charge due to two other charges placed on the same plane (line of action) • Calculate the force between three charges placed collinearly • Define an electric field • Represent diagrammatically the electric field lines around and between two point charges • Calculate the electric field strength at a point due to charges placed collinearly and at right angles	**2.Electrostatics** **2.1 Electric charge** (6 periods) • electric charge and law of conservation of charge • charging processes (rubbing, conduction, and induction) • charge distribution on a conductor • lightning and lightning rod • applications of electrostatics (paint, spray, electrostatic photocopier) • electrostatics danger	Demonstration: Electrostatic Attraction of water Adjust the tap so it releases the smallest continuous stream of water possible. Bring the charged comb near the stream and note that it shifts the flow by means of electrostatic attraction. ACTIVITY: Hanging balloons with electrostatic force Inflate a balloon and then briskly rub one side of it on your hair. Place this surface of the balloon toward a wall or door and release it when it appears to be sticking. What can you conclude about the nature of the surfaces to which the balloon sticks? Demonstration: Induction Tear a sheet of newspaper into small bits approximately 1.5 cm in diameter. Place the paper bits under a glass plate supported by two books. Rub the glass vigorously with silk and notice how the paper jumps up to the glass. What attracts the paper to the glass? Why does not it stay attached to the glass? Discuss with the group. Demonstration: A typical 25 cm–diameter Van de Graaf generator is capable of generating a 200,000-volt potential difference that can cause gasses in a fluorescent tube to glow. Darken the room, turn on the generator, and slowly move a fluorescent tube toward the generator and observe that it starts to glow. Why does the portion between the tube and your hand and the generator glow?

Competencies	Contents	Suggested activities
Students will be able to: • Distinguish between electric field between inside and outside a spherical metallic conductor • Define electric potential and it's SI unit • Distinguish between absolute potential and potential difference • Show that 1N/C=1V/m • Explain about equipotential lines and surfaces • Draw equipotential lines and surfaces in an electric field • Define the term electric potential energy • Define what is meant by a dielectric material • Describe the structure of a simple capacitor • Define the term capacitance and it's SI unit • Use the circuit symbol to represent a capacitor • Apply the definition of capacitance to solve numerical problems • Explain the charging and discharging of capacitor • Identify combination of capacitors in series, parallel, and series-parallel • Define the term dielectric • Explain the effect of inserting dielectric in the gap between the plates of a parallel plate capacitor • Derive an expression for the effective capacitance of capacitors connected in series and parallel	**2.2 Electric forces and fields** (5 periods) • Coulomb's law • Force between charges • Electric field strength • Electric field lines • Electric field due to a point charge • Electric field inside and outside a spherical metallic conductor **2.3. Electric potential** (4 periods) • Absolute potential and potential difference • Equipotential lines and surfaces • Electric potential energy • Conversion of mechanical to electrical and electrical to mechanical	

Competencies	Contents	Suggested activities
Students will be able to: • Compare the effective capacitance of combination of capacitors in series and parallel • Solve problems on combination of capacitors • Define parallel plate capacitor • Describe the factors that affect the capacitance of a parallel plate capacitor • Calculate the capacitance of a parallel plate capacitor • Compare the capacitance of a parallel plate capacitor with and without a dielectric • Appreciate an expression for the electric potential energy stored in a capacitor • Calculate the energy stored in a capacitor using one of the three possible formulae • Draw electric circuit diagram for a simple capacitor, series and parallel connections of two or more capacitors using symbols • State some uses of capacitors in everyday life	**2.4. Capacitors and capacitances** (4 periods) • Definition of a capacitor • Charging and discharging processes • Combination of capacitors in series • Combination of capacitors in parallel • Combination of capacitors in series-parallel • Parallel-plate capacitor • Capacitance of a parallel plate capacitor with and without dielectric. • Energy stored in a capacitor • Applications of capacitors	Demonstration: Obtain large capacitors 350+mf from dead TV power supplies. They look like small beer cans. Charge the capacitor for a few minutes. Let it power a small light. Observe the behaviour of the light's decay. Invite student hypotheses about what happened. What was stored? What drained? If sufficient numbers of capacitors are available let student teams experiment with charging and discharging the capacitor. Invite them to make drawings of light intensity vs. time graph as the capacitor decays. Is the graph linear or not? Experiment with capacitors in series and parallel. Which takes longer to decay? Why? All done qualitatively. There should be much experimentation with capacitors (big ones from dead TVs) They store enough energy to power a bulb for a short time. Capacitors build up the idea of electron flow and the idea of transient currents. This treatment is much too theoretical. Get the big capacitors (like a beer can) or a film canister and let students experiment with them. Less boardwork. Much more hands on. Put in a resistor. What happens to the discharge of the large capacitor? Put some in series, in parallel. What happens with the discharge?

Assessment

The teacher should assess each students work continuously over the whole unit and compare it with the following description, based on the competencies, to determine whether the student has achieved the minimum required level.

Students at minimum requirement level

A student working at the minimum requirement level will be able to: demonstrate an understanding of the concepts, principles, and laws related to electric forces and fields, and explain them in qualitative and quantitative terms; state Coulomb's law and compare it with Newton's law of universal gravitation; apply Coulomb's law quantitatively in specific contexts; compare the properties of electric and gravitational fields by describing and illustrating the source and direction of the field in each case; describe and explain, in qualitative terms, the electric field that exists inside and on the surface of a charged conductor.

Students above minimum requirement level

Students working above the minimum requirement level should be praised and their achievements recognised. They should be encouraged to continue working hard and not become complacent.

Students below minimum requirement level

Students working below the minimum requirement level will require extra help if they are to catch up with rest of the class. They should be given extra attention in class and additional lesson time during breaks or at the end of the day.

