# Physics

## Teacher Guide
## Grade 11

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# Contents

# 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 11 physics course

When students have completed Grade 11 Physics they should have developed:

- An understanding of the basic concepts of physics and the laws of dynamics, and different kinds of forces
- An understanding and working knowledge of the quantification and forms of energy, the way energy is transformed and transmitted, and the concepts and units related to energy, work and power
- An understanding and working knowledge of the laws of conservation of energy and of momentum for objects moving in one dimension
- An understanding of the properties of mechanical waves, sound, and light, and the principles underlying their production and transmission
- The ability to analyse the relationships between physics and technology, and to consider the impact of technological applications of physics on society and the environment
- Manipulative and problem-solving skills.

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.<br>Useful to stimulate thinking.<br>Students develop skills such as identification, observation, recording, making predictions, synthesis, analysis and drawing conclusions.<br>Students develop qualities such as self-confidence, curiosity and inquiry.<br>Useful for large numbers of students.<br>Makes students passive because it is one-way communication.<br>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.<br>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.<br>Can be useful at start of a lesson to motivate students.<br>Allows everyone to participate actively.<br>A few people may end up dominating the discussion.<br>Not easy to conduct for large classes.<br>Can be time-consuming.<br>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.<br>Useful for beginning and ending a lesson.<br>Need to ensure sufficient questions are framed to stimulate thinking – closed questions do not achieve this.<br>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.<br>Students develop desirable qualities such as seeking knowledge, curiosity, enquiry and responsibility.<br>Worked examples in the Students' Book can usefully be presented as problems for students to solve – see notes for each topic for further details.<br>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.<br>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.<br>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<br>*This method is highly recommended and should be used as much as possible.* | Gives teacher an opportunity to develop students' interest in the subject.<br>Teacher has opportunity to interact with students.<br>Teacher provides the standard/expected results for each activity.<br>Can be used with discussion method (during discussion of results).<br>Students develop skills such as identification, observation, collecting, measurement, manipulation, data recording, investigation, making predictions, interpretation, evaluation, synthesis and drawing conclusions.<br>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.<br>Students appreciate the environment.<br>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.<br>Students develop skills in using scientific methods.<br>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.<br>Allows development of analytical and problem-solving skills.<br>Allows exploration of solutions for seemingly complex problems.<br>Students may not see application to their own situation.<br>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 Physics 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 focussed 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, summarise, criticise, conclude, defend*.

## Model lesson plan

Topic: Bulk properties of matter
Sub-topic: Elastic behaviour
Duration: 40 minutes
Class: Grade 11
Date: 20 May 2011

### *Rationale*

This is the second lesson in Unit 8: Bulk properties of matter. In this lesson students will explore tensile deformation.

### *Lesson objectives*

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

- describe an experiment to explore tensile deformation.

Pre-requisite skills and knowledge

- students will need to be able to measure accurately with a vernier scale and draw graphs to show the results of experiments.

### *Teaching/learning resources*

apparatus shown in Student Book Figure 8.2

| **Stage (time)** | **Teaching and learning activities** | **Learning points** |
|---|---|---|
| Introduction (10 minutes) | Students discuss the following question with a partner. 'Why do you think steel has a lower elastic limit than rubber?'. Allow them about 5 minutes for this discussion and then take feed back of ideas. Record suggestions on the board. | Students need to think about the structure of the materials at an atomic and molecular level. This question requires them to apply their knowledge to a different situation. Steel has a lower elastic limit than rubber because it is easier for its layers of atoms to slide over each other than it is for rubber molecules to slide over each other. (See http://www.worsleyschool.net/science/files/rubber/molecule.html) |
| Development (20 minutes) | Divide the class into small groups to carry out Activity 8.2.<br>While students are carrying out the activity, walk around the class to check on progress. Question students to test understanding. | Students will take readings from which they can plot a graph. |
| Summary and conclusion (10 minutes) | Students work with a partner to begin a report on the activity using the writing frame on pages 19–20 of the Student Book. This will need to be completed at home. | Students will learn the importance of clear communication of scientific investigations. |
| Evaluation | Students have opportunity to ask questions and comment on the activity. | |

## 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.

Construct a spider diagram.

# Measurement and practical work

Unit 1

**Learning Competencies for Unit 1**

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

- State the scientific method, what it is and its key sections.
- Choose appropriate units for data that will be collected.
- Define the term uncertainty.
- Appreciate some techniques to determine the uncertainty in measurements.
- State the meanings of the terms random error, systematic error and zero error.
- Identify some techniques to minimise errors.
- Define the terms precision, accuracy and significance.
- Appreciate the importance of the precision of the measuring instrument.
- Investigate some useful techniques for writing scientific reports.

This unit should fill approximately **8 periods** of teaching time.

## 1.1 Science of measurement

This section should fill approximately **1 period** of teaching time.

### Learning Competencies

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

- State the scientific method, what it is and its key sections.
- Choose appropriate units for data that will be collected.
- Define the term uncertainty.
- Appreciate some techniques to determine the uncertainty in measurements.

### Starting off

This section introduces the scientific method. This process is exceptionally important to science: it ensures theories are thoroughly tested in a way that provides answers to some of the most important questions we ever ask. Students should be made aware that science is not only a body of knowledge but a process with clear rules and procedures to follow.

### Teaching notes

Start by asking the students: What is science? What makes science different from other disciplines? Try to elicit the idea of experimental work and the development of theories to explain the world around us.

**Activity 1.1: Answer**

Students' own hypotheses.

**Activity 1.2: Answer**

football pitch: m

book width: cm

seed diameter: mm

finger nail width: cm

page area: $cm^2$

classroom area: $m^2$

football pitch area: $m^2$

book volume: $cm^3$

classroom volume: $m^3$

bottle volume: $m^3$

soccer ball volume: $cm^3$

**Activity 1.3: Answer**

Students' own results.

**Activity 1.4: Answer**

Students' own results.

**Activity 1.5: Answer**

Students' own results.

Explain that all science starts with a question; this may be based on an observation. For example, a car crashes into the back of another car waiting at a red light. One simple but important question might be: Why did this happen? Discuss the fact that to answer this scientifically a procedure must be followed and this procedure is called the scientific method.

Outline the scientific method. Ask the students to work in pairs following the method to answer the question mentioned above (stopping short of conducting an experiment). Discuss the different hypotheses that are formed (maybe the brakes didn't work, the driver fell asleep, the road had oil on it, etc.).

Take time to go over the steps in the method, discussing each one and eliciting examples from the students in each case. Stress the importance of testing the method through experiment and what happens if the results are unexpected or do not fit the prediction. Several real examples could be discussed here, including the UV catastrophe, the discovery of helium, etc.

Students could follow the scientific method to design their own simple experiment to test a hypothesis based on an observation. This could then be discussed in pairs or small groups. It is worth highlighting that the process of peer review is crucial to science. Once a hypothesis has been tested this process must be re-tested by several other scientists who must concur with the findings if the hypothesis is to be accepted.

Ensure you stress the importance of making measurements in science. Go on to explain the importance of scientific data in assessing the validity of any hypothesis. Explain the importance of significant figures when making measurements. Some students find this idea very difficult; try to give plenty of examples of making measurements and their significance (see Section 1.3 on page 12).

Explain the meaning of the term uncertainty and use the examples given to explain how one might arrive at a particular value for an uncertainty. Ask them to express the uncertainty in several different examples of measurements taken from different experiments. Try to include those with a very small uncertainty (thickness of a book using a micrometer or vernier calliper) and those with a very high uncertainty (measuring the bounce height of a ball, or timing the flight of a football through the air). Students could conduct a range of simple experiments and express the uncertainties in their readings. It is important to stress that the statement of the uncertainty is a value judgement: there is not really a right answer to various uncertainties (although as discussed in the Students' Book some values are definitely more appropriate). At this stage the key point is to encourage the students to think about their uncertainties, moving away from the idea of an exact answer.

Discuss techniques for determining the uncertainty in calculated values (via percentage error). Students should experimentally collect data to calculate a property (speed, volume, density, etc.) and express the uncertainty in their final reading. They benefit from practising this through three or four simple experiments and discussing their findings.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **The science of measurement** | |
| **SA** | Activity 1.1 with a partner. Feed back ideas.<br>Activity 1.2 in a small group. Feed back ideas. |
| **MA** | Activity 1.3 in a small group.<br>Activity 1.4 in same small group. |
| **CA** | Activity 1.5 with a partner. Feed back ideas.<br>Review questions 1–5 to be tackled with a partner. |

## Activities

- Discuss the scientific method.
- Design simple experiments using the scientific method.
- Express the uncertainty in a range of readings (either through description or collected experimentally).
- Calculate percentage uncertainties from data.

## Where next?

The scientific method raises several important philosophical questions that are beyond the scope of this course. However, an interesting discussion might be: Are there any questions that science cannot answer?

Additionally students should be encouraged to express the uncertainty in all of their readings in future experiments. This process does not get any more complex, even into university level.

## Answers to review questions

1. The scientific method is exceptionally important to the process of science. It ensures a rigorous, evidence-based structure where only ideas that have been carefully tested are accepted as scientific theory.

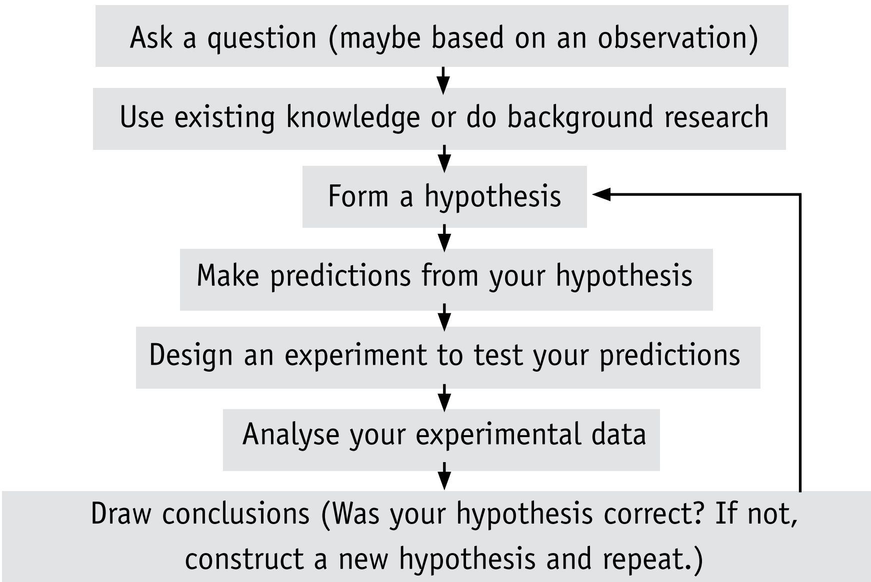



***Figure 1.2** The scientific method*

Your hypothesis will have to be tested by others before it becomes an accepted scientific theory. This process of peer review is very important and prevents scientists making up data.

The process of science begins with a question. For example: Why is the sky blue? Why does the Sun shine? Scientists are curious about the world around them; it is this curiosity that is the spark of the process.

When you have a question, scientists may have already looked into it and devised an explanation. So the first step is to complete some preliminary research into the existing theories. These theories may provide answers to your question. It is quite probable most of the questions you encounter in your physics course already have answers. However, there are still some big unanswered questions in physics. They are waiting for someone like you to answer them! Are there any questions that science cannot answer?

Using your existing knowledge or information collected via research, the next step is to form a **hypothesis**.

A hypothesis is just an idea that might provide an answer to your question. A scientific hypothesis is based on scientific knowledge, not just made up!

For example: *Why does the Sun shine?*

You might form two hypotheses:

- Nuclear fusion reactions in the Sun release heat and light.
- There is a large lamp in the centre of the Sun powered by electricity.

The first is clearly a more scientific hypothesis using some thoroughly tested existing ideas. That is not to say you shouldn't be creative in making a hypothesis but you should include some scientific reasoning behind your ideas.

It is important to note your hypothesis might be incorrect, and this is what makes science special. An investigation must be carried out to test the ideas before you either rule out an idea or accept it.

It is important that your experiment is clearly planned. This will enable others to test your experiment and check your ideas (more detail on this can be found in Section 1.4).

Once you have carefully conducted your experiment, you will need to **analyse** your results and draw **conclusions**. At this stage you need to decide if your results support your prediction. If they do, then perhaps your hypothesis was correct. This will need to be confirmed by several other scientists before it becomes accepted as scientific fact.

If your results do not support your prediction, then perhaps your hypothesis was wrong. There is nothing wrong with that, you just go back and form a different hypothesis. This process continues and it may take years to come up with a correct hypothesis!

2. a) 3 b) 2 c) 12 d) 4
3. Using mutiple measurements (e.g. 20 swings of a pendulum not just 1) reduces percentage uncertainty.
4. The result should not be too more significant figures than the lowest number of significant figures un the readings. In this case, there is a measurement of 0.41 A (two significant figures) so Melesse is correct to give the answer as 13Ω.
5. 3.8Ω t 0.15

## 1.2 Errors in measurement

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

### Learning Competencies

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

- State the meanings of the terms random error, systematic error and zero error.
- Identify some techniques to minimise errors.

### Starting off

This section introduces the concept of experimental errors to students. These often require the student to reassess their understanding of what is a right or wrong answer. Many may believe science provides exact values for certain quantities; this is rarely the case (except through definition, e.g. speed of light).

Different types of error are discussed and some strategies are shown to minimise, but never truly eliminate, their effect. There is some opportunity for simple experimentation as part of this section; however, it may be better to take a more theoretical approach highlighted with simple mini-practicals until more of this unit has been completed.

## Teaching notes

Explain the concept of errors (as opposed to mistakes). Stress that errors are due to the process and not the individual. All experiments contain errors and part of the skill of a scientist is to recognise them appropriately. Discuss with the students the differences between a measured value and a true (accepted) value. Discuss how errors cause measurements to be different from the true value. Give a couple of simple examples, although more will follow when looking at specific errors.

Ask the students to come up with a list of the sources of error in a particular experiment: that is, anything that might cause them to record a reading that is different from the true value. Get them to share some of their ideas leading to a notion that there may be different types of experimental error.

Ask the students to complete the ruler activity in the Students' Book. This leads into a discussion on random errors. Take time to stress that this kind of error causes measurements both above and below the true value. Elicit other examples from the students.

**Activity 1.6: Answer**

Students' own results.

Review parallax errors. Using a metre rule, ask a few volunteers to read off the height of a chair from different angles. This should provide a variation of over 1 cm, depending on the size of the angles. Discuss ways to remove this effect (eye level, use of mirror and pin/marker).

Ask the students if there are any other kinds of error they can think of. They will probably come up with an example of a systematic error. Use this as a lead into explaining systematic errors. Give some examples and the procedure for removing their effect. If possible they could collect some data using a piece of equipment with a zero error and then adjust their results accordingly.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Random errors** | |
| **SA** | With a partner, discuss the difference between 'mistakes' and 'errors'. Feed back ideas. |
| **MA** | Activity 1.6 with a partner. |
| **CA** | With a partner, discuss examples of random errors and how to minimise them. Feed back ideas. |
| **Parallax and systematic errors** | |
| **SA** | With a partner, experiment with reading scales and avoiding parallax errors. |
| **MA** | In a small group, measure different objects using Vernier callipers. |
| **CA** | Review questions 1–2 to be tackled with a partner. |

## Activities

- Home-made ruler practical.
- Correcting for systematic errors from simple practical.

## Where next?

There is not really anything to add to this topic. The nature of the errors does not change; however, identifying them and removing their effect become significantly more complex with more demanding experiments.