Unit 3: Current electricity (14 periods)

Unit outcomes: Students will be able to:

- Acquire knowledge and understanding in electric current, Ohm's law, combinations of resistors, measuring instruments, emf of a cell, electrical energy and power.
- Conduct investigations and analyse and solve problems related to electric charges, electric circuit.
- Evaluate and describe the social and economic impact of technological developments related to the concept of electricity.
- Design and build electrical circuits that perform a specific function.
- Analyse the practical uses of electricity and its impact on everyday life.
- Design and conduct investigations into electrical circuits found in everyday life and into the quantitative relationships among current, potential difference, and resistance.
- Evaluate the social, economic, and environmental costs and benefits arising from the methods of electrical energy production used in Ethiopia.

Competencies	Contents	Suggested activities
Students will be able to: • Define electric current and it's SI unit • Explain the flow of electric charges in a metallic conductor • Compute the number of electrons that pass a point at a given length of time when the current in the wire is known	**3. Current electricity** **3.1 Electric current** (2 periods) • Flow of electric charges in a metallic conductor • Electric energy from chemicals • Electric energy from heat	Make it clear that most substances obey Ohm's law but it is not a true universal law of physics. Many important substances, like semiconductors and transistors are not Ohmic. Demonstration: Use a compass needle to determine a magnetic north. Wrap approximately 30 turns of thin–gauge insulated copper wire around this compass in a north/south direction, and connect it to a 1.5v light bulb that is connected to a 1.5V battery. Note that when the circuit is closed, a current will flow, the lamp will glow, and the needle will move. This simple galvanoscope can be used whenever you want to detect the presence of small currents. Activity 1: Thermal and electrical conductivity both depend upon the transport of energy by electrons. To test this hypothesis, examine the electrical conductivity of copper, steel, and plastic by observing the deflection of galvanoscope needle when equal-sized pieces of copper, steel, or plastic are substituted for the light bulb. Rank the substances tested from high to low electrical conductivity. All electrochemical cells require two electrodes made of two different conductors, an electrolyte solution (a solution that conducts electricity) that reacts with the electrodes, and a conductive wire through which electrons may flow. Activity 2: Roll a lemon, orange, grapefruit, or other citrus on a firm surface to break the internal membranes. Cut strips (approximately 4 cm x 3 cm) of copper and zinc sheet metal and insert these in the fruit so they are approximately 1 cm apart. Attach the test wires of a volt-ohm-milliammter to the strips and measure the electric potential and current. Will the voltage of your wet cell change if you change the size of the electrodes? Try it. Will the voltage change if you construct the cell using different electrodes? Demonstration: the transformation of heat energy directly into electric energy. Thermocouple (see beck effect) refers to the generation of electricity in a circuit composed of two wires whose junctions are at different temperatures. Create thermocouple junctions at both ends of a section of iron wire by twisting the ends together with copper wires. Place one copper/iron junction in a beaker with ice water while leaving the other junction outside. The two remaining ends of the copper wires should be connected to a sensitive galvanometer. Heat the exposed junction with a Bunsen burner or match and record the current. Does the current increase or decrease if the heat source is removed?

Competencies	Contents	Suggested activities
		Is the change in current immediate? Discuss these questions. Activity 3: Cells in series and parallel. Let the students do these activities in groups. The citric acid in lemons or oranges provides an excellent electrolyte solution for a simple wet cell. After rolling the fruit firmly on a table to rupture its internal membranes, insert two electrodes made of two different metals, making certain the electrodes do not touch. Nails may serve as iron electrodes, stripped electrical wires may serve as copper electrodes, silver jewelleries may serve as silver electrodes. Add a second and then a third similar ″fruit cell″ in series with the first cell and record the voltages. Continue adding cells until the light is brightly lit. Add a second and then a third similar "fruit cells" in parallel with the first one and record the voltages. What is the advantage of adding cells in series, in parallel? Discuss.
Students will be able to: • Describe factors affecting the resistance of a conductor • Write the relationship between resistance R, resistivity ρ,length l and cross-sectional area A of a conductor • Compute the resistance of a conductor using the formula $R=\rho l/A$ • Find the relationship between resistivity and conductivity • Construct and draw electric circuit consisting of source, connecting wires, resistors, switch, bulb, using their symbols • Explain why an ammeter should be connected in series with a resistor in a circuit • Explain why a voltmeter should be connected in parallel across a resistor in a circuit • DO EXPERIMENTS (at least have students touch the equipment) using an ammeter and a voltmeter to investigate the relationship between current and p.d for metallic conductors at constant temperature	**3.2 Ohm's law and electrical resistance** (3 periods) • Resistivity and conductivity electric circuit	Demonstration: Ohm's law A resistor is an electrical component that opposes the flow of current in a circuit. Since pencil "lead' is made of carbon, an element frequently used in resistors, we can use it here. Connect a flash light bulb (1 to 2 V) in series with a pencil lead and a 6V battery. Turn off the room lights and observe the brightness of the bulb. Move one wire contact along the length of the pencil lead and observe the changes in the intensity of light. Repeat the activities with a pencil lead of different diameter. What influence does the diameter of the resistor have upon the net resistance? What effect does the length of the resistive path have upon the total resistance? Discuss these questions. Use a board with 6-8 clips to make circuits. Include capacitors in some circuits. Use big ones. Try to pick non-polar caps to avoid punch through. When students connect them backwards and make a hole in the dielectric film. The work need not have every student group with a meter. Let them build a circuit and have the instructor come over with the meter to measure current and volt.

Competencies	Contents	Suggested activities
Students will be able to: • Identify combinations of resistors in series, parallel, and series- parallel connection • Derive an expression for the effective resistance of resistors connected in series • Derive an expression for the effective resistance of resistors connected in parallel • Compute the effective resistance of resistors connected in series • Compute the effective resistance of resistors connected in parallel • Calculate the current through each resistors in a simple series, parallel, and series-parallel combinations • Calculate the voltage drop across each resistor in a simple series, parallel, and series-parallel connection	**3.3 Combinations of resistors** (3 periods) • series combination • parallel combination • series-parallel combination	
• Define electromotive force of a cell • Distinguish between e.m.f. and terminal p.d of a cell • Write the relationship between emf, p.d, current, and internal resistance in a circuit • Use the equation $V=\varepsilon-Ir$ to solve problems in a circuit • Identify cells combinations in series and parallel • Compare the emf of combinations of cells in series and parallel	**3.4 E.m.f. and internal resistance of a cell** (3 periods) • combination of cells in series and parallel	Activity 4: series and parallel circuits. Let the students do these activities in groups. Connect one bulb in series with a battery and note its brightness. Now connect a second and third bulb in series with the bulb. Is there any change in the brightness of the first bulb when the second and third bulbs are added? Once all bulbs are lit, remove one of the bulbs. What happens to the brightness of the others? Confirm their understandings. Connect one bulb to a battery and note its brightness. Now connect a second and third bulb in parallel with this bulb. Is there any change in brightness of the first bulb when the second or third ones are added? Once all bulbs are lit, remove one. Is there any change in the brightness of the remaining bulbs? Confirm their understandings. Demonstration: Measuring electromotive force and terminal voltage of a source. Set up a circuit consisting of a dry cell, a bulb, a switch and a voltmeter. Take the reading in the voltmeter while the switch is on. Then take another reading while the switch is off. Compare the two readings. Which one is larger? Which reading is the e.m.f? Discuss with the group

Competencies	Contents	Suggested activities
Students will be able to: • Define electrical energy and power in an electrical circuit • Find the relationship between KWh and joule • Use P= VI=V2/R=I2R to solve problems in electric circuits	**3.5 Electric energy and power** (2 periods) • cost of electric energy	Activity 5: Which appliances in your home consume the greatest amount of energy? Is it the refrigerator? The TV set? The electric stove? You can find out by inspecting appliances in your home and determining the number of watts each consumes and multiplying this by the number of hours operated. By law, each electric device must specify power requirements, and these are generally recorded on a small tag located on the appliance or on the power cable connected to it. Inspect all the appliances in your home and record power requirements in the table.
• Use W=VIt=I2Rt=V2t/R to compute electric energy dissipated in an electric circuit • Perform calculations on cost of electrical energy expressed in KWh	**3.6 Electric installation and safety rules** (1 period) • Engineering project	New designs for cars employ hybrid motors. Cars use both electricity and petrol for power. When going down hill, instead of standard brakes which converts kinetic energy into heat, these cars capture energy by using "electric brakes "that recharge the battery or convert the energy into rotational energy in a massive fly wheel. Students design on paper a hybrid car that captures as much energy as possible. Teams may wish to build a model of their design, showing innovative ways to save energy.

Assessment

The teacher should assess each student's work continuously over the whole unit and compare it with the following description, based on the competencies, to determine whether the student has achieved the minimum required level.

Students at minimum requirement level

A student working at the minimum requirement level will be able to: define and describe the concepts and units related to electrical systems(e.g., e.m.., electric potential, resistance, power, energy); compare direct current and alternating current in qualitative terms, and describe situations in which each is used; analyze, in quantitative terms, circuit problems involving potential difference, current, and resistance; use appropriate meters (analog or digital), to measure electric potential difference, current, and resistance in electrical circuits; construct simple electrical circuits using common tools appropriately and safely; draw, by hand schematic diagrams to represent real circuits; analyse, in quantitative terms real circuits using Ohm's law; describe common applications of simple circuits, and identify the energy transformations that occur (e.g., energy transformations in one of the following appliances or devices: refrigerator, kettle, food mixer, amplifier, television set, light bulb, oscillator, electromagnet, electric motor, garage door opener); identify and describe proper safety procedures to be used when working with electrical circuits, and identify electrical hazards that may occur in the science classroom or at home.

Students above minimum requirement level

Students working above the minimum requirement level should be praised and their achievements recognised. They should be encouraged to continue working hard and not become complacent.

Students below minimum requirement level

Students working below the minimum requirement level will require extra help if they are to catch up with rest of the class. They should be given extra attention in class and additional lesson time during breaks or at the end of the day.

Unit 4: Electromagnetism (20 periods)

Unit outcomes: Students will be able to:

- Demonstrate an understanding of the properties, physical quantities, principles, and laws related to electricity, magnetic fields, and electromagnetic induction;
- Carry out experiments or simulations, to demonstrate characteristic properties of magnetic fields and electromagnetic induction;
- Identify and describe examples of domestic and industrial technologies that were developed on the basis of the scientific understanding of magnetic fields. (e.g. generator, motor, and transformer)
- Appreciate the link between electricity and magnetism, the contributions electricity and magnetism to modern life.

Competencies	Contents	Suggested activities
Students will be able to: • Investigate the domain theory of magnetism	**4. Electromagnetism** **4.1 Magnetism** (4 periods) • Magnetic Domains • Magnetisation • Magnetic shielding • Geomagnetism	Activity 1: To investigate magnetic domains, magnetisation, demagnetisation Fill a test tube two thirds full with iron filings or shredded steel wool and approach the north and then the south end of a compass needle with the end of the tube. Is one end of the needle more attracted than the other? Record the maximum angle to which the needle is deflected. Repeat these observations after stroking the tube 50 times with a permanent magnet and after shaking the test tube vigorously for one minute. In which situation was the test tube more highly magnetised? Why? Let the students' discuss in groups. Demonstration: Magnetisation by heating and cooling within a strong magnetic field Use insulated tongs or pliers to heat a nail in the hottest part of the flame until it glows. Remove the nail from the flame and place it lengthwise on a permanent bar magnet. After the nail has cooled, measure its magnetic strength by determining the number of small paper clips that can be suspended in a chain from one end. Compare the magnetic strength of this nail with the strength of one that was not heated, but rested on the permanent bar magnet for an equal length of time. Record your findings in the table. Demonstration: Magnetic shielding Support a bar magnet using a stand on a table, and attach a thread to a paper clip and suspend it below the magnet. Given no disturbances, the paper clip will remain floating in space indefinitely due to magnetic lines of force between the magnet and the paper clip. Slide a small sheet of paper in to the gap between the paper clip and the magnet, being careful not to touch either.