## Answers to review questions

1. An error is something that occurs as part of your investigation that causes the reading to vary from the real value.
2. Random errors are errors with no pattern or bias. They cause measurements to vary in an unpredictable manner. Importantly, they cause your measurements to be sometimes above the accepted value, sometimes below the accepted value.

   For example, if you were measuring the acceleration due to gravity, random errors will cause your readings to vary both above and below the accepted value.

   The use of a ruler for length is not without its problems at times. If you wanted to measure the diameter of a table-tennis ball, how might you do it?

   When the object and the scale lie at different distances from you, it is essential to view them from directly above if you are to avoid what we call parallax errors.

   A systematic error is a type of error that shows a bias or a trend. It makes your readings too high every time, or too low every time. Taking repeated readings will not help account for this type of error.

   A simple example might be an ammeter that always reads 0.4 A too low. So if your reading was 6.8 A, the true value for the current would be 7.2 A. More complex examples include ignoring the effect of friction in Newton's second law experiments, or not measuring to the centre of mass of a simple pendulum.

## 1.3 Precision, accuracy and significance

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 terms precision, accuracy and significance.
- Appreciate the importance of the precision of the measuring instrument.

### Starting off

This section is essentially an extended explanation of the three terms above. These terms are often muddled by students, and so a correct understanding is essential if they are to produce high-quality experimental write-ups.

## Teaching notes

It is important to ensure the students have a clear distinction in their minds between accuracy and precision. The two terms are often muddled, particularly in common language.

Ask the students to define accuracy and precision. Spend time discussing their ideas and provide them with the correct definitions. A discussion on significance is also helpful here (first touched on in Section 1.1), in particular the limitations of calculators and the extra precision they imply.

The target analogy often helps students understand the difference between accurate readings and precise readings. It is worth giving one example then asking the students to come up with the other three themselves, discussing their work in pairs.

Show two different pieces of length-measuring equipment (e.g. metre rule and micrometer). Discuss precision in relation to instruments. Ensure students are aware of the importance of selecting an instrument with an appropriate precision. This should go both ways; there is no need to measure the mass of a car to the nearest milligram!

**Activity 1.7: Answer**

Students' own results.

**Activity 1.8: Answer**

Students' own results.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Precision and accuracy** | |
| **SA** | With a partner, discuss the meaning of the terms 'precision' and 'accuracy'. Feed back ideas. |
| **MA** | With a partner, make a poster to summarise Students' Book pages 13–14. |
| **CA** | Present your poster to the rest of the class. |
| **Instrument precision** | |
| **SA** | With a partner, summarise notes on instrument precision on Students' Book page 15. |
| **MA** | Activity 1.7 with a partner. |
| **CA** | Feed back results of activity. |
| **Uncertainty in measurements** | |
| **SA** | Worked example 1.1 to be tackled with a partner before given solution is revealed. |
| **MA** | Activity 1.8 with a partner.<br>Discussion activity on page 15 of Students' Book. |
| **CA** | Review questions 1–4 to be tackled with a partner. |

## Activities

- Compile a list of the precisions of a range of laboratory equipment.
- Conduct simple experiments (e.g. pendulum) to determine uncertainty in readings.

## Where next?

If students take their physics further they will need to do more complex statistical analyses on their results. The next step may include determining the standard deviation in their results to allow a more quantitative discussion on precision.

## Answers to review questions

1. Accuracy means how close a reading is to the true value.

   Precision is a measure of the degree of 'exactness' of a value.

   Accuracy might vary, for example, in readings for acceleration due to gravity.

   Precision will depend on measuring instruments – some instruments will give more precise measurements than others. For example, an ordinary ruler will not be as precise as vernier callipers.

2. Answers will vary.

3. 167 cm

   $66'' = 66 \times 2.54$ cm

   $$\begin{array}{r} = 254 \\ \times\ 66 \\ \hline 15240 \\ {\scriptstyle 3\,2} \\ 1524 \\ {\scriptstyle 3\,2} \\ \hline 167.64 \end{array}$$

   Abeba is 0.64 cm taller.

4. a) The answer would be $\frac{914}{600}$

   $$\begin{array}{r} 1.5233 \\ 600\,\overline{)\,914} \\ \underline{600} \\ 3140 \\ \underline{3000} \\ 1400 \\ \underline{1200} \\ 2000 \\ \underline{1800} \\ 2000 \end{array}$$

   Rounded to 3 sf this is 1.52 m/s.

   b) By rounding each step the final answer could be very imprecise.

## 1.4 Report writing

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

### Learning Competencies

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

- Investigate some useful techniques for writing scientific reports.

### Starting off

This section provides a suggested framework for writing up experiments. This could be used throughout the next two years.

## Teaching notes

Discuss the importance of presenting data clearly. Relate this back to the scientific method. Show examples of poorly presented data and ask the students to identify issues.

Spend some time reviewing the suggested framework for writing up experiments. Discuss each point in turn and ideally give examples of each section. Stress that at times an experiment may focus on a particular section (for example, accuracy or error analysis). However, some experiments will be written up completely and contain all 10 sections.

Describe some simple experiments the student could carry out (examples in the Students' Book). Students should produce a simple hypothesis and follow the scientific method to design, test and fully write up the experiment. This provides excellent revision of this entire unit and may take a few lessons to complete properly.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Presenting information** | |
| **SA** | With a partner, discuss the sort of information that you need to present in different areas of the curriculum. |
| **MA** | In a small group, look back at the activities in this unit and decide how you could have presented the information. |
| **CA** | Feed back the results of your discussion to the rest of the class. |
| **Report writing** | |
| **SA** | With a partner, discuss why reports are needed in science. Feed back ideas. |
| **MA** | With a partner, select an activity from this unit to report and produce the report. |
| **CA** | End of unit questions to be tackled with a partner. |

## Answers to end of unit questions

1. The scientific method ensures a rigorous, evidence-based structure where only ideas that have been carefully tested are accepted as scientific theory.
2. **hypothesis** a proposed explanation for an observation

   **experiment** a test under known conditions to investigate the truth of a hypothesis

**analyse** examine in detail to discover the meaning of a set of results

**conclusions** the overall result or outcome of an experiment. The hypothesis being tested may be supported by the results or may be proven incorrect

**significant figures** the number of digits used in a measurement, regardless of the location of the decimal point

**uncertainty** the amount of doubt in a measurement

**multiple values** several readings of the same measurement

**accepted/true value** the actual value of the property being measured, made without any experimental errors

**random errors** unpredictable errors that have no pattern or bias and which may be above or below the true value

**systematic errors** errors caused by a bias in measurement and which show a bias or trend

**zero errors** errors caused by equipment that has not been correctly zeroed

**accuracy** the closeness of a measurement to its true value

**precision** the quality of being exact and the degree to which repeated measurements under the same conditions give the same value

**significance** the number of significant figures used in a reading, which should be appropriate to the precision of the measuring instrument

**conversion factor** a numerical factor used to multiply or divide a quantity when converting from one system of units to another

**framework** an outline structure that can be used as the basis for a report

3. Answers will vary depending on student's choice of investigation.
4. Answers will vary depending on student's choice of investigation.
5. Makeda is incorrect. Answers should only be given to lowest accuracy of anyone of the measurements.

# Vector quantities

# Unit 2

**Learning Competencies for Unit 2**

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

- Appreciate the meaning of the terms vector and scalars (including examples).
- State the different types of vector.
- Show how to use vector notation.
- Resolve a vector into two components.
- Calculate vectors by graphical and mathematical methods.
- Appreciate the parallelogram rule and the triangle rule.
- Solve more complex examples of vectors.
- Calculate the scalar product of two vectors.
- Project one vector onto another.
- Use the scalar product to test for orthogonal vectors.
- Use the vector product to test for collinear vectors.

This unit should fill approximately **18 periods** of teaching time.

## 2.1 Types of vector

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

### Learning Competencies

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

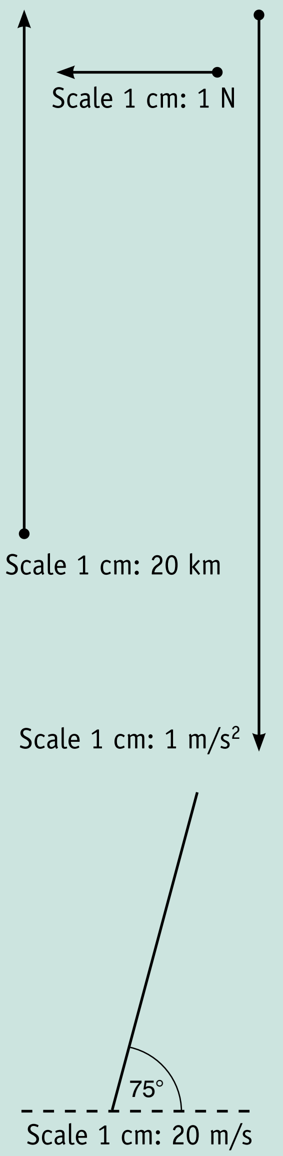
- Appreciate the meaning of the terms vector and scalars (including examples).
- State the different types of vector.
- Show how to use vector notation.

### Starting off

Vectors are very important in Physics. However, at this stage their importance is rather hidden. It is not until students use complex mathematics that their importance comes to the fore. Students should be encouraged to think about the quantities they are measuring and what they actually mean. This helps distinguish between vectors and scalars.

Representing vectors is limited to scale diagrams and simple analytical descriptions; there is no need to develop vector notion as part of this topic.

**Activity 2.1: Answer**




## Teaching notes

Start by asking the students what is meant by a vector or scalar quantity. Some may recall the correct definitions. Try to use the word magnitude in place of size, which would have been used in Grade 9. Discuss the meaning of these definitions using two simple examples (mass and force, perhaps). Write a long list of quantities on the board and ask the students to classify them into vectors or scalars. Include potentially tricky ones (KE, temperature, charge, etc.).

### Think about this…

Which of the following do you think are scalars and which are vectors? Electric current (V), moment (V), time (S), potential difference (S), resistance (S), volume (S), air resistance (V) and charge (S).

Revise the use of arrows to represent vectors, including the direction, magnitude and sense of the vector. This is slightly more detailed than material covered in Grade 9. Students could practise drawing one or two sample vectors to scale, but this is quite simple and may not be necessary. Explain the usual written notation of vectors (lower case, bold typeface) although at this stage this is not really required.

Introduce some of the different types of vector students will encounter in this unit. Limit this to position, unit, collinear and coplanar. There is not much to this, just a simple explanation of each with examples should suffice.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Scalars and vectors** | |
| **SA** | With a partner, write down definitions of scalars and vectors. Feed back ideas. |
| **MA** | Discussion activity on page 23 of Students' Book in small groups. |
| **CA** | Feed back results of discussion and justify answers. |
| **Representing vectors** | |
| **SA** | With a partner, discuss how vectors are represented. |
| **MA** | Activity 2.1 with a partner. |
| **CA** | Feed back results of activity. |
| **Types of vector** | |
| **SA** | With a partner, list all the types of vector you can think of. Feed back ideas. |
| **MA** | With a partner, make a poster to summarise Students' Book pages 24–25. |
| **CA** | Review questions 1–2 to be tackled with a partner. |

## Activities

- Identify different scalars and vectors.
- Construct simple scale arrows to represent various vectors.

## Where next?

More complex use of vectors may be encountered in mathematics or at university. For example, a velocity of 20 m/s vertically could be represented by the vector $\boldsymbol{v}$ (0,20,0) (in three dimensions with the positive $y$ axis as 'up'), the three values represent the three dimensions ($x$,$y$,$z$).

A force of 60 N at 40° to the horizontal may be represented as: $\boldsymbol{F}$ (46, 39, 0), 46 N and 39 N being the horizontal and vertical components of the vector.

Other physical vectors, such as the electric and magnetic field, are represented as a system of vectors at each point of a physical space: that is, a vector field.

## Answers to review questions

1. A vector quantity has both magnitude (size) and direction – force, displacement, velocity, acceleration, momentum, etc.

   A scalar quantity has magnitude (size) only – distance, speed, mass, energy, temperature, time, etc.

2. Position vector – describes the position of an object, e.g. position vector for a particle.

   Unit vector – has a magnitude of 1 in direction parallel to one of the axes, e.g. $i$, $j$ or $k$.

   Collinear vectors – vectors that are in the same line, e.g. →→□←

   Coplanar vectors – vectors in same two dimensional plane, e.g. →5 km E<br>↑5 km N

## 2.2 Resolution of vectors

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

### Learning Competencies

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

- Resolve a vector into two components.

### Starting off

This brief section provides a recap of how to resolve one vector into perpendicular coplanar vectors. It is essential trigonometry applied to vectors. Again, this was introduced in Grade 9 and there is a more detailed discussion in the Grade 9 Teacher's Book.

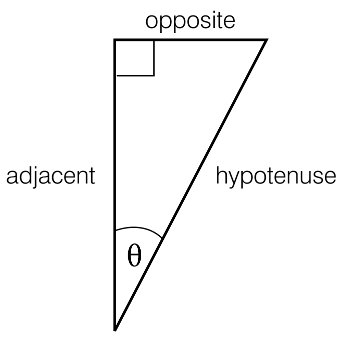
## Teaching notes

Ask the students if any can recall what it means to resolve a vector. Explain that resolution of a vector means splitting it into two perpendicular coplanar vectors, and this is very helpful when completing vector addition.

This may be very simple for some; however, it is worth spending a few minutes getting the students to practise resolving a few examples of vectors into horizontal and vertical components. Give them a few examples and try to relate these to their experiences and involve different vectors (displacement, velocity and force are perhaps the most accessible).

Examples could be made more complex by giving the students different angles other than the straightforward angle to the horizontal.

## Trigonometry




Students find remembering this quite difficult. Perhaps use SOH-CAH-TOA to help.

SOH: $\sin \theta = \dfrac{\text{opposite}}{\text{hypotenuse}}$

CAH: $\cos \theta = \dfrac{\text{adjacent}}{\text{hypotenuse}}$

TOA: $\tan \theta = \dfrac{\text{opposite}}{\text{adjacent}}$

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Resolving vectors** | |
| **SA** | With a partner, discuss the meaning of the term 'resolving'. Feed back ideas. |
| **MA** | With a partner, resolve a selection of given vectors (begin with those in Activity 2.1). |
| **CA** | Feed back results of activity. |
| **Using trigonometry and Pythagoras's theorem** | |
| **SA** | With a partner, write down the definitions of the three basic trigonometric ratios. Feed back ideas. |
| **MA** | With a partner, use an appropriate method to resolve given vectors. Begin with worked example 2.1 (without given solution). |
| **CA** | Review questions 1–2. |

## Activity

- Practise resolving simple vectors.

## Answers to review questions

1. To split the vector into two perpendicular components.
2. Drawings completed to scale plus:

| Vector | Vertical component (2 s.f.) | Horizontal component (2 s.f.) |
|---|---|---|
| a | 30 N | 52 N |
| b | 44 m/s | 7.8 m/s |
| c | 1600 km | 950 km |

## 2.3 Vector addition and subtraction

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

### Learning Competencies

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

- Calculate vectors by graphical and mathematical methods.
- Appreciate the parallelogram rule and the triangle rule.
- Solve more complex examples of vectors.

## Teaching notes

Start by quickly reviewing how to add scalars (simple arithmetic) and give an example (20 s + 40 s = 60 s !). Remind students that adding vectors, because of their directionality, is much more complex. The example of 10 + 15 = 18 is a good one to start discussion (18 would be the resultant if two vectors of 10 and 15 were perpendicular to each other).