Competencies	Contents	Suggested activities
		Does paper interfere with the magnetic field? Repeat the process using a sheet of plastic, aluminium foil, and the lid of a "tin" can. Which, if any of the above, interfered with the magnetic field and allowed the paper to fall? Activity 2: Let students do these activities in groups Cut the bottoms from two paper cups of different sizes, two plastic cups of different sizes, two iron ("tin") cans of different sizes. Place a compass on a table and record the direction of magnetic north. Now place two bar magnets 7 cm to the east and west of the compass so that the N-pole of one magnet faces the S-pole of the other and record the angle of deflection. Remove the magnets, place a tin can over the compass, replace the magnets, and again record the angle of needle deflection. Remove the magnets, place a second can around the first, replace the magnets, and again record the angle of compass-needle deflection. Does the iron interfere with the magnetic field? Repeat the process using paper or plastic cups. Which of the substances best protects or shields the compass from the magnetic field of the bar magnets? Confirm their understanding.
Students will be able to: • Describe magnetic field • Perform and describe an experiment that demonstrate the existence of magnetic field around a current-carrying wire • Sketch the resulting magnetic field lines pattern of a current-carrying wire • Apply the right–hand rule to tell the direction of magnetic field lines around a straight current-carrying wire • Calculate the magnetic field strength at a point due to a straight current carrying wire • Sketch the magnetic field lines pattern of a current loop • Sketch the magnetic field lines pattern of a solenoid • Specify the polarity of a solenoid using a right–hand rule • Compute the magnetic field strength at the centre of a solenoid • Describe the factors on which the force on a moving charge in magnetic field depend	**4.2 Concepts of magnetic field** (3 periods) • Magnetic field around a straight current-carrying wire • Magnetic field of a solenoid	Demonstration: Magnetic fields in two dimensions Place a strong bar magnet under a clear sheet of glass. Position the transparent sheet so it is level and then repeatedly tap a beaker filled with iron filings so they fall evenly over the surface. The iron filings should align themselves with the magnetic lines of flux. The points where lines appear to converge represent locations of greatest magnetic flux density. Magnetic flux density is a measure of magnetic force and is defined as the number of flux lines per unit area. Place a number of small compasses around a magnet and draw a diagram showing the orientation of the needles. Demonstration: Magnetic fields in three dimensions Place iron filings in the bottom of a glass jar and fill 90% of the remainder of the jar with salad oil. If you don't have iron filings, you may create iron shreds by rubbing two pieces steel wool together rapidly. Shake the container vigorously until the iron filings are evenly distributed throughout the container and then expose the jar to the magnetic fields of bar magnets outside the jar. Allow time for the iron filings to align with the magnetic field. Let the students draw a diagram of the field lines when the S-pole of one magnet is opposite the N-pole of another.

Competencies	Contents	Suggested activities
Students will be able to: • Demonstrate the relation B=mv/qR from the fact that the centripetal force is provided by magnetic force • Compute the magnitude of a force acting on a moving charge in a uniform magnetic field • Determine the direction of a force acting on a moving charge using right hand rule • Demonstrate the existence of a force on a straight current-carrying conductor placed in a magnetic field • Derive the expression F=BIlsinθ from F=qvB sinθ • Apply right hand rule to tell what will happen when current flows perpendicular to a uniform magnetic field • Describe the factors on which the force of a moving charge in the magnetic field depend • Calculate the magnitude of a force on a straight current-carrying wire placed perpendicular to a uniform magnetic field • Compute the magnitude and direction of force between two parallel current carrying conductors in a uniform magnetic field • Define the SI unit Ampere • Draw a diagram to show the forces acting on a rectangular current carrying wire in a uniform magnetic field • Draw diagrams to show the action of a force on a simple DC motor and a moving coil galvanometer	**4.3 Magnetic force** (6 periods) • Magnetic force on a moving charge • Magnetic force on a current-carrying conductor • Magnetic force between two parallel current-carrying conductors • Definition of ampere • Force on a rectangular current-carrying wire	