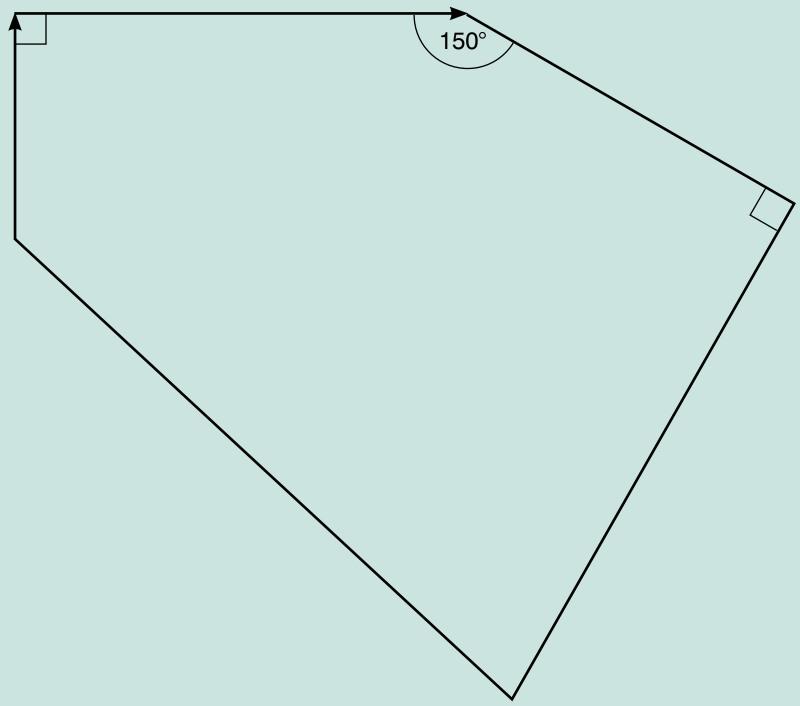
Quickly recap the concept of a resultant vector. Revise drawing simple diagrams to add vectors, stressing the importance of scale and taking time to draw them carefully. Explain that scale diagrams may only be used to add collinear and/or coplanar vectors; they are limited to 2D! However computer modelling could be used to construct 3D scale diagrams in exactly the same way.

Start with simple scale diagrams and provide the students with a list of vectors to add using a scale diagram (see more information in the Students' Book). The fact that vectors can be added in any order (the commutative law) should also be highlighted by making the students complete the same scale diagram using the same vectors but drawn in a different order.

To extend this, and revise the concept of no resultant vector, students should be given a couple of examples where the resultant vector is zero; for example, when an object is in equilibrium or when a journey ends up back at the start. They might be given several vectors but one is unknown, by constructing scale diagrams they can

### Activity 2.2: Answer

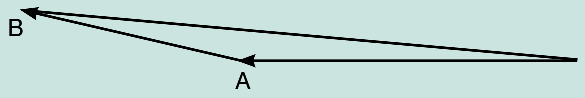
Scale 1 cm: 4 km




Resultant: 21.6 km at angle 142° to vertical

## Activity 2.3: Answer

Scale 1 cm: 10 N



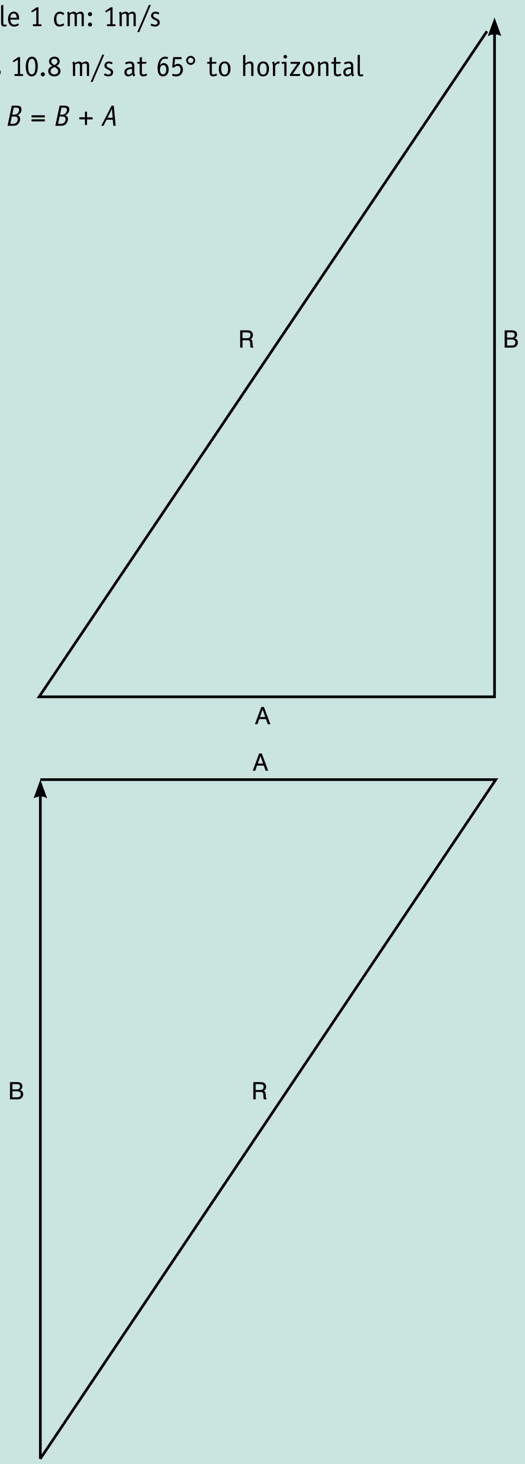

Resultant: 72 N at angle 167.5° to horizontal

## Activity 2.5: Answer

Scale 1 cm: 1m/s

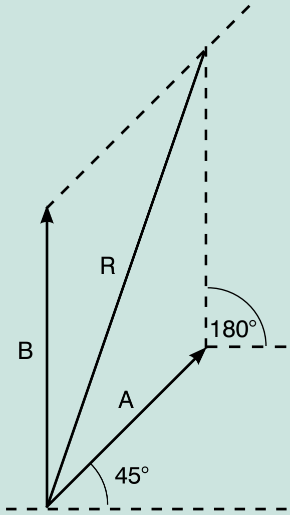
R is 10.8 m/s at 65° to horizontal

$A + B = B + A$




## Activity 2.4: Answer

Scale 1 cm: 10 m/s




Resultant:
A + B is 68 m/s at angle 66° to horizontal

Resultant:
A + B + C = 0
A + B = 68 m/s at angle 66° to horizontal
C = −68 m/s at angle 246°

then determine the magnitude and direction of the unknown vector.

Revise the parallelogram method for adding two coplanar vectors. Students should carefully draw a few examples of parallelograms, including vectors that are not perpendicular to each other. Go on to the triangle method (again for adding two coplanar vectors). Students usually find these quite easy, but it is worth spending a little time ensuring they understand the key ideas. More advanced students could start thinking about how to add two coplanar vectors mathematically. Most will be happy with simple trigonometry, but push them to think about how to add the vectors if the triangle is not a right-angled triangle (cosine and sine rules).

Briefly revise adding collinear vectors mathematically, paying particular attention to the direction and its impact on the vector sum. Go on to add perpendicular vectors using Pythagoras's theorem.

Discuss with students how you can add and subtract vectors that are in component form.

Make sure that you give your students plenty of practice at adding and subtracting vectors using all the different methods.

Before carrying out Activity 2.6, you may wish to discuss how to set up the experiment with the class. The activity will provide a practical demonstration of the resolution of two forces to produce a resultant force. Which force is the resultant? (Each force is the resultant of the other two.)

Question 6e) in the review question shows how three non-zero vectors can be added up to zero. You may wish to discuss the implications of this with the class.

**Activity 2.6: Answer**

Students' own results.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Scale diagrams** | |
| **SA** | With a partner, discuss situations where 'scale' is used in everyday life (e.g. maps). Feed back ideas. |
| **MA** | Activity 2.2 with a partner. |
| **CA** | Discuss activity. What scales did you use? Why? |
| **Parallelogram rule** | |
| **SA** | With a partner, write a definition of a parallelogram. Feed back ideas. |
| **MA** | Activity 2.3 with a partner. |
| **CA** | Feed back results of activity. Why is the parallelogram rule given this name? |
| **Triangle rule** | |
| **SA** | With a partner, discuss the techniques you could use to find the resultant of two perpendicular coplanar vectors. Feed back ideas. |
| **MA** | Discussion activity on page 30 of Student's Book in small group. |
| **CA** | Feed back results of discussion. |
| **Adding vectors** | |
| **SA** | Activity 2.4 with a partner. |
| **MA** | Activity 2.5 with a partner. |
| **CA** | Review questions 2–3 to be tackled with a partner |
| **Component method** | |
| **SA** | With a partner, discuss why the vector in Figure 2.13 can be expressed in component form as (3, 4). Feed back ideas. |
| **MA** | Review questions 1, 6 to be tackled with a partner. |
| **CA** | Discuss answers to review questions. |
| **Adding forces** | |
| **SA** | With a partner, write down Newton's laws of motion. Feed back ideas. |
| **MA** | Activity 2.6 in a small group. |
| **CA** | Discuss why the force C in Figure 2.22 must be equal and opposite to the resultant of forces A and B. |
| **Sine and cosine rule** | |
| **SA** | With a partner, work through Worked example 2.3. |
| **MA** | With a partner, tackle further examples like Worked example 2.3. |
| **CA** | Review questions 4, 5, 7–9 to be tackled with a partner. |

## Activities

- Practice drawing scale diagrams.
- Find an unknown force by drawing a scale diagram.
- Determine a resultant velocity using parallelogram and triangle rules.
- Demonstrate commutative law by adding vectors in a different order.
- Add forces practically and using vector addition.

For A ctivity 2.6, for each group you will need three newtonmeters, three lengths of string, and a wooden block with eyes attached to it. Alternatively, the activity could be carried out as a whole class.

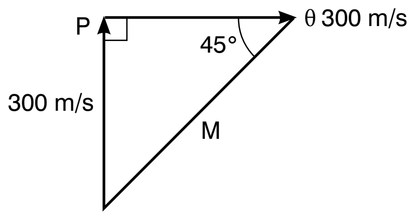
## Where next?

Students will need to be able to express vectors in component form when they calculate scalar and vector products in the next section.

## Answers to review questions

1. a) 11.67 m at an angle 59° above *x* direction

   b) 11.67 m at an angle 59° below *x* direction

2. 5.8 km at 59° E of N
3. 26.8 N at 63° to the 12 N force
4. 230 m/s at an angle 5.3° to the E of S
5. 


   Since velocity P = velocity θ, angles of vector triangle are 90°, 45° and 45°.

   Resultant magnitude *M*

   $M^2 = 300^2 + 300^2$

   $M = \sqrt{300^2 + 300^2}$

   $= \sqrt{180\,000}$

   $= 424.3$ m/s

   Direction is 45° to direction of θ.

6. a) (–2, 9) b) (3, –5) c) (–5, 14) d) (–1, 13) e) (0, 0)
7. Magnitude $= \sqrt{(27)^2 + (18)^2}$

   $= \sqrt{1053}$

   $= 32.4$ N

   Direction $\tan\theta = \frac{18}{27} = \frac{2}{3}$

   $\theta = 33.7°$

8. a) $a = \begin{bmatrix} 1500 \\ 3000 \\ 200 \end{bmatrix}$ Point B is $\begin{bmatrix} 1500 + 2000 \\ 3000 - 5000 \\ 200 - 100 \end{bmatrix} = \begin{bmatrix} 3500 \\ -2000 \\ 100 \end{bmatrix}$

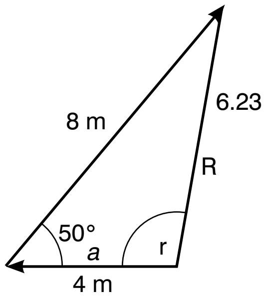
b) Magnitude $= \sqrt{(3500)^2 + (-2000)^2 + (100)^2}$

$= \sqrt{1.225 \times 10^7 + 4 \times 10^6 \times 1 \times 10^4}$

$= \sqrt{1.626 \times 10^7}$

$= 4032.4$ m

9. a)




$R^2 = 4^2 + 8^2 - 2 \times 4 \times 8\cos 50$

$= 80 - 41.138$

$R = \sqrt{38.862}$

$= 6.23$ m

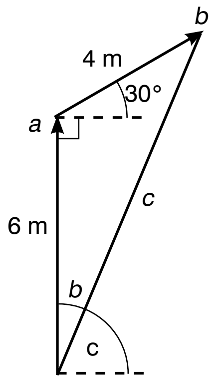
$\frac{\sin r}{8} = \frac{\sin 50}{6.23}$

$\sin r = \frac{\sin 50}{6.23} \times 8 = 0.984$

$r = 79.7°$

Resultant is 6.23 m at 79.7° to horizontal.

b)




$c^2 = a^2 + b^2 - 2ab\cos 120°$

$= 36 + 16 - 2 \times 6 \times 4 \times -0.5$

$= 52 - -30$

$= 82$

$c = \sqrt{82}$

$= 9.06$ m

$$\frac{\sin b}{4} = \frac{\sin 120}{9.06}$$

$$\sin b = \frac{\sin 120}{9.06} \times 4$$

$$= 0.3824$$

$$b = 22.48°$$

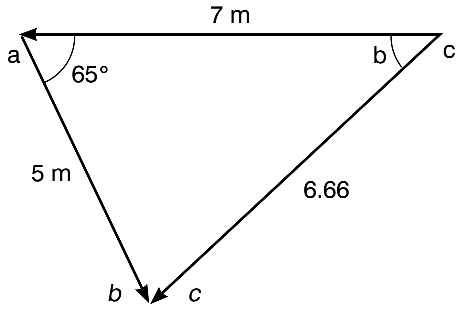
$$c = 90 - b$$

$$= 90 - 22.48$$

$$= 67.5°$$

Resultant is 9.06 m at angle of 67.5° to horizontal.

c)




$$c^2 = 7^2 + 5^2 - 2 \times 7 \times 5 \times \cos 65$$

$$= 74 - 29.58$$

$$c = \sqrt{44.42}$$

$$c = 6.66 \text{ m}$$

$$\frac{5}{\sin b} = \frac{6.66}{\sin 65}$$

$$\frac{5 \times \sin 65}{6.66} = \sin b$$

$$0.6804 = \sin b$$

$$b = 42.87$$

$$c = 180 - 42.87$$

$$= 137.13°$$

Resultant is 6.66 m at 137.13° below horizontal.

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

## 2.4 Multiplication of vectors

### Learning Competencies

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

- Calculate the scalar product of two vectors.
- Project one vector onto another.
- Use the scalar product to test for orthogonal vectors.
- Use the vector product to test for collinear vectors.

## Teaching notes

Note that the work here on vectors is limited to vectors in two dimensions.

### *Multiplying a vector by a scalar*

Start by asking the students what the resultant is when two identical vectors are added together, e.g. **a** = (3, 2), **a** + **a** = (6, 4). What has happened to the magnitude and direction of the resultant? Discuss with students that this is the same as multiplying the vector by 2 and that 2 is a scalar. Reach the general conclusion that multiplying a vector by a scalar changes the magnitude but not the direction of the vector. Go through the example in the text that shows this.

Make sure that students understand that the scalar does not have to be a whole number and that it can also be less than one – you can multiply a vector by a scalar that is a fraction or a decimal, as well as negative numbers.

### *Scalar product*

Explain to the students that there are different ways of multiplying vectors together – one of them produces a vector (which will be covered later in the unit) and the other produces a scalar, which is known as the scalar product. Make sure that students are aware that this is also known as the dot product. Introduce the definitions of the scalar product as given in the Students' Book, and show how this can be used to work out the angle between two vectors. This can often be simpler than using trigonometry.

Go through the first two worked examples, which show how to calculate the scalar product of two vectors and the angle between two vectors. Emphasise the importance of drawing diagrams to show the vectors – this is good practice that will help them to solve problems in future work. It very often helps to see the directions of the vectors, to give an idea of the direction and size of the resultant.