Competencies	Contents	Suggested activities
Students will be able to: • Define the magnetic flux and its SI unit • State Faraday's law of induction • Perform simple experiments that demonstrate an induced e.m.f. caused by changing magnetic flux • State Lenz's law • Indicate the direction of induced currents, given the direction of motion of a conductor and the direction of a magnetic field • Describe the factors that affect the magnitude of induced e.m.f. in a conductor • Describe the link between electricity and magnetism • Apply Faraday's law to calculate the magnitude of induced e.m.f. • Define inductance and it's SI unit • Distinguish between self and mutual inductance • Apply the definition of inductance to solve simple numerical problems • Explain the action of the simple a.c. generator • Build a simple AC motor • Explain the action of the simple AC generator • Compare the actions of d.c. and a.c. generators • Draw a diagram of a transformer • Give a simple explanation of the principles to operate a transformer • Identify that for an ideal transformer Pout=Pin • Show that for an ideal transformer; Vs/Vp=Ns/Np=Ip/Is • Apply the transformer formulas to solve simple problems	**4.4 Electromagnetic induction** (7 periods) • Magnetic flux • Faraday's law of induction • Lenz's law • Inductance (self and mutual inductances) • D.c. motor • A.c. and d.c. generator • Transformer (step up and step down)	Demonstration: Use the weighted bicycle wheel's rims as the object of the eddy current production. Bring the magnet close to the rim. It must be non-ferrous. The magnet will slow the wheel's spinning noticeably. If one has some background in magnetism and rotational dynamics, one can calculate the deceleration from the induced current. Have a metal disk rotating quickly. Make the disk out of a non-magnetic metal like aluminum (use thicker metal like used for roofing). Bring a strong magnet near the disk. The magnet will induce a current in the metal by Faraday's law. The magnetic field will oppose that of the magnet. It will act as a break on the wheel; the spinning wheel slows down rapidly. The disk cannot become magnetic - aluminum is not structurally a magnet. Demonstration: drop a strong small magnet through a non-ferrous tube (without any seams). A thicker copper pipe is fine and better. Make the tubes about one metre long. Have two tubes. Drop a rock through one and the magnet through the other. The magnet will induce an electric current to oppose the motion of the magnet. It will float down the tube quite slowly. If you put a lot of windings around the tube at one point, say 1,000 turns or more. It will light up a small bulb for a flash. Demonstration: Suspend a non-ferrous ring from two points. Let it swing freely and stop it. Put the magnet on a stick and push it through the ring, then it will pump the ring like a child pumps height on a swing. PEER INSTRUCTION on Faraday's law Let the students discuss in a group about the law. Demonstration: The instructor runs a current through two thin wires or pieces of very thin foil (from gum wrappers). The wires or foil bend from the magnetic fields The instructor also uses the Fresnel overhead to project images of iron filings sprinkled on top of a glass with a magnet beneath Classroom Demonstration: Stored energy in a magnetic field. Use a Fly back (step- up) transformer from an old TV. See http://en.wikipedia.org/wiki/Flyback_transformer

Competencies	Contents	Suggested activities
		These transformers step up voltage drastically. Connect a small bulb in series with a 12 V source and a flyback transformer. It will light for an instant then stop. PEER INSTRUCTION: Why does the bulb light and then stop? Check for any heart problems. Invite students to make a human wire complete loop in series with the flyback connected to a 1.5 V battery (not the 12 V). Release the connection. A small current will pass through. It will last milliseconds. What is the source? PEER INSTRUCTION Inductance. Lenz and Faraday. Decaying fields. The primary coil of a transformer is connected to a battery, a resistor, and a switch. The secondary coil is connected to an ammeter. When the switch is thrown closed, the ammeter shows Card 1-zero current Card 2-a non zero current for a short instant Card 3-a steady current Let students discuss this question and confirm their understanding Decaying are transient currents. Some uses for transient currents are: Spark plugs in a car. Heart starting paddles in the hospital. Electric fences for animals. Activity: Make a high number of windings from a broken transformer's wires. Let the magnet fall through the coils. It will cause a transient electric current that can light up a small bulb Project work: Build an AC motor. The cost of materials is very low, next to zero. Build either the toothpick motor or the cork motor: See: http://www.ceressoft.org/Files/emotors.htm This describes how to build an AC motor Student groups build a motor at their desks. They measure the rotation rate. The fastest rotators convert the electrical energy to kinetic energy most efficiently. These get higher grades. Engineering Challenge: Build an AC motor with any design you choose that has the fastest rotation. The motor must have a small piece of reflecting material that bounces back a flashlight beam. That beam hits a simple photo transistor circuit connected to a buzzer. Students count the buzzes in 2 minutes.

Assessment

The teacher should assess each student's work continuously over the whole unit and compare it with the following description, based on the competencies, to determine whether the student has achieved the minimum required level.

Students at minimum requirement level

A student working at the minimum requirement level will be able to: describe the terms magnetic domains, magnetisation, magnetic shielding; identify the properties of magnetic field interpret and illustrate the magnetic field produced by a current flowing in a long straight conductor and in a coil; identify the factors that affect the magnitude and direction of the electric current induced by a changing magnetic field; describe the properties, including the three-dimensional nature, of magnetic fields; describe and illustrate the magnetic field produced by an electric current in a long straight conductor and in a solenoid; analyse and predict, by applying the right-hand rule, the direction of the magnetic field produced when electric current flows through a long straight conductor and through a solenoid; state the motor principle, explain the factors that affect the force on a current-carrying conductor in a magnetic field, and, using the right-hand rule, illustrate the resulting motion of the conductor; analyse and describe electromagnetic induction in qualitative terms, and apply Lenz's law to explain, predict, and illustrate the direction of the electric current induced by a changing magnetic field, using the right-hand rule; compare direct current (DC) and alternating current (AC) in qualitative terms, and explain the importance of alternating current in the transmission of electrical energy; explain, in terms of the interaction of electricity and magnetism, and analyse in quantitative terms, the operation of transformers (e.g., describe the basic parts and the operation of step-up and step-down transformers; solve problems involving energy, power, potential difference, current, and the number of turns in the primary and secondary coils of a transformer).

Students above minimum requirement level

Students working above the minimum requirement level should be praised and their achievements recognised. They should be encouraged to continue working hard and not become complacent.

Students below minimum requirement level

Students working below the minimum requirement level will require extra help if they are to catch up with rest of the class. They should be given extra attention in class and additional lesson time during breaks or at the end of the day.

Unit 5: Introduction to electronics (11 periods)

Unit outcomes: Students will be able to:

- Gain elementary knowledge and understandings in vacuum tubes devices, thermionic emission, CRO, semiconductor diodes, and transistors
- Understand common applications of electrical and electronic circuits, and the function and configuration of the components used
- Investigate the development and application of electrical technologies and their impact on local and global economies and the environment.