You could also give students two vectors in the form of a magnitude and a direction (e.g. 5 N at an angle of 60° to the positive **x** direction) and ask them to resolve the components of the vectors and then to find the scalar product and the angle between them.

### *Scalar projection*

Introduce the idea of the scalar projection of one vector on to another, and how it shows the magnitude of the component of one vector that is in the direction of another vector. Help students to work out that the basis of calculating the scalar projection comes from trigonometry.

Go through the worked example. Again, you could give students vectors in different forms and ask them to resolve the vectors into their components to find the scalar projection of one onto the other.

When the students carry out Activity 2.7, you may need to prompt them to see that if vectors are orthogonal, the angle between them is 90° and the cosine of the angle is 0. If they look at the equation for working out the angle between two vectors, for cos θ to be zero, the top line of the right-hand side of the equation is zero. Therefore a quick way to check that two vectors are orthogonal is to work out their scalar product – if it is zero, the vectors are orthogonal.

**Activity 2.7: Answer**

Angle between **a** and **b** is 90°. Angle between **c** and **d** is 90°.

Scalar product is zero.

**Activity 2.8: Answer**

Area of parallelogram is 21 $cm^2$.

Vector product gives the area of the parallelogram.

**Activity 2.9: Answer**

1. a) $-17\hat{n}$
   b) 90°
   c) 17 square units
2. Vector product is zero.

### *Vector product*

Introduce the vector product to students as the multiplication of two vectors to produce another vector. Explain that the vector product is in a direction which is perpendicular to the plane that the two vectors are in.

Introduce the right-hand rule as shown in the Students' Book. Emphasise that they need to use the right hand, not the left hand. Ask students why – they should answer that this gives the opposite direction.

Work through some examples with the students including working out the vector product and the angle between the vectors. You could also give students some examples that are in the form of a magnitude and direction and ask them to resolve the components of the vectors before working out the vector product.

In Activity 2.8, you may need to prompt students to come up with the result that the vector product gives the area of the parallelogram produced by using the parallelogram method to add the vectors.

In Activity 2.9, you may need to prompt students to see that when vectors are collinear, the vector product is zero, and that you can calculate the product $(a_x b_y - a_y b_x)$. If this product is zero, then the vectors are collinear.

Students can plan an investigation into the forces acting on a ladder that is resting against a wall at an angle. They can then write a report of their investigation using the writing frame in Unit 1 of the Students' Book.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Multiplying by a scalar** | |
| **SA** | With a partner, discuss what is meant by 'scalar'. Feed back ideas. |
| **MA** | Review question 1 to be tackled with a partner. |
| **CA** | Discuss answer to review question. |
| **Scalar product** | |
| **SA** | With a partner, write a definition of the mathematical term 'product'. Feed back ideas. |
| **MA** | With a partner, make a poster about the scalar product. |
| **CA** | Why is the scalar product called this? Discuss with a partner and feed back ideas. |
| **Vector product (1)** | |
| **SA** | What sort of product do you think will result from the vector product? Discuss with a partner and feed back ideas. |
| **MA** | Activity 2.7 with a partner.<br>Activity 2.8 with a partner. |
| **CA** | Feed back results of activities. |
| **Vector product (2)** | |
| **SA** | With a partner, list the essential features of the vector product. Feed back ideas. |
| **MA** | With a partner, make a poster about the vector product. |
| **CA** | Activity 2.9 with a partner. |

| **Forces on a ladder** | |
|---|---|
| **SA** | With a partner, consider a ladder resting against a wall. List the forces acting on it. Feed back ideas. |
| **MA** | In a small group, carry out the project on page 36 of the Students' Book. |
| **CA** | Review the project in your group. What went well? What would you change if you repeated the project? |
| **Applications of vectors** | |
| **SA** | In a small group, begin a spidergram about applications of vectors which you will add to during this lesson. |
| **MA** | Discussion activity on page 36 of Students' Book in small groups. Add to your spidergram. |
| **CA** | End of unit questions to be tackled with a partner. |

## Activities

- Check to see if vectors are orthogonal.
- Use the vector product to calculate an area.
- Check to see if vectors are collinear.
- Project: examine forces acting on a ladder resting against a wall.

## Where next?

Students will use the scalar product of two vectors in later units; for example, work done is the scalar product of force and distance, which are both vectors.

## Answers to review questions

1. a) 2 N at 50° to the $x$ direction
   b) 9 N in the $x$ direction and 6 N in the $y$ direction
   c) (–12, –4)
   d) $\frac{1}{2}$ N at 50° to the $x$ direction
   e) $-\frac{3}{4}$ in the $x$ direction and $-\frac{1}{2}$ in the $y$ direction
   f) (1.5, 0.5)
2. a) i) –42
      ii) 18
      iii) 85.2°
      iv) 136.4°
   b) Yes, by working out the scalar product.

3. a) $\mathbf{i} = \begin{pmatrix}1\\0\\0\end{pmatrix}$ $\mathbf{j} = \begin{pmatrix}0\\1\\0\end{pmatrix}$ $\mathbf{k} = \begin{pmatrix}0\\0\\1\end{pmatrix}$

b) $\mathbf{i}\,.\,\mathbf{j} = 1\times0 + 0\times1 + 0\times0$

$= 0$

$\mathbf{j}\,.\,\mathbf{k} = 0\times0 + 1\times0 + 0\times1$

$= 0$

$\mathbf{i}\,.\,\mathbf{k} = 1\times0 + 0\times0 + 0\times1$

$= 0$

since $\mathbf{i}\,.\,\mathbf{j} = |i||j| \cos\theta$

and $|i| = 1$ $|j| = 1$

$\cos\theta = 0$

$\theta = 90°$

This means that **i**, **j** and **k** are orthogonal.

4. $\mathbf{i}\times\mathbf{i} = \begin{pmatrix}1\\0\\0\end{pmatrix} \times \begin{pmatrix}1\\0\\0\end{pmatrix}$

$= [(0\times0) - (0\times0)]\mathbf{i} + [(0\times1) - (1\times0)]\mathbf{j} + [(1\times0) - (0\times1)]\mathbf{k}$

$= 0$

$\mathbf{i}\times\mathbf{i} = |i|\;|i| \sin\theta$

$= 0$

since $|i| = 1$ $\sin\theta = 0$

$0 = 0$

**i** and **i** are collinear.

$\mathbf{j}\times\mathbf{j} = \begin{pmatrix}0\\1\\0\end{pmatrix} \times \begin{pmatrix}0\\1\\0\end{pmatrix}$

$= [(1\times0) - (0\times1)]\mathbf{i} + [(0\times0) - (0\times0)]\mathbf{j} + [(0\times1) - (1\times0)]\mathbf{k}$

$= 0$

$\mathbf{j}\times\mathbf{j} = |j|\;|j| \sin\theta$

$= 0$

since $|j| = 1$ $\sin\theta = 0$

$0 = 0$

**j** and **j** are collinear.

$\mathbf{k} \times \mathbf{k} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \times \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

$= [(0\times1) - (1\times0)]\mathbf{i} + [(0\times1) - (1\times0)]\mathbf{j} + [(0\times0) - (0\times0)]\mathbf{k}$

$= 0$

$\mathbf{k} \times \mathbf{k} = |k|\ |k| \sin\theta$

$= 0$

since $|k| = 1$ $\sin\theta = 0$

$0 \ = 0$

**k** and **k** are collinear.

## Answers to end of unit questions

1. **magnitude** the size of a value

   **scalar** a quantity specified only by its magnitude

   **collinear vectors** vectors that are parallel to each other and which act along the same line

   **coplanar vectors** vectors that act in the same two-dimensional plane

   **position vector** a vector that represents the position of an object in relation to another point

   **unit vector** a vector with a length of one unit

   **component vectors** two or more vectors that, when combined, can be expressed as a single resultant vector

   **resolving** splitting one vector into two parts that, when combined, have the same effect as the original vector

   **commutative law** a process obeys the commutative law when it does not matter which order the quantities are in. For example, the addition of numbers obeys the commutative law

   **orthogonal** at right angles. When two vectors are at right angles to each other, they are said to be orthogonal

2. The scalar product of two vectors is when they are multiplied together to give a scalar quantity $a \,.\, b = a_x b_x + a_y b_y = |a||b| \cos\theta$.

3. $\mathbf{a} \,.\, \mathbf{b} = (3\mathbf{i} - \mathbf{j} + 2\mathbf{k}) \,.\, (2\mathbf{i} + \mathbf{j} - 2\mathbf{k})$

   $= (3 \times 2) + (-1 \times 1) + (2 \times -2)$

   $= 6 - 1 - 4$

   $= 1$

   b) $\cos\theta = \dfrac{\mathbf{a} \,.\, \mathbf{b}}{|\mathbf{a}|\ |\mathbf{b}|}$

   $|\mathbf{a}^2| = \mathbf{a} \,.\mathbf{a}$

   $= (3 \times 3) + (-1 \times -1) + (2 \times 2)$

   $= 9 + 1 + 4$

   $= V14$

$|a| = \sqrt{14}$

$|\mathbf{b}^2| = \mathbf{b} \cdot \mathbf{b}$

$= (2 \times 2) + (1 \times 1) + (-2 \times -2)$

$= 4 + 1 + 4$

$= 9$

$|b| = 3$

$$\cos\theta = \frac{1}{V14 \times 3}$$

$$= \frac{1}{11.22}$$

$\theta = 84.9°$ (1 d. p.)

4. a) $\mathbf{p} \cdot \mathbf{q} = (4\mathbf{i} + 3\mathbf{j} + 2\mathbf{k}) \cdot (2\mathbf{i} - \mathbf{j} + 11\mathbf{k})$

$= (4 \times 2) + (3 \times -1) + (2 \times 11)$

$= 8 - 3 + 22$

$= 27$

b) $\mathbf{q} \cdot \mathbf{p} = (2\mathbf{i} - \mathbf{j} + 11\mathbf{k}) \cdot (4\mathbf{i} + 3\mathbf{j} + 2\mathbf{k})$

$= (2 \times 4) + (-1 \times 3) + (11 \times 2)$

$= 8 - 3 + 22$

$= 27$

5. a) $\mathbf{x} \cdot \mathbf{y} = (2\mathbf{i} - 3\mathbf{j} - 4\mathbf{k}) \cdot (-2\mathbf{i} + 14\mathbf{j} + \mathbf{k})$

$= (2 \times -2) + (-3 \times 14) + (-4 \times 1)$

$= -4 - 42 - 4$

$= -50$

a) $\mathbf{y} \cdot \mathbf{y} = (-2\mathbf{i} + 14\mathbf{j} + \mathbf{k}) \cdot (-2\mathbf{i} + 14\mathbf{j} + \mathbf{k})$

$= (-2 \times -2) + (14 \times 14) + (1 \times 1)$

$= -4 + 196 + 1$

$= 193$

6. The vector product of two vectors is when two vectors are multiplied together to produce another vector.

$\mathbf{a} \times \mathbf{b} = |a||b| \sin\theta$

$= (a_y b_z - a_z b_y)\mathbf{i} + (a_z b_x - a_x b_z)\mathbf{j} + (a_x b_y - a_y b_x)\mathbf{k}$

7. $\mathbf{a} \times \mathbf{b} = [(-2)(-8) - (5)(4)]\mathbf{i} - [(3)(-8) - (5)(7)]\mathbf{j} + [(3)(4) - (-2)(7)]\mathbf{k}$

$= (16 - 20)\mathbf{i} - (-24 - 35)\mathbf{j} + (12 - -14)\mathbf{k}$

$= -4\mathbf{i} - (-59)\mathbf{j} + (26)\mathbf{k}$

$= -4\mathbf{i} + 59\mathbf{j} + 26\mathbf{k}$

8. a) $\mathbf{a} \times \mathbf{b} = [(1)(1) - (-2)(-3)]\mathbf{i} - [(8)(1) - (-2)(5)]\mathbf{j} + [(8)(-3) - (1)(5)]\mathbf{k}$

$= (1 - (+6))\mathbf{i} - (8 - -10)\mathbf{j} + (-24 - 5)\mathbf{k}$

$= -5\mathbf{i} - 18\mathbf{j} - 29\mathbf{k}$

b) $\mathbf{b} \times \mathbf{a} = [(-3)(-2) - (1)(1)]\mathbf{i} - [(+5)(-2) - (1)(8)]\mathbf{j} + [(5)(1) - (-3)(8)]\mathbf{k}$

$= (6 - 1)\mathbf{i} - (-10 - 8)\mathbf{j} + (5 - -24)\mathbf{k}$

$= 5\mathbf{i} - (-18)\mathbf{j} + 29\mathbf{k}$

$= 5\mathbf{i} - 18\mathbf{j} + 29\mathbf{k}$

9. a) If the scalar product of two vectors = 0 the vectors are orthogonal ($\cos \theta = 0$)

b) If the vector product of two vectors = 0 the vectors are collinear ($\sin \theta = 0$)

10. Some applications are as follows:
- Analysing forces on a bridge.
- Analysing the motion of an aeroplane.
- Programming motion or the position of an object in a computer game or animation.
- Displaying graphics (in the form of vector graphics) so that the diagram can be resized easily without any loss of quality.
- Modelling and planning the trajectory (path) of a space probe.
- Analysing the motion of planets.
- Analysing magnetic fields.

# Kinematics

# Unit 3

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

**Learning Competencies for Unit 3**

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

- Describe motion using vector analysis.
- Define the term reference frame.
- Explain the difference between average speed (velocities) and instantaneous speed (velocity).
- Solve numerical problems involving average velocity and instantaneous velocity.
- Define instantaneous acceleration.
- Solve problems involving average and instantaneous acceleration.
- Solve quantitative and qualitative kinematics problems related to average and instantaneous velocity and acceleration.
- Derive equations of motion for uniformly accelerated motion.
- Apply equations of uniformly accelerated motion in solving problems.
- Draw graphs from the kinematics equations.
- Interpret s–t, v–t and a–t graphs.
- Solve numerical kinematics problems.
- Relate scientific concepts to issues in everyday life.
- Explain the science of kinematics underlying familiar facts, observations and related phenomena.
- Describe the conditions at which falling bodies attain their terminal velocity.
- Analyse and predict, in quantitative terms, and explain the motion of a projectile with respect to the horizontal and vertical components of its motion.
- Derive equations related to projectile motion.
- Apply equations to solve problems related projectile motion.
- Define centripetal force and centripetal acceleration.
- Identify that circular motion requires the application of a constant force directed toward the centre of the circle.
- Distinguish between uniform and non-uniform circular motion.
- Analyse the motion of a satellite.
- Identify that satellites are projectiles that orbit around the Earth.
- 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.
- Determine the relative velocities of bodies moving at an angle relative to each other.
- Use the relative velocity equation to convert from one measurement to the other in reference frames in relative motion.

## 3.1 Motion in a straight line

This section should fill approximately **10 periods** of teaching time.

### Learning Competencies

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

- Describe motion using vector analysis.
- Define the term reference frame.
- Explain the difference between average speed (velocities) and instantaneous speed (velocity).
- Solve numerical problems involving average velocity and instantaneous velocity.
- Define instantaneous acceleration.
- Solve problems involving average and instantaneous acceleration.
- Solve quantitative and qualitative kinematics problems related to average and instantaneous velocity and acceleration.
- Derive equations of motion for uniformly accelerated motion.
- Apply equations of uniformly accelerated motion in solving problems.
- Draw graphs from the kinematics equations.
- Interpret s–t, v–t and a–t graphs.
- Solve numerical kinematics problems.
- Relate scientific concepts to issues in everyday life.
- Explain the science of kinematics underlying familiar facts, observations and related phenomena.
- Describe the conditions at which falling bodies attain their terminal velocity.