Competencies	Contents	Suggested activities
Students will be able to: • Define the term electronics • Mention the importance of electronics in their daily life Concept map: all items in daily life that use electronics • State what is meant by thermionic emission • Describe the behaviour of vacuum tubes • Describe the function of a cathode ray tube • Describe the uses of a cathode ray tube • Represent both d.cand a.c on current-time or voltage-time graphs • Use the current-time or voltage-time graphs to find the period and frequency of alternating currents or voltages • Distinguish between conductors, semiconductors, and insulators • Give examples of semi-conductor elements • Distinguish between intrinsic and extrinsic semiconductors • Describe a semi-conductor in terms of charge carriers and resistance • Explain doping to produce the two types of semi-conductors • Identify semi-conductors as P-type and N-type	**5. Introduction to electronics** **5.1 Vacuum tube devices** (3 periods) • Thermionic emission • Cathode ray oscilloscope (CRO) • Using CRO • Some uses of oscilloscope • TV picture tube **5.2 Conductors, semi conductors and insulators** (1 periods) **5.3 Semiconductors (impurities, doping)** (4 periods) • Semiconductor diode (I-V characteristic) • P-n junction diode as a rectifier (qualitative treatment) • LED • LDR • Thermistor • Photodiode	Use a model of CRO if it is available or use a well labelled diagram of the cathode–ray oscilloscope for your explanation of the structure and function of the CRO Don’t emphasise the CRO. It is a relatively specialised piece of equipment that one doesn’t understand until one uses one. Deeper study of the TV tube is more helpful. Use the Human Wire to explore semiconductors and PN junctions. Students modelling silicon have 4 electron rocks. Those modelling boron have 3 rocks and a basket. It is important to model the 3 dimensional structure of the semiconductor. Use toothpicks and gummy candy to build a tetrahedral lattice (have a marshmallow represent the hole) have an extra gummy piece represent the extra electron from the doped N material, like arsenic. Discuss how a p-n junction can be formed using p-n junction diagrams. Explain the apparent movement of ‘hole’ and ‘electron’ movement and how a potential barrier is set up in the depletion layer. Demonstration: demonstrate the current–voltage characteristics of a semiconductor diode. If the materials are not available, discuss the current-voltage characteristics of a semiconductor diode using a typical characteristics curve for a silicon diode. Using a circuit diagram of half wave rectifier circuit, explain the rectification of a diode when an a.c. supply is used. Explain briefly how a bridge –rectifier gives a full wave rectification and further smoothing can be made by the use of a capacitor. Demonstration: show the amplification action of a transistor Demonstrate the amplification action of a transistor using transistor amplifier circuit. Ask students to calculate the current gain.

Competencies	Contents	Suggested activities
Students will be able to: • Describe the mode of conduction by the majority and minority carriers • Define the term diode and show it's circuit symbol • Draw a current vs voltage characteristics (graph)to show the behaviour of p-n junction • Describe how a semiconductor diode can be used in a half –wave rectification • Sketch voltage time graphs to compute the variation of voltage with time before and after rectification • Distinguish between direct current from batteries and rectified alternating current by consideration of their voltage time graphs • Show the circuit symbols of semi conductor devices such as thermistor, LED, LDR, and transistors • Distinguish between p-n-p and n-p-n transistors • Identify the base, emitter, and collector of a transistor • Use the following terms correctly: forward biased and reverse biased • Describe the behaviour of semi conductor devices such as thermistor, LED, LDR, photodiode, and transistors (all qualitatively) • Use the circuit symbols for the gates • Draw the truth tables for the different logic gates and for a combination of logic gates • Explain the action of logic gates: NOT, OR, AND, NOR, NAND		Explain briefly how a voltage amplification can be achieved using well drawn simple one transistor amplifier circuit.The explanation should all be done qualitatively. The key is "why does the transistor amplify current?". Discuss about photo voltaic cells, making electricity directly from the Sun. Let the students identify a diode, an LED, a transistor, IC, a resistor, and a capacitor from a mixed collection of such items. Project work: Students should know about photovoltaic cells. Current efficiencies are about 7-9%. Higher cost cells produce efficiencies of about 30%. Calculate the number of meters of photovoltaic cells needed to supply all of Ethiopia's energy needs. Ethiopia has potential to generate 30,000MW of power using hydro plants. See http://www.capitalethiopia.com/archive/2007/May/week2/feature.htm Current installations are as large as 160Mwatts, equal to the largest hydro plant in Ethiopia. Ethiopia does have significant hydroelectric potential, unlike many African nations. But it is dependent on rainfall. Solar production is constant, though there must be storage at night.

Assessment

The teacher should assess each student's work continuously over the whole unit and compare it with the following description, based on the competencies, to determine whether the student has achieved the minimum required level.

Students at minimum requirement level

A student working at the minimum requirement level will be able to: describe the function of basic circuit components (e.g., power supplies, resistors, diodes, fuses, circuit breakers, light-emitting diodes [LEDs], capacitors, and switching devices), describe the characteristics of transistors, identify the logic gates and explain their actions.

Students above minimum requirement level

Students working above the minimum requirement level should be praised and their achievements recognised. They should be encouraged to continue working hard and not become complacent.

Students below minimum requirement level

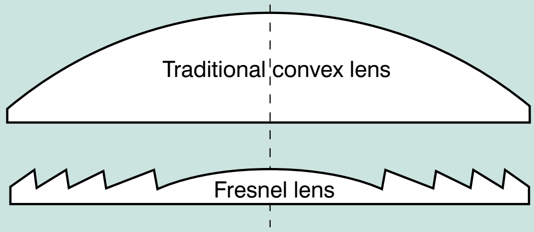
Students working below the minimum requirement level will require extra help if they are to catch up with rest of the class. They should be given extra attention in class and additional lesson time during breaks or at the end of the day.