### Starting off

Students will have covered many of the concepts introduced in the first half of this unit in Grade 9. As the students may well not have seen these concepts since Grade 9, there is comprehensive revision of them.

Check that students remember the four equations of motion on page 39 of the Students' Book.

## Activity 3.1: Answer

- Students A and B see student C coming from right, in front of them, then to left.
- Rest of class see student C coming towards them.
- No, different frame of reference.
- Depends on your requirements.
- Frame of reference affects viewpoint of observations.

## Activity 3.3: Answer

Discuss the definitions of average and instantaneous velocity with students.
Check that they understand that the instantaneous is not the same as average velocity and can have a very different value. If a body is moving at a constant velocity, then the instantaneous and average velocities will be the same.

## Activity 3.4: Answer

The student moving in non-straight line is accelerating because velocity changes when direction changes.

# Teaching notes

### *Frame of reference*

Go through the Indian story of the seven blind men and the elephant. Ask students to discuss this story in small groups and its implications for science. Ask groups of students to report back to the rest of the class.

Start by carrying out Activity 3.1 as a whole class. If necessary prompt students that they are working from different frames of reference and that this accounts for the differences in the observation. If necessary prompt students to the conclusion that when measuring vector quantities, we need to measure them against a frame of reference and this means that we can understand the vectors giving displacement, velocity, etc. independently of the position of the observer.

Show students a simple coordinate grid with a couple of points marked on it. Ask them to give the coordinates of the two points. How do we know how to give coordinates? Check that students understand that we give the coordinates against an agreed frame of reference, the horizontal coordinate first and then the vertical coordinate.

Discuss the results of Activity 3.2 with students.

## Activity 3.2: Answer

Ensure that students understand that there are four possible positions for the body, as shown in Figure 3.1. A better way of expressing it is in the form (8.67, 5), which can be worked out using trigonometry.

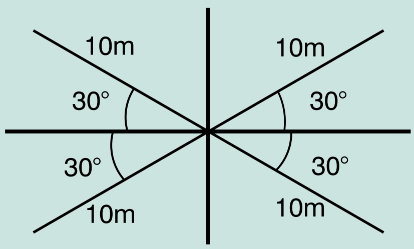



*Figure 3.1 Four possible positions of a displacement of 10 m at 30° to the horizontal.*

### *Average and instantaneous velocity*

Remind students what they learned in Grade 9 on average and instantaneous velocity – average velocity is the velocity over a certain period of time, instantaneous velocity is the velocity at one instant in time and they will only be the same if the body is moving uniformly.

Discuss the results of Activity 3.3 with the students.

Go through the first worked example. Emphasise the importance of drawing a sketch before doing the calculations.

### *Average and instantaneous acceleration*

Discuss the definitions of average and instantaneous acceleration with the students and then carry out Activity 3.4. Students can report back the results of their discussions to the rest of the class. Students may well come up with the idea that if an object is moving in a circle then it is accelerating because it is changing direction. If students do not, remind them that velocity is a vector and prompt them to come up with this.

### *Motion with constant acceleration*

Ask students to discuss the velocities and accelerations in the table on page 43 of the Students' Book. Ask them to report back to the rest of the class. Check that they have concluded that when an object is speeding up, the velocity and acceleration have the same signs; when they have opposite signs, the object is slowing down. Take them through the various scenarios, e.g. when an object is slowing down to zero, the signs will then become the same again and the object will be accelerating.

Emphasise that negative acceleration does not necessarily mean slowing down, and positive acceleration does not necessarily mean speeding up.

Ask students to carry out Activity 3.5 – you will need a ramp, car and ticker tape timer (or similar) for each group. Use as long a ramp as possible, with a fairly gentle slope – this will give slower speeds. This could also be carried out as a class activity if you do not have enough apparatus.

Ask students to plan the activity. What will they change? What will they keep the same? Students then write a report of the activity using the writing frame in Unit 1.

Guide students through drawing a line at parallel to the curve of a displacement–time graph (a tangent, but you don't need to mention this) (Figure 3.7 in the Students' Book). Students could carry this out on the displacement–time graphs they have drawn for Activity 3.5. Do they get the same results for the velocity?

Go through Worked example 3.3 with the class. Ensure that they take the correct approach to problem solving, by selecting the correct equation, rearranging the equation to make the unknown the subject and then substituting the values into the equation to find the unknown. Also encourage students to work out the dimensions of their answer by putting the dimensions of the different quantities into the equation and seeing what dimensions they end up with. Are these the dimensions they expected?

### *Freely falling bodies*

Explain to students what the forces are on a freely falling body. Introduce the effects of air resistance. Show students a free-body diagram and explain what it shows.

Ask students in small groups to carry out Activity 3.6. Ask the groups to report back to the rest of the class. Alternatively this could be a class demonstration. Ask them what they think will happen. Why do they think this?

Go through Worked example 3.3 with the class.

Activity 3.7 could be messy, and you may wish to carry this out as a demonstration. It is recommended that students drop their cups into a bucket or basin. Use a knife to punch two holes on opposite sites of a plastic cup near the bottom. Fill with water and drop from a height of at least 2 metres.

Go through Galileo's thought experiment with the students – discuss the concept of thought experiments and their uses.

**Activity 3.5: Answer**

Students' own results.

**Activity 3.6: Answer**

Students should conclude that both objects hit the floor at the same time.

**Activity 3.7: Answer**

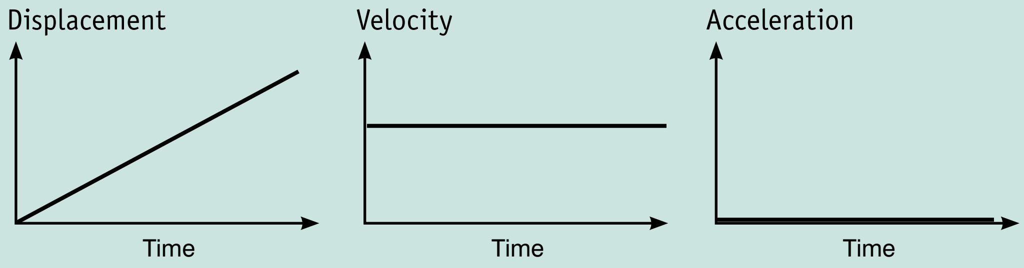
Ensure that the students understand that when the cup is falling, no water comes out of the cup because both of them are being accelerated at the same rate and the water exerts no weight on the cup.

### *Graphical presentation of motion*

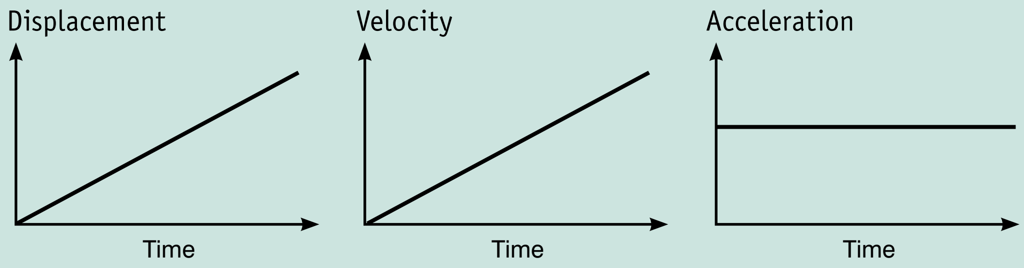
Work through the types of graphs of motion with the students – they will have come across them before and you may just need to revise them. Go through the worked examples and ask students to do Activity 3.8.

**Activity 3.8: Answer**

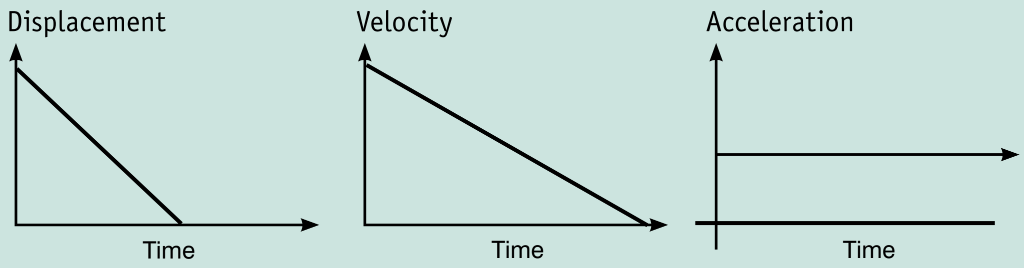
a) Bus




b) Car




c) Car



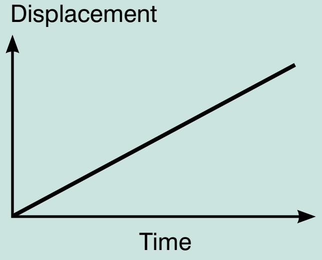

Ask the students to do Activity 3.9. Students often confuse a graph of the motion of an object with a graph showing the trajectory of an object – this activity should help the students to show the differences between them. To help break the habit of associating the path of the motion with the graph of the motion, ask the students to compare distance–time graphs with similar graphs that represent entirely different situations.

**Activity 3.9: Answer**

a) speed = $\frac{\text{distance}}{\text{time}}$ speed × time = displacement

| Time (s) | 0 | 0.5 | 1.5 | 2.0 | 2.5 | 3.0 |
|---|---|---|---|---|---|---|
| Displacement (m) | 0 | 10 | 30 | 40 | 50 | 60 |

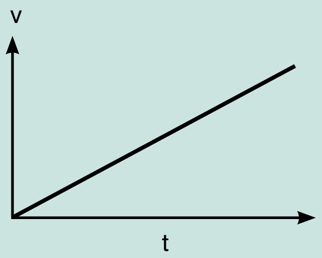
Draw a graph using these figures
(0, 0) (0.5, 10) (1.5, 30) (2.0, 40) (2.5, 50) (3.0, 60)



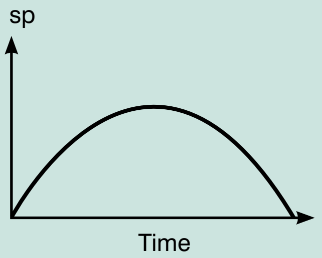

b) v = u + at
u = 0 a = 9.81 t = t

| V (m/s) | 0 | 4.91 | 9.81 | 14.72 | 19.62 | 24.5 | 24.43 |
|---|---|---|---|---|---|---|---|
| t (s) | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 |

Draw a graph using these figures
(0, 0) (0.5, 4.9) (1, 9.8) (1.5, 14.7)
(2, 19.6) (2.5, 24.5) (3, 24.4)




c) Di




Ask the students to do Activity 3.10 – they made need some practice to be able to do the movement without pausing.

**Activity 3.10: Answer**

Students' own results.

| **SA = starter activity MA = main activity CA = concluding activity** | |
|---|---|
| **Frame of reference** | |
| **SA** | Discussion activity on page 40 of Students' Book in small groups. |
| **MA** | Activity 3.1 in small groups. |
| **CA** | With a partner, summarise the learning from this lesson. |
| **Average and instantaneous velocity** | |
| **SA** | Activity 3.2 with a partner. |
| **MA** | Activity 3.3 in a small group. |
| **CA** | Worked example 3.1 with a partner without given solution. Feed back ideas. |
| **Average and instantaneous acceleration** | |
| **SA** | With a partner, write a definition of acceleration. Feed back ideas. |
| **MA** | Activity 3.4 in a small group. |
| **CA** | With a partner, list examples of average and instantaneous acceleration. Feed back ideas. |

| Motion with constant acceleration | |
|---|---|
| SA | Discussion activity on page 43 of Students' Book in small groups. |
| MA | Activity 3.5 (first two bullet points) in small groups. |
| CA | Report on Activity 3.5 with a partner. |
| **Freely falling bodies (1)** | |
| SA | With a partner, write a description of gravity. Feed back ideas. |
| MA | Activity 3.6 in a small group. |
| CA | Worked example 3.3 with a partner without given solution. Feed back ideas. |
| **Freely falling bodies (2)** | |
| SA | With a partner, write down what you learnt about freely falling bodies in the last lesson. Feed back ideas. |
| MA | Activity 3.7 with a partner. |
| CA | Feed back ideas for the explanation of Activity 3.7. |
| **Graphical representation of motion (1)** | |
| SA | With a partner, write an alternative interpretation of Figure 3.10. Feed back ideas. |
| MA | Activity 3.8 with a partner. |
| CA | Worked example 3.5 with a partner without given solution. Feed back ideas. |
| **Graphical representation of motion (2)** | |
| SA | Why does the area under a velocity–time graph represent distance? Discuss this question with a partner and feed back ideas. |
| MA | Activity 3.9 with a partner. |
| CA | Feed back on similarities and differences between graphs in activity. |
| **Graphical representation of motion (3)** | |
| SA | Worked example 3.8 with a partner without given solution. Feed back ideas. |
| MA | Activity 3.10 with a partner. |
| CA | Feed back on activity. |
| **Summary of learning** | |
| SA | With a partner, consider Figure 3.18. Draw a velocity–time graph for the plane as it takes off. Feed back ideas. |
| MA | With a partner, make a spidergram to summarise this topic. |
| CA | Review questions to be tackled with a partner. |

## Activities

- Discuss the story of the seven blind men and the elephant.
- Different frames of reference.
- Expressing a vector uniquely.
- Average and instantaneous velocities.
- Average and instantaneous accelerations.
- Difference accelerations and velocities.

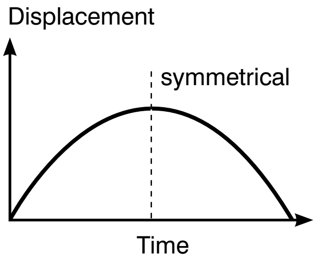
- Finding the acceleration of a moving object.
- Demonstrating all objects fall at the velocity.
- Falling cup with holes in it.
- Drawing graphs of motion.
- Acting out graphs of motion.

## Where next?

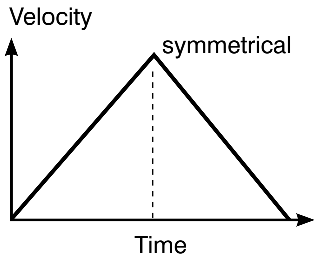
Many of the concepts covered here will be used later on in Grade 11.

## Answers to review questions

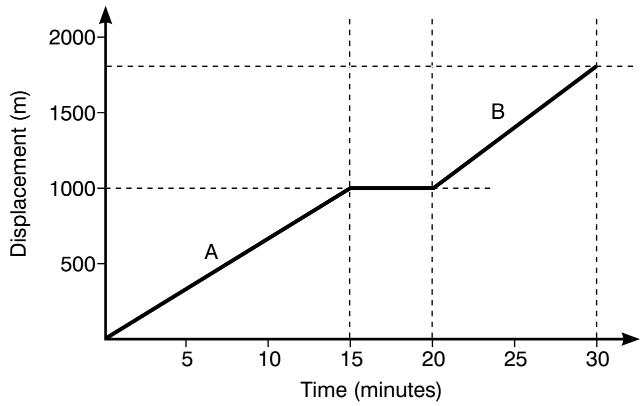
1. 75 km/h north
2. (33.3, –16.7) km/h or 37.3 km/h at an angle of 27° South of East.
3. (–4.64, 0.89) m/s or 4.72 m/s at an angle of 11° North of West.
4. (0.81, 0.13) m/s or 0.82 m/s at an angle 81° North of East (or 9° East of North).
5. 36 m
6. a) 2.0 m/s$^2$
   b) 24 m
7. 1.3 km
8. Thinking distance = 12.6 m, braking distance = 35.2 m, so 17.8 m past the stop line.
9. a) 30 m/s
   b) 15 m/s
   c) 45 m
   d) It is assumed that the time for the sound of the splash to reach the listener is negligible.
10. a) 11.5 m
    b) 1.53 s
11. a)




b)



12. a)



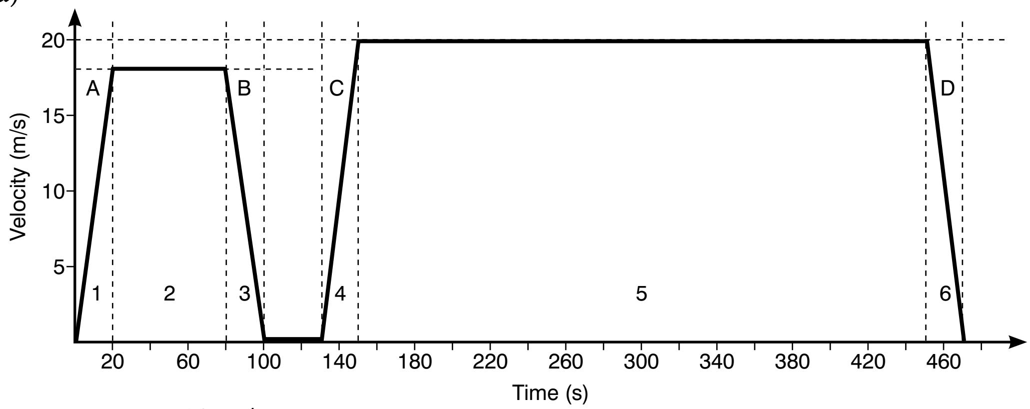

b) $\dfrac{1800 \text{ m}}{(30 \times 60)\text{s}} = \dfrac{1800}{1800} = 1 \text{ m/s}$

c) In section A, she was walking at $\dfrac{1000}{(15 \times 60)} = \dfrac{1000}{900} = 1.11 \text{ m/s}$

In section B, she was walking at $\dfrac{800}{(10 \times 60)} = \dfrac{800}{600} = 1.33 \text{ m/s}$

She was walking fastest in section B.

13. a)




b) Section A: $\dfrac{18 \text{ m/s}}{20 \text{ s}} = 0.9 \text{ m/s}^2$

Section B: $\dfrac{18 \text{ m/s}}{20 \text{ s}} = 0.9 \text{ m/s}^2$

Section C: $\dfrac{20 \text{ m/s}}{25 \text{ s}} = 0.8 \text{ m/s}^2$

Section D: $\dfrac{20 \text{ m/s}}{20 \text{ s}} = 1 \text{ m/s}^2$

Acceleration greatest between 450 s and 470 s.

c) Distance = area under graph.

$\Delta$ 1 = 10 × 18 = 180 m

☐ 2 = 18 × 60 = 1080 m

$\Delta$ 3 = 10 × 18 = 180 m

$\Delta$ 4 = 12.5 × 20 = 250 m

☐ 5 = 300 × 20 = 6000 m

$\Delta$ 6 = 20 × 10 = 200 m

Total distance = 7890 m

= 7.89 km

## 3.2 Motion in a plane

This section should fill approximately **10 periods** of teaching time.

### Learning Competencies

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

- Analyse and predict, in quantitative terms, and explain the motion of a projectile with respect to the horizontal and vertical components of its motion.
- Derive equations related to projectile motion.
- Apply equations to solve problems related projectile motion.
- Define centripetal force and centripetal acceleration.
- Identify that circular motion requires the application of a constant force directed toward the centre of the circle.
- Distinguish between uniform and non-uniform circular motion.
- Analyse the motion of a satellite.
- Identify that satellites are projectiles that orbit around the Earth.
- 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.
- Determine the relative velocities of bodies moving at an angle relative to each other.
- Use the relative velocity equation to convert from one measurement to the other in reference frames in relative motion.

## Teaching notes

### *Projectile motion*

Students covered projectile motion in one dimension in Grade 10. This section extends the coverage to two dimensions and applies their knowledge of vectors which they covered in Unit 2.

Check that the students understand what a projectile is. If something is powered (has a means of applying a driving force), e.g. an aeroplane, it is not a projectile. An aeroplane can become a projectile if it loses the driving force.

Ask the students to carry out Activity 3.11. Check that they understand that this shows that the horizontal and vertical components of motion are independent of each other.

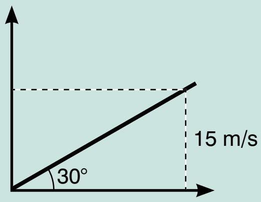
**Activity 3.11: Answer**

Students' own results.

Go through Worked example 3.9 on page 53 of the Students' Book with students. You could ask them to derive the general equations for maximum height, time of flight and range and then compare their equations with the ones in the Students' Book.

Ask the students to do Activity 3.12. Like Activity 3.9, this activity should help students to avoid confusing a graph of the motion of an object with a graph showing the trajectory of an object.

## Activity 3.12: Answer




$V_{vert}$ = 15 sin 30°

= 7.5 m/s

$V_{hor}$ = 15 cos 30°

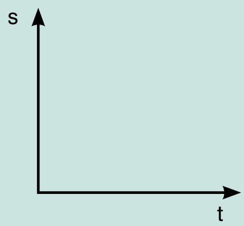
= 12.99 m/s

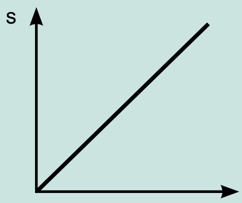
= 13 m/s (nearest unit)

a)

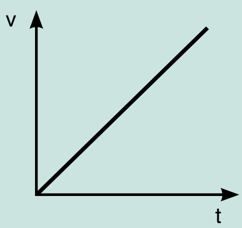
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s | 0 | 1.875 | 3.75 | 5.625 | 7.5 | 9.375 | 11.25 | 13.1 | 15.25 | 16.875 | 18.75 | 20.625 |
| t | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 |

Draw a graph using these figures
(0, 0) (0.5, 1.9) (1, 3.8) (1.5, 5.6) (2, 7.5) (2.5, 9.4)
(3, 11.3) (3.5, 13.1) (4, 15.3) (4.5, 16.8)

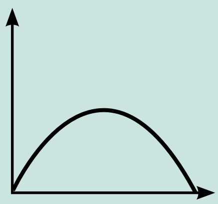



b)




c)



Activity 3.13 is about the monkey and hunter question. Ask the students to discuss this in small groups and then report back to the class.

## Activity 3.13: Answer

Guide them to conclude that the bullet drops below the aim line because of the effect of gravity on it. As the vertical acceleration on the monkey and bullet are the same, they will both drop by the same amount and so the bullet will hit the monkey.

This can also be shown using the equation $s = ut + \frac{1}{2}gt^2$. The bullet drops the distance $\frac{1}{2}gt^2$ below the straight line path of the gun to the monkey – this is also the distance that the monkey drops.

### *Uniform circular motion*

Go through the material on pages 55–57 of the Students' Book with the students. Check that students are clear what a radian is and that they understand how the equations are derived. Students should also understand that circular motion needs a constant (radial) force directed towards the centre of the circle.

Go through Worked example 3.10 and ask the students to do Question 6 on page 63.

**Activity 3.14: Answer**

Students should write a report of their experiment using the writing frame in Unit 1. Pool all the results from the class. What is the class average value for g? What uncertainty is attached to this value?

### *Motion in a vertical circle*

Demonstrate to the students how the forces on a body vary in vertical circular motion by drawing free-body diagrams for the body at different points on the circle.

Ask the students to carry out Activity 3.14.

Go through Worked example 3.11 and ask the students to do Question 7 on page 63.

### *Motion of a satellite*

The students came across Newton's law of universal gravitation in Grade 10. This section revises what they covered in Grade 10.

Discuss with the students why satellites are launched from sites close to the equator. It is because the satellite will already have considerable angular velocity from the rotation of the Earth when it is launched. At the equator you have considerable speed from the rotation of the Earth (about 1670 km/h). Satellites are also placed in orbits outside the Earth's atmosphere so that they are not subject to drag caused by the atmosphere. In fact, there is a very small amount of drag at the level of the orbits of the International Space Station and the Hubble Space Telescope – eventually they will fall to Earth if they are not pushed up again into a higher orbit.

Go through Worked example 3.14 and ask the students to do Question 8 on page 63.

### *Relative velocity*

The students covered relative velocity in one dimension in Grade 9. Revise relative velocities in one dimension and then ask the students to carry out Activity 3.15. Ask the students to discuss the activity in small groups and then report back to the class.

**Activity 3.15: Answer**

Discuss frames of reference here.

Go through Worked Example 3.15 – you may need to do some additional examples with the students. Students can then do Question 9 on page 63.

| **SA = starter activity MA = main activity CA = concluding activity** | |
|---|---|
| **Projectile motion (1)** | |
| **SA** | With a partner, write a definition of a projectile. Feed back ideas. |
| **MA** | Activity 3.11 with a partner. |
| **CA** | Feed back results of activity. |
| **Projectile motion (2)** | |
| **SA** | Worked example 3.9 with a partner without given solution. Feed back ideas. |
| **MA** | Activity 3.12 with a partner. |
| **CA** | Why can projectile motion be used to model the motion of a stone fired from a catapult and the motion of a frog leaping to catch a fly? Discuss with a partner and feed back ideas. |

| | |
|---|---|
| **Projectile motion (3)** | |
| **SA** | With a partner, summarise Students' Book page 54. |
| **MA** | Activity 3.13 with a partner. |
| **CA** | Feed back on activity. |
| **Uniform circular motion** | |
| **SA** | With a partner, write down all you can remember from previous grades about uniform circular motion. Feed back ideas. |
| **MA** | With a partner, make a poster to summarise Students' Book pages 55–56. |
| **CA** | Worked example 3.10 without given solution to be tackled with a partner. Feed back ideas. |
| **Radial force** | |
| **SA** | With a partner, discuss why there must be a resultant force on a body moving in a circle. Feed back ideas. |
| **MA** | In a small group, devise an experiment to demonstrate the radial force. |
| **CA** | Worked example 3.11 with a partner without given solution. Feed back ideas. |
| **Motion in a vertical circle** | |
| **SA** | Why does the speed of a body moving in a horizontal circle stay constant? Discuss with a partner and feed back ideas. |
| **MA** | With a partner, devise an experiment to demonstrate the variation in speed when a body moves in a vertical circle. |
| **CA** | Feed back results of experiment. |
| **Motion of a pendulum** | |
| **SA** | With a partner, list examples of uses of pendulums. |
| **MA** | Activity 3.14 in a small group. |
| **CA** | Report on activity with a partner. |
| **Motion of a satellite** | |
| **SA** | With a partner, write down Newton's law of universal gravitation. |
| **MA** | Discussion activity on page 60 of Students' Book in small groups. |
| **CA** | Worked example 3.14 with a partner without given solution. Feed back ideas. |
| **Relative velocity** | |
| **SA** | With a partner, write definition of 'frame of reference'. Feed back ideas. |
| **MA** | Activity 3.15 in a small group. |
| **CA** | How are frames of reference linked to Activity 3.15? Discuss with a partner and feed back ideas. |
| **Summary of learning** | |
| **SA** | With a partner, write down one thing you have learnt from this topic. Feed back ideas. |
| **MA** | Review questions to be tackled with a partner. |
| **CA** | End of unit questions to be tackled with a partner. |

## Activities

- Demonstrating independence of vertical and horizontal components of velocity.
- Drawing graphs to show the difference between graphs of motion and a graph of a trajectory.
- The monkey and hunter problem.
- Using a pendulum to find g.
- Demonstrating relative velocity.

## Where next?

Students will use many of the concepts and ideas covered here later in Grade 11.

## Answers to review questions

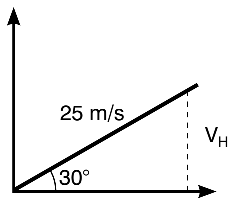
1. a) (70, 0) m/s

   b) 12.8 s

   c) (70, –125) m/s or 140 m/s at an angle of –60.7° to the horizontal.

   d), e) Students' own answer

2. a)




   $V_H = 25 \sin 30$
   $= 12.5$ m/s

   b) –12.5 m/s

   c) u = 12.5 m/s
   v = 0 at maximum height
   $a = 9.8$ m/s$^2$
   $s = v^2 = u^2 + 2\,as$
   $\frac{v^2 - u^2}{2\,a} = s$
   $\frac{-(12.5)^2}{-19.6} = 7.97$ m

   d) 1.3 s

   e) 2.6 s

   f) 25 cos 30°

   g) 21.7 m/s

   h) 56 m

3. a) (14.4, 10.8) m/s
   b) 18 m/s downwards at an angle of 37° to the horizontal.
   c) 32 m
   d) We have assumed that frame of reference is stationary.
4. a) (10.8, 14.4)
   b) Because the angle from the horizontal is bigger and so the vertical component of velocity is bigger.
   c) 32 m
5. Students' own answers
6. 2.3 m/s
7. a) $8\pi$ rad/s
   b) $40\pi$ rad
   c) $v = r\omega$
      $= 0.01 \times 40\pi$
      $= 0.4\pi$ rad/s
   d) $a = \frac{v^2}{r}$
      $= \frac{(0.4\pi)^2}{0.01}$
      $= 157.9$ rad/s$^2$
8. a) $1.2 \times 10^3$ N
   b) through friction between the tyres and the road
   c) $4.9 \times 10^3$ N
9. 13 m/s, 4.2 rad/s
10. a) 940 rad/s
    b) $1.8 \times 10^3$ N
    c) towards the centre
    d) turning of centrifuge
    e) $9.8 \times 10^{-2}$ N
11. 1.57 m/s
12. a) For the toy to move in a circle
    $F + mg = \frac{mv^2}{r}$
    When toy stops moving in circle, F = 0
    $v = \sqrt{(rg)}$
    $= \sqrt{(0.8 \times 9.81)}$
    $= \sqrt{(7.848)}$
    $= 2.8$ m/s
    Since velocity is 2 m/s <2.8 m/s, toy will not move in circle.

b) $T = \frac{mv^2}{r} + mg\cos\theta$

$r = 0.8$ m  $v = 3.5$ m/s  $m = 0.15$ kg

At top of circle, $\theta = \pi$ so

$T = \frac{0.15 \times (3.5)^2}{0.8} + 0.15 \times 9.81 \times \cos\pi$

$= 2.297 + 1.4715$

$= 0.8$ N

At bottom of circle, $\theta = 0$ so

$T = \frac{0.15 \times (3.5)^2}{0.8} + 0.15 \times 9.81 \times \cos\theta$

$= 2.297 + 1.4715$

$= 3.8$ N

At halfway point $\theta = \frac{\pi}{2}$ so

$T = \frac{0.15 \times (3.5)^2}{0.8} + 0.15 \times 9.81 \times \cos\frac{\pi}{2}$

$= 2.297 + 0$

$= 2.3$ N

13. a) Period = 24 hours = $24 \times 60 \times 60$ s = 86 400 s

$\frac{1}{\text{period}} = \frac{1}{86\ 400} = 1.157 \times 10^{-5}$ = frequency

$\theta = 2 \times \pi \times$ frequency $= 6.28 \times 1.157 \times 10^{-5} = 7.26 \times 10^{-5}$ as required

b) $g = \frac{-GM}{\sqrt{r}} = \frac{-6.67 \times 10^{-11} \times 6 \times 10^{24}}{\sqrt{6\ 400\ 000 + 42\ 000}} = 9.64 \text{ m s}^{-2}$

14. 1.4 hours. People would slide, rather than be thrown off.