Unit 6: Electromagnetic waves and geometrical optics (16 periods)

Unit outcomes: Students will be able to:

- Acquire knowledge and understanding of the properties of light and the principles underlying the transmission of light through a medium and from one medium to another;
- Investigate the properties of light through experimentation, and illustrate and predict the behaviour of light through the use of ray diagrams and algebraic equations;
- Evaluate the contributions to such areas as entertainment, communications, and health made by the development of optical devices and other technologies designed to make use of light.

Competencies	Contents	Suggested activities
Students will be able to: • Explain how electromagnetic waves are produced • Describe the nature of electromagnetic waves • Compare mechanical and electromagnetic waves • Draw diagrams to represent transverse waves • Use straight lines to represent the direction of energy flow (rays) • Identify that electromagnetic waves emitted by the sun have a very wide continuous range of frequencies s (and wave lengths) • Explain some uses for electromagnetic radiation • Explain what is meant by the rectilinear propagation of light • State the laws of reflection • Perform experiments to test these laws using a plane mirror • Use the laws of reflection to explain how images are formed in a plane mirror • Find the position of a virtual image produced by a plane mirror using a ray tracing method • Use the laws of reflection to solve problems • Give examples of the uses of plane mirrors • Distinguish between concave and convex mirrors • Identify the meanings of terms in relation to concave and convex mirrors: principal axis, principal focus, radius of curvature, magnification • Distinguish between real and virtual image • Apply the appropriate sign convention when using mirror equations	**6. Electromagnetic waves and geometrical optics** **6.1 Electromagnetic waves** (3 periods) • Transverse nature of electromagnetic waves • Speed of electromagnetic waves • Electromagnetic spectrum (elementary facts about their uses) **6.2. Reflection of light** (6 periods) • Laws of reflection • Image formation by a plane mirror • Image formation by curved mirrors • Mirror equation	Use the "human wave" for transverse forms. In one row, one set of students uses hands to model the electric field. The student sitting beside them models the magnetic field. The students apply Faraday's law that increasing E fields induce a B field. Decreasing E fields induce a B field in the opposite direction. The rows of students hold a rope to model the increasing and decreasing E and B fields. Or alternately, The instructor uses a large ball to model the motion of a charge. Its E field changes with motion. The change in the E field propagates with the speed of light. Use just one wave length at first. Start with just the E field wiggle. Add the B field later when the students understand the mechanics of the emulation process. What is moving? Make it clear that it is the electric field at that point in space, it is not a "thing" that is moving. Add in the B field at 90 degrees. Use cylindrical lenses if possible. VERY IMPORTANT: use multiple rays. Do not rely on the 3 ray model. Students do not understand it. They think that the light is an arrow. The arrow only indicates direction, not the wave itself. Demonstration: Mirror lab. Student groups: flashlight, comb, paper and mirror. Send light into a reflecting mirror using a comb. Send multiple rays in. Match to the paper it is on the "say left edge" of the light passing through the comb and bouncing off the mirror. Construct the rays that appear to be coming from the virtual image. Break every other tooth of the comb if the image is too faint. Do the experiments first before any equations. Concept first, equations later. Demonstration: Lens Lab Send light into a lens using a comb. Send in multiple rays. Notice that one ray comes through unchanged. Select a ray on the periphery. That one goes through the focus. Note traditional text drawings that show only 3 rays, there are countless numbers of them. Do not use pins. This confuses students. What does a pin have to do with light? Use the light wave itself to investigate behaviour. On all experiments use the comb to make multiple rays of light. Repeat the Human Medium experiment with the piece of wood "light wave" entering the student body as the "medium". It bends as it goes slower.

Competencies	Contents	Suggested activities
Students will be able to: • Find the position and nature of the image formed by a concave and a convex mirrors using mirror equation and a ray tracing method • Use the relation magnification=Si/So=hi/o to solve problems • Give examples of the uses of curved mirrors (concave and convex mirrors) • Define the term refraction • State the conditions in which refraction occurs • Perform experiments to test the laws of refraction • Draw a diagram representing the passage of light rays through a rectangular glass block • Give examples of observations that indicate light can be refracted • Identify that the passage of a ray of light through a parallel–sided transparent medium result in the lateral displacement of a ray • Define the refractive index of a material • Use Snell's law to solve simple problems • Use the formula refractive index=real depth/apparent depth to find the refractive index of a liquid and a solid in the form of rectangular glass block • Define the critical angle θc • Explain with the aid of a diagram, what is meant by critical angle and total internal reflection • Identify the conditions necessary for total internal reflection to occur	**6.3 Refraction of light** (7 periods) • Laws of refraction (refractive index, real and apparent depth) • Total internal reflection and it's uses • Refraction through thin lenses • Thin lens formula • Magnification • Power of a lens • Combination of thin lenses • Optical instruments (human eye, microscope, telescope) • Optics of the human eye: far and near sightedness and corrections. • Diffraction of light. • Two slit diffraction • Diffraction by reflection grating • dispersion of light • Looking at spectra using a spectroscope • refraction through a prism • dispersion of light and colour mixing	Use the "Human Optical Bench" and the Fresnel lens to perform investigations of Two slit diffraction: You will need the Fresnel lens to make a simple overhead projector to put the pattern on the ceiling. The key to the optics experiments is a Fresnel Lens. Here is what it looks like in a diagram.  All the glass is sheared away with the lens replaced by concentric prisms. This is huge light gathering power. It works in daylight easily. It will do great solar cooker experiments as well. Activity: Light is not observed to diffract under normal circumstances because its wavelengths are much smaller than openings of obstructions with which we are familiar. To observe the diffraction of light it is therefore necessary to create an opening with a diameter of approximately the same dimension as wavelength of light. Use two pencils or other straight edges. Place a piece of tape or around the shaft of one pencil to provide a spacer between them and then place them side by side. Darken the room, peer through the slit between the pencils, and observe a candle flame at a distance of 2 m.The students should be able to observe an interference pattern. Rotate the pencils and describe the changes in the interference pattern. Increase and decrease the pressure on the shafts to alter the width of the gap and describe the changes in the interference pattern. Activity: Model diffraction with a liquid in the Fresnel plate. "Bound by clay dikes". It will project on the ceiling. Use coloured water to emphasise the pattern. Use a small electric motor with an eccentric cam to make water waves to go through the double slit. Observe the interference. Perform some experiments to model different ways to correct human vision. Add a lens to increase the focal length. Add a lens to decrease the focal length.