15. 15 km/h away from A

16. a) 424 m/s

b) 45°

17. (−4, 2) or 4.5 m/s at angle of 63° to the current

## Answers to end of unit questions

1. **frame of reference** a rigid framework or coordinate system that can be used to measure the motion of an object

   **average velocity** difference in displacement between two points divided by the time taken to travel between the two points

   **instantaneous velocity** velocity of an object at a point

   **average acceleration** change in velocity divided by the time taken for the change to happen

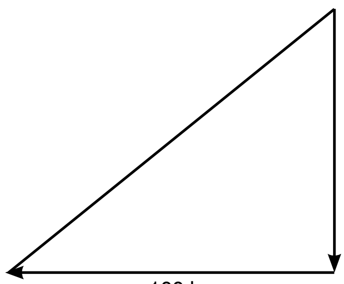
   **instantaneous acceleration** acceleration of an object at a point

   **free body diagram** a simplified diagram of an object showing all the forces acting on it. It can also show the size and direction of the forces

   **projectile** an object that is propelled through space by a force. The action of the force ceases after the projectile is launched

**trajectory** the path a moving object follows through space
**maximum height** the vertical distance to the highest point reached by a projectile and the point at which the projectile is momentarily at rest
**range** the horizontal distance travelled by a projectile
**time of flight** the duration of a projectile's motion from launch to landing
**uniform circular motion** when a body is moving at a constant speed in a circle
**radial force** the force acting on a body moving in a circle which is directed towards the centre of the circle
**tangential acceleration** when a particle is moving in circular motion, the component of a particle's acceleration at a tangent to the circle
**radial acceleration** acceleration towards the centre of the circle when a particle is moving in a circle
**centripetal force** the force acting on a body moving in a circle which is directed towards the centre of the circle
**absolute velocity** velocity observed from a stationary frame of reference
**relative velocity** the vector difference between the velocities of two objects

2. When a ball is dropped from a height of 2 m, it will accelerate due to gravity. When it hits the ground it will rebound to a height less than 2 m, and repeat the process until it has no more kinetic energy.
3. Average velocity is the total displacement in a specified direction divided by the total time taken to travel the displacement. Instantaneous velocity is velocity at a point.
4. Draw a sketch.




The total displacement is (110,80) km.
The total time taken in 2 + 3 = 5 hours.
The average velocity of the bus is $\left(\frac{100}{5}, \frac{80}{5}\right)$ km/h
$= (20, 16)$ km/h

5. a) Initial velocity $u = 50$ km/h
$= \frac{5000\text{m}}{3600\text{s}}$
$= 1.39$ m/s

Final velocity $v = 0$ m/s
$t = (1.5 + 5) = 6.5$s

Use $s = \frac{1}{2}(u + v)t$
$= \frac{1}{2}(1.39 + 0) \times 6.5$
$= 4.5$ m

Car stops in time.

b) $u = 1.39$ m/s

$v = 0$ m/s

$t = (2.5 + 5) = 7.5$ s

Use $s = \frac{1}{2}(u + v)t$

$= \frac{1}{2}(1.39) \times 7.5$

$= 5.21$ m

Car does not stop in time.

c) $u = 64$ km/h

$= \frac{6400}{3600s}$

$= 1.78$ m/s

$v = 0$ m/s

$t = 6.5$s

Use $s = \frac{1}{2}(v + u)t$

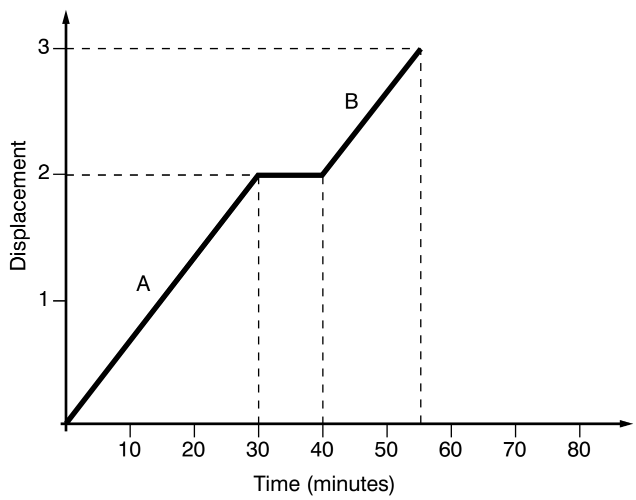
$= \frac{1}{2} \times 1.78 \times 6.5$

$= 5.79$ m

Car does not stop in time.

6. Unless told otherwise, you should assume that air resistance has a negligible effect on the progress of the falling body.

7. a)




b) $\text{velocity} = \frac{\text{distance}}{\text{time}}$

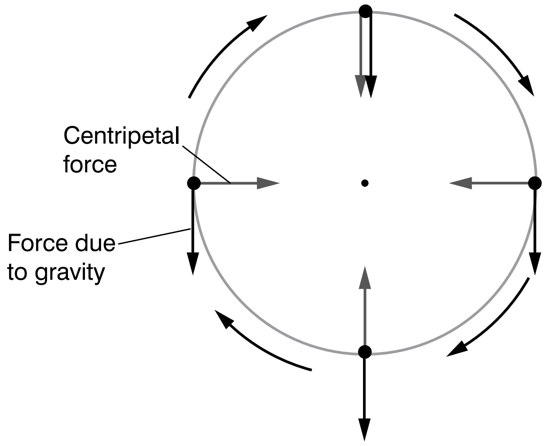
$= \frac{3 \text{ km}}{55 \text{ minutes}}$

$= \frac{3000 \text{ m}}{55 \times 60 \text{ s}}$

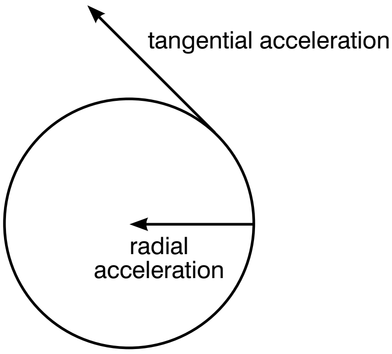
$= 0.91$ m/s

8. In uniform horizontal circular motion, there is acceleration because the velocity is constantly changing. This means that there is a resultant radial force which acts towards the centre of the circle.

9. The forces on a body moving in a horizontal circle vary as shown in the diagram.




10. Radial acceleration is the acceleration towards the centre of the circle and tangential acceleration is the acceleration at a tangent to the circle.




11. Relative velocity is the velocity measured from a given frame of reference.

# Dynamics

## Unit 4

**Learning Competencies for Unit 4**

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

- Identify the four basic forces in nature.
- Define and describe the concepts and units related to force.
- Define the term dynamics.
- Define and describe the concepts and units related to coefficients of friction.
- Use the laws of dynamics in solving problems.
- Interpret Newton's laws and apply these to moving objects.
- Explain the conditions associated with the movement of objects at constant velocity.
- Solve dynamics problems involving friction.
- State Newton's universal law of gravitation.
- Analyse, in qualitative and quantitative terms, the various forces acting on an object in a variety of situations, and describe the resulting motion of the object.
- Define, and when appropriate give examples of, such concepts as gravity and Newton's law of universal gravitation.
- Describe how Newton's laws of motion and his law of universal gravitation explain the phenomenon of gravity and necessary conditions of 'weightlessness'.
- Describe the terms momentum and impulse.
- State the law of conservation of linear momentum.
- Discover the relationship between impulse and momentum, according to Newton's second law.
- Apply quantitatively the law of conservation of linear momentum.
- Distinguish between elastic and inelastic collisions.
- Describe head-on collisions.
- Describe glancing collisions.
- Define and describe the concepts and units related to torque.
- Describe centre of mass of a body.
- Determine the position of centre of mass of a body.
- Describe explosions and rocket propulsion in relation to momentum conservation.
- Interpret Newton's laws and apply these to objects undergoing uniform circular motion.
- Solve dynamics problems involving friction.

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

This section should fill approximately **1 period** of teaching time.

## 4.1 The force concept

### Learning Competencies

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

- Identify the four basic forces in nature.
- Define and describe the concepts and units related to force.

### Starting off

Students will have covered many of the concepts introduced in the first half of this unit in Grade 9. As students may well not have seen these concepts since Grade 9, there is comprehensive revision of them in this unit. Also the students will be applying the principles using vectors, which they will not have done before.

### Teaching notes

Revise what the students know about forces. Check that they understand that force is a vector. Go through Worked example 4.1. Emphasise the importance of drawing a sketch of the forces involved. It is a good habit to get into and will help in the analysis of problems when the combination of forces becomes more complicated.

Check that students understand that very often we need to resolve forces into horizontal and vertical components as we need to analyse the forces in a particular direction. This can be demonstrated using Activity 4.1. Link this to the study of vectors and what the students have learned about vectors so far.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Forces** | |
| **SA** | With a partner, write a definition of force. Feed back ideas. |
| **MA** | Discussion activity on page 67 of Students' Book in small group. |
| **CA** | Review questions to be tackled with a partner. |

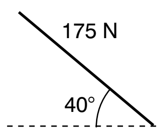
### Activity

- Force used to move a box.

### Where next?

Being able to resolve forces into components and deciding which component to use is key to solving problems in the rest of this unit.

### Answers to review questions

1. 70.7 N
2. a) 

   b) 112.5 N

## 4.2 Basic laws of dynamics

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

### Learning Competencies

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

- Define, and when appropriate give examples of, such concepts as gravity and Newton's law of universal gravitation.
- Describe how Newton's laws of motion and his law of universal gravitation explain the phenomenon of gravity and necessary conditions of 'weightlessness'.
- Define the term dynamics.
- Define and describe the concepts and units related to coefficients of friction.
- Use the laws of dynamics in solving problems.
- Interpret Newton's laws and apply these to moving objects.
- Explain the conditions associated with the movement of objects at constant velocity.
- Solve dynamics problems involving friction.
- State Newton's universal law of gravitation.
- Analyse, in qualitative and quantitative terms, the various forces acting on an object in a variety of situations, and describe the resulting motion of the object.

### Starting off

Students will have been introduced to Newton's laws of motion in Grade 9.

## Teaching notes

***Newton's laws of motion***

Revise and recap with the students Newton's laws of motion. If possible, demonstrate the laws of motion using an air track and two students on trolleys as described in the Students' Book. You could also demonstrate them using a powder track timer or tickertape timer. If these are not available, you can also demonstrate them using a steel ball rolling across a smooth table – the friction is low enough to demonstrate the laws adequately.

Students can discuss other ways they can think of to demonstrate Newton's laws using the trolleys shown in Figure 4.5 on page 70 of the Students' Book.

Discuss with the students how vectors can be used in Newton's second law. Students can also carry out the discussion in the Students' Book. Then go through Worked example 4.2. You may need to check that the students understand how to find the components of the force and which one they need to use in this example.

**Activity 4.1: Answer**

Students' own results.

### *Friction*

Students will have come across the concept of friction earlier in their studies. Revise what students understand about it. Introduce the concepts of static friction and kinetic friction.

You might like to demonstrate this by attaching a newtonmeter to a block on a horizontal ramp and slowly increasing the force until the block starts to slide. Introduce the concept of limiting equilibrium.

Go through Worked example 4.3 on page 71 of the Students' Book. Emphasise that when working out the normal force, you need to calculate the force that is perpendicular to the surface that the object is sitting on. This will usually involve a component of the weight of the object. Check that the students know which component of the weight of the object they need to calculate – some students may get confused and try to work out the component of the object's weight that is parallel to the surface the object is resting on.

The students can then carry out Activity 4.2.

Discuss kinetic friction with the students and go through Worked example 4.4 on page 72 of the Students' Book. Students can then find the coefficient of kinetic friction in Activity 4.3. You could also discuss with students whether they could use this method to find the coefficient of static friction. What difficulties can they see? Which method is easier?

Students can then carry out Activity 4.4. Discuss students' conclusions as a class.

Students could then carry out the discussion on Galileo's thought experiment in small groups or as a whole class. Students can also carry out the project detailed in the Students' book on the importance of friction in everyday life. This could be done as a presentation to the class, or a written report.

**Activity 4.2: Answer**

Students' own results.

**Activity 4.3: Answer**

Students' own results.

**Activity 4.4: Answer**

Students' own results.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Forces** | |
| **SA** | With a partner, write a definition of force. Feed back ideas. |
| **MA** | Discussion activity on page 67 of Students' Book in small group. |
| **CA** | Review questions to be tackled with a partner. |
| **Newton's laws of motion** | |
| **SA** | With a partner, write down Newton's laws of motion. Feed back ideas. |
| **MA** | Activity 4.1 in a small group. |
| **CA** | Discussion activities on page 70 of Students' Book in small groups. |
| **Friction (1)** | |
| **SA** | With a partner, write down what you understand by term 'friction'. Feed back ideas. |
| **MA** | Activity 4.2 in small groups. |
| **CA** | With a partner, begin to prepare presentation on friction (see Students' Book page 71). This should be completed for the beginning of next lesson. |

| Friction (2) | |
|---|---|
| **SA** | Presentations on friction. |
| **MA** | Activity 4.3 in small group.<br>Activity 4.4 in small group. |
| **CA** | Discussion activity on page 73 of Students' Book in small group.<br>Review questions to be tackled with a partner. |

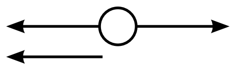
## Activities

- Demonstration of Newton's laws.
- Consideration of forces as vectors.
- Finding the coefficient of static friction between two surfaces.
- Finding the coefficient of kinetic friction between two surfaces.
- Force needed to move a block on a ramp at different angles.
- Galileo's thought experiment on motion.
- Project on importance of friction in everyday life.

## Where next?

Students will apply what they have learned here later in the unit.

## Answers to review questions

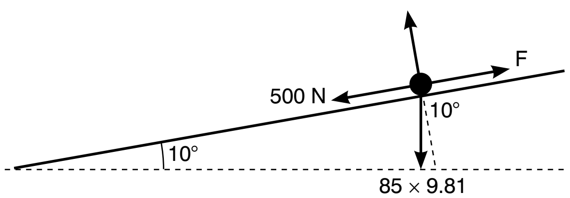
1. a) 500 N  1 kN

Forces unbalanced so girl will move in direction of 1 kN force.

Netforce 500 $= 85 \times a$

$a = 5.88$ m/s$^2$

b)




To move up hill, F must be greater than

$500 + 85 \times 9.81 \times \sin 10 =$

$500 + 144.8$ N $= 644.8$ N

Resistive force now 644.8

Assuming girl still providing 1000 N

net force $= 355.2$

$= 85 \times a$

$a = \dfrac{355.2}{85}$

$= 4.18$ m/s$^2$

2. Resultant force:

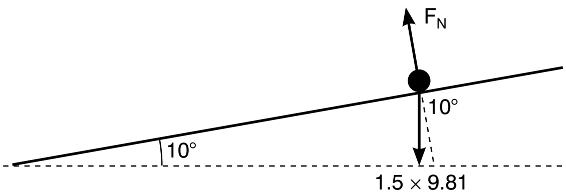
   $25\text{ kN} - (10\text{ kN} = 8 \times 10^3 \times 9.81 \text{ x } \sin 15)$

   $25 \times 10^3 - (10 \times 10^3 + 20\,312)$

   $25 \times 10^3 - 30\,312 =$

   $- 5.312\text{ N}$

   Truck will have resultant force acting down hill.

3. 

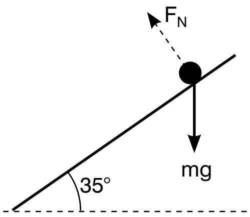

   $F_s = \mu_s F_N$

   $F_N = 1.5 \times 9.81 \times \cos 10°$

   $= 14.49\text{ N}$

   $F_s = 0.2 \times 14.49$

   $= 2.898\text{ N}$

4. 