Competencies	Contents	Suggested activities
Students will be able to: • Prform calculations involving critical angle and total internal reflection • Describe how total internal reflection is used in optical fibres • Distinguish between convex and concave lenses • Identify the meaning of the following terms in relation to converging and diverging lenses: principal focus, principal; axis, focal point, radius of curvature magnification • Apply the appropriate sign convention when using thin lens equations • Find the position nature of the image formed by a convex and a concave lens using the thin lens formula and a ray tracing method • Define the power of a lens • Explain how image is formed due to combination of thin lenses • Draw a ray diagram showing how images are formed by lenses used in a simple microscope and simple telescope • Compare and contrast the structure and functions the human eye and camera • Describe how human eye forms an image on the retina for different object distances • Identify some defects of the eye and their corrections with lenses • Explain what is meant by the dispersion of white light to produce a spectrum		Fresnel lens. Put a paper over 1/2 of it. Does it make ½ an image? Use the Fresnel lens to quantitatively explore the lens equations. Use the Human Optical bench model. Have a bright source (one red flashlight, one green or white one). Have students draw in the rays on a lab sheet. Demonstration: the visible spectrum, let the students do it in groups. To disperse white light into the spectrum requires one prism, and to recombine the spectrum requires a second prism. If there is no access to prisms students can make glass/water prisms with microscope slides, tape, and modelling clay. After filling the triangular container with water, seal the other end with clay. Spectral displays are best observed under very dark conditions. Place cardboard or other material over the windows of your room. If light is shining upon a window, you may use it as a light source simply by cutting a hole in the cardboard on that window. Position the prisms with respect to the light source. Adjust the positions of both prisms so the light dispersed from the first prism is recombined to produce white light by the second. Trace and identify the positions of the prisms and the positions of the various bands of colours on a piece of white paper. Activity: The CD spectroscope Students build a group spectroscope using a cracked CD. They observe spectra of a flashlight, a regular bulb, an infrared bulb, a flashlight with a coloured filter, sunlight, a fluorescent bulb. Let them take it home and look at other spectra such as a street light, or the moon. Students observe sunsets. They can see some absorption lines with the instrument. Why do the grooves of the CD function to break light apart into colours? It is like a multiple double slit. The CD must be at an angle so that light bounces off the reflective surface but each groove bounces light off a bit later than the neighbour slit. There is interference which makes the light add along some angles and cancel along others. Demonstration: Measuring the solar constant. Use the Fresnel lens to measure the heat input from the Sun. It should be about 1,366 watts per square metre, but the atmosphere filters out many wavelengths. The Fresnel will not pass IR (infrared). They calculate the efficiency of the class demonstration.

Competencies	Contents	Suggested activities
Students will be able to: • Identify that the passage of a ray of light through a triangular transparent prism results in a deviation of a ray		Project work: Students design a collector that will concentrate and capture the heat of the Sun the most effectively. One should be able to get a kilowatt per square metre. The challenge is to find the best design that will heat up 50cc of water to the highest temperature in 10 minutes. Students may employ a Fresnel lens (borrowed from the class for their demo) or some other reflective surface, such as mirrors or reflective aluminium. The limit is that the area of the reflector must be less than 1 square metre.

Assessment

The teacher should assess each student's work continuously over the whole unit and compare it with the following description, based on the competencies, to determine whether the student has achieved the minimum required level.

Students at minimum requirement level

A student working at the minimum requirement level will be able to: define and explain the concepts and units related to communications technology (e.g., frequency, period, cycle, wavelength, amplitude, longitudinal and transverse waves, electromagnetic waves, reflection, refraction, total internal reflection, interference, transmission, absorption); describe the characteristics of waves, and analyse, in quantitative terms, the relationships among velocity, frequency, and wavelength to explain the behaviour of waves in different media; predict, in qualitative and quantitative terms, the refraction of light as it passes from one medium to another, using Snell's law; explain the conditions required for total internal reflection. using light-ray diagrams, and analyse and describe situations in which these conditions occur; describe and explain, with the aid of light-ray diagrams, the characteristics and positions of the images formed by lenses: describe the effects of converging and diverging lenses on light, and explain why each type of lens is used in specific optical devices; analyse, in quantitative terms, the characteristics and positions of images formed by lenses; demonstrate and illustrate, using light-ray diagrams, the refraction, partial refraction and reflection, critical angle, and total internal reflection of light at the interface of a variety of media; predict, using ray diagrams and algebraic equations, the image position and characteristics of a converging lens.

Students above minimum requirement level

Students working above the minimum requirement level should be praised and their achievements recognised. They should be encouraged to continue working hard and not become complacent.

Students below minimum requirement level

Students working below the minimum requirement level will require extra help if they are to catch up with rest of the class. They should be given extra attention in class and additional lesson time during breaks or at the end of the day.