   $F_N = mg \cos 35$

   In limiting equilibrium

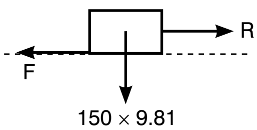
   $F_s = \mu_s F_N$

   $\mu_s F_N = mg \sin 35$

   $\mu_s mg \cos 35 = mg \sin 35$

   $\mu_s = \dfrac{\sin 35}{\cos 35}$

   $= 0.7$

5. a) 


   $F = \mu_s F_N$

   $= 0.45 \times 150 \times 9.81$

   $= 662.2\text{ N}$

   To start table moving R > F

   so R > 662.2 N

   R = 66.3 N

b) When table moving

$F_k = \mu_k F_N$

$= 0.4 \times 150 \times 9.81$

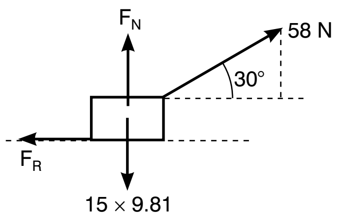
$= 588.6$ N

$R > F_k$

$R > 588.6$ N

$R = 589$ N

6.




$F_N = 15 \times 9.81$

$= 147.15$ N

For box to move $F_R \leq 58 \cos 30°$

$F_R \leq 50.22$ N

$F_R = \mu_k F_N$

$50.22 = \mu_k \times 147.15$

$\frac{50.22}{147.15} = \mu_k$

$= 0.34$

7. There are no forces acting on it.
8. 0.854 m/s$^2$ at angle 5° to horizontal (0.854, 0.074) m/s$^2$
9. (0.29, 0.05) m/s$^2$

## 4.3 Law of conservation of linear momentum and its applications

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

### Learning Competencies

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

- Describe the terms momentum and impulse.
- State the law of conservation of linear momentum.
- Discover the relationship between impulse and momentum, according to Newton's second law.
- Apply quantitatively the law of conservation of linear momentum.

### Starting off

Students learned about momentum in Grade 9.

## Activity 4.5: Answer

If necessary, assist students to the conclusion that the horizontal component of momentum stays constant while the vertical component changes because of the vertical acceleration due to gravity.

## Activity 4.6: Answer

$P = mv$

$kgms^{-1}$ $kg \times m^{s-1}$

## Activity 4.7: Answer

Students' own results.

## Activity 4.8: Answer

Momentum of student on trolley is conserved.

Momentum transferred from ball to student.

## Activity 4.9: Answer

First car:
Impulse
$= F\Delta t$
$= 75 \times \left[\frac{20}{0.01}\right]\left[0.01\right]$
$= 1500$ Ns

Second car:
Impulse
$= F\Delta t$
$= 75 \times 0.2 \times 0.1$
$= 1500$ Ns

# Teaching notes

### *Law of conservation of linear momentum*

Revise the concept of momentum with the students. Introduce the concept of momentum as a vector, as described in the Students' Book.

Ask students to carry out Activity 4.5. Students should apply what they learnt about projectiles in Unit 3 and should be able to describe the motion of the ball and its momentum.

Discuss the concept of the conservation of linear momentum with the students. How does this relate to Newton's laws of motion? If appropriate, demonstrate the conservation of linear moment using the demonstration described in the Students' Book.

Go through Worked example 4.6 on page 77 of the Students' Book – the new concept here is applying the law in two dimensions rather than one. Emphasise the importance of drawing a diagram to show what is going on and of choosing and using an appropriate frame of reference.

Ask students to carry out Activities 4.7 and 4.8 to demonstrate the conservation of linear momentum. These activities could also be carried out as a class activity. Help the students, if necessary, to apply the law to what they are doing.

Discuss with the students how this principle can also be used to explain the phenomenon of gravity and what the conditions of 'weightlessness' are. Students may have problems understanding that astronauts are constantly falling when orbiting the Earth and that this is why they experience 'weightlessness'. You could also discuss why the Earth does not appear to move – it does, but its movement is very very small because the mass of the Earth is so much bigger than the mass of an astronaut.

### *Impulse*

Revise what students know about impulses from Grade 9. Ask students to discuss the two equations shown. If necessary, lead them towards the conclusion that they are Newton's second law expressed in a different way.

Go through Worked example 4.8 on page 79 of the Students' Book with the students. Then go through the examples of applications of the law of conservation of linear momentum – check that the students understand how it is applied in each case.

Ask the students to do Activity 4.9. Discuss their conclusions as a class. The students should conclude that safety features work by reducing the speed of momentum change – by changing the momentum over a longer time, the forces involved are greatly reduced.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Momentum** | |
| **SA** | With a partner, write a definition of 'momentum'. Feed back ideas. |
| **MA** | Activity 4.5 with a partner. |
| **CA** | Activity 4.6 with a partner. |
| **Law of conservation of linear momentum (1)** | |
| **SA** | Why can you use Newton's third law to predict the motion of one mass pushing another mass if you know the velocity of the other mass? Discuss with a partner and feed back ideas. |
| **MA** | In a small group, demonstrate the conservation of linear momentum as shown in Figure 4.16. |
| **CA** | Activity 4.7 in a small group. |
| **Law of conservation of linear momentum (2)** | |
| **SA** | With a partner, write down the law of conservation of linear momentum. Feed back ideas. |
| **MA** | Activity 4.8 in small groups. |
| **CA** | Worked example 4.7 with a partner without given solution. Feed back ideas. |
| **Impulse** | |
| **SA** | With a partner, write down what you can remember about impulse from Grade 9. Feed back ideas. |
| **MA** | Discussion activity on page 78 of Students' Book with a partner. |
| **CA** | Worked example 4.8 with a partner without given solution. Feed back ideas. |
| **Momentum and safety** | |
| **SA** | With a partner, discuss how seat belts and crumple zones work in terms of momentum. |
| **MA** | Activity 4.9 with a partner. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Momentum of a ball.
- Conservation of linear momentum.
- Link between impulse and Newton's second law.
- Impulse, crashes and safety features.

## Where next?

Students will apply these principles in the next section and also later in Grade 11.

## Answers to review questions

1. Intitial velocity $\begin{bmatrix} 4 \\ -9 \end{bmatrix}$ m/s

   Final velocity $\begin{bmatrix} 4 \\ 9 \end{bmatrix}$ m/s

   Impulse = change in momentum

Initial momentum = $4\begin{bmatrix}4\\-9\end{bmatrix} = \begin{bmatrix}16\\-36\end{bmatrix}$ kg m/s

Final momentum = $4\begin{bmatrix}4\\9\end{bmatrix} = \begin{bmatrix}16\\36\end{bmatrix}$ kg m/s

Change in momentum $\begin{bmatrix}16\\36\end{bmatrix} - \begin{bmatrix}16\\-36\end{bmatrix}$ kg m/s

$= \begin{bmatrix}0\\72\end{bmatrix}$ kg m/s

Impulse = $\begin{bmatrix}0\\72\end{bmatrix}$ kg m/s

Force = $\dfrac{\text{Impulse}}{\text{Time}}$

$= \begin{bmatrix}\frac{0}{15}\\ \frac{72}{15}\end{bmatrix}$ N

$= \begin{bmatrix}0\\48\end{bmatrix}$ N

2. a) Momentum = mass × velocity

= 0.2 × $\upsilon$

$\upsilon^2 = u^2 + 2as$

$= 0 + 2 \times 9.81 \times 2$

$= 39.24$

$\upsilon = \sqrt{39.24}$

$= 6.26$ m/s

Momentum = 0.2 × 6.26

= 1.252 kg m/s

b) Impulse = change of momentum

Initial momentum = 0

Final momentum = 1.252 kg m/s

Impulse = 1.252 kg m/s

c) Force = $\dfrac{\text{impulse}}{\text{time}}$

$= \dfrac{1.252}{0.05}$

= 25.04 N

3. Initial momentum: mass of bullet × velocity bullet

$= 0.01 \times \begin{bmatrix}200\\0\end{bmatrix}$

$= \begin{bmatrix}2\\0\end{bmatrix}$ kg m/s

Final momentum: mass of bullet + sand × velocity bullet + sand

$\begin{bmatrix}2\\0\end{bmatrix}$ = 0.01 + 9.99 × velocity + sand

$\begin{bmatrix}2\\0\end{bmatrix}$ = 10 × velocity bullet + sand

Velocity bullet + sand = $\begin{bmatrix}0.2\\0\end{bmatrix}$ m/s

4. Before collision momentum $= 2\begin{bmatrix}6\\-2\end{bmatrix} + 3\begin{bmatrix}10\\8\end{bmatrix}$

$$= \begin{bmatrix}12\\-4\end{bmatrix} + \begin{bmatrix}30\\24\end{bmatrix}$$

$$= \begin{bmatrix}42\\20\end{bmatrix}$$

After collision momentum $= 4\begin{bmatrix}42\\20\end{bmatrix} = 5\begin{bmatrix}\upsilon_x\\\upsilon_y\end{bmatrix}$

$$\upsilon_x = 42 \div 5 = 8.4 \text{ m/s}$$
$$\upsilon_y = 20 \div 5 = 4 \text{ m/s}$$

Combined velocity $\begin{bmatrix}8.4\\4\end{bmatrix}$

## 4.4 Elastic and inelastic collisions in one and two dimensions

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

### Learning Competencies

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

- Distinguish between elastic and inelastic collisions.
- Describe head-on collisions.
- Describe glancing collisions.

### Starting off

Students covered simple collisions in Grade 9. This section extends the coverage to two dimensions.

## Teaching notes

Revise what students know about collisions from Grade 9. Go through page 82 of the Students' Book to remind them of the differences between elastic and inelastic collisions.

Students can carry out Activity 4.10. You can then demonstrate their suggestions using an air track, if you have one available. You could also discuss the 'Did you know' box on this page. Discuss how much information about subatomic particles has been found from collisions of them. New particles have also been found by looking at the results of collisions to see if they match the prediction.

Go through Worked example 4.9 on page 83 of the Students' Book with the students. For further reinforcement, you could work out the angles relative to the horizontal that the balls are moving at before and after the collision.

Ask the students to carry out Activity 4.11. You may wish to carry this out as a class activity. Discuss the results of the activity as a class.

Ask the students to carry out Activity 4.12. The students will need to plan exactly how they are going to carry out this activity. You may need to help them to work out how they will do this. The students put a billiard ball at the top of a smooth ramp and let it go. They can calculate the velocity of the ball as it leaves the ramp using the component of the acceleration on the ball that is parallel to the slope of the ramp.

**Activity 4.10: Answer**

Students' own suggestions.

**Activity 4.11: Answer**

Students' own results.

**Activity 4.12: Answer**

Students' own results.

They aim the ball at a stationary ball and look at the velocities of the two balls after collision. The velocities of the balls can be measured by recording the time taken for the balls to travel a marked distance. The students will need to work in pairs to do this – each one measuring the time taken by one of the balls. They should also measure the angles of the paths of the balls.

They can then work out the momentum before and after the collision and see if the law of conservation of momentum is obeyed. Once they have made a series of measurements, can they also predict what will happen in another collision?

In the review questions you could also ask students to express the velocities in the form of magnitude and angle to the horizontal.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Elastic and inelastic collisions** | |
| SA | What is conserved in a collision? Discuss with a partner and feed back ideas. |
| MA | Activity 4.10 with a partner. |
| CA | What is the difference between an elastic and inelastic collision? Discuss with a partner and feed back ideas. |
| **Collisions and momentum** | |
| SA | With a partner, write down the forms of energy that kinetic energy from inelastic collisions might be transferred into. |
| MA | Activity 4.11 in a small group. |
| CA | Write a report on Activity 4.11 with a partner. |
| **Types of collisions** | |
| SA | With a partner, discuss the difference between a head–on and a glancing collision. Feed back ideas. |
| MA | Activity 4.12 in small groups. |
| CA | Review questions to be tackled with a partner. |

## Activities

- Demonstrating elastic and inelastic collisions on an air track.
- Trolley collisions.
- Billiard ball collisions.

## Where next?

The law of conservation of momentum will be extended to cover variable mass systems in Section 4.6.

## Answers to review questions

1. (–1.5, 0.25) m/s
2. (–20, 22.5) m/s
3. (3, –1) m/s

## 4.5 Centre of mass

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

### Learning Competencies

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

- Define and describe the concepts and units related to torque.
- Describe centre of mass of a body.
- Determine the position of centre of mass of a body.

### Starting off

This is a new topic for the students. The concepts of centre of mass and torque are introduced.

## Teaching notes

Go through the text on torque in the Students' Book. You could also demonstrate the turning action shown in Figure 4.26 on page 85 using a book on a desk. Students could try this out themselves.

Ask the students what they understand by the term centre of mass. Go through the text in the Students' Book, including Figure 4.27. You may need to explain clockwise and anticlockwise torque quite carefully. It may help to have some sort of balance or see-saw that you can use to demonstrate clockwise and anticlockwise torque. Then go through Worked example 4.11 on page 86 of the Students' Book. You may have to explain that for the purposes of these calculations we have to consider the bar connecting the two masses as having no mass – in practice it does have a mass, but this makes the calculations much more complicated. We are simplifying the calculation here so that we can understand the principle. Activity 4.13 may bring this out.

Ask the students to carry out Activity 4.13.

#### Activity 4.13: Answer

Taking clockwise and anticlockwise torque they should be able to predict where they need to place the other mass. If the mass used is not large, it will become clear that the distance they calculate is not exactly the distance they have to use because the ruler or whatever is used does have a mass, which does affect the calculations.

Then ask the students to carry out Activity 4.14.

#### Activity 4.14: Answer

You may need to help them realise that as long as the centre of mass is directly above a point inside the base that is in contact with the desk, the box will be stable. If the centre of mass is above a point that is outside the base, the box will fall over. Students should be able to see that there is a line along which the centre of mass lies.

Ask the students to carry out Activity 4.15. This builds on Activity 4.14.

**Activity 4.15: Answer**

Students find the centre of mass of a planar object that has uniform thickness, such as a piece of cardboard. The second half of the activity will help them to realise that a centre of mass does not need to be inside the object, but can also be outside it. You could also show students a cup or glass and ask them where they think its centre of mass is. You could then discuss the Did you know box with the students.

Activity 4.16 is a bit of fun!

**Activity 4.16: Answer**

This should help to highlight that the centre of mass for women is lower down than it is for men – women tend to have larger hips, which lowers the centre of mass, whereas men tend to have larger shoulders, which raises the centre of mass. When doing this activity, it means that in girls the centre of mass tends to be behind the knees, whereas in boys it tends to be in front of the knees. Girls should find it easier than boys to knock the object over.

Question 2 of the review questions involves setting up an equation and solving it for $x$.

| **SA = starter activity MA = main activity CA = concluding activity** | |
|---|---|
| **Torque** | |
| **SA** | With a partner, write a definition of torque. Feed back ideas. |
| **MA** | Activity 4.13 with a partner.<br>Activity 4.14 with a partner. |
| **CA** | Summarise the results of the activities with a partner. |
| **Finding centres of mass** | |
| **SA** | Worked example 4.11 with a partner without given solution. Feed back ideas. |
| **MA** | Activity 4.15 with a partner.<br>Activity 4.16 with a partner. |
| **CA** | Review questions to be tackled with a partner. |

## Activity

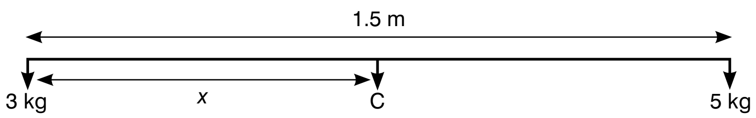
Balancing a see-saw using torque calculations.

- Centre of mass.

## Where next?

The students will return to torque in Unit 6.

## Answers to review questions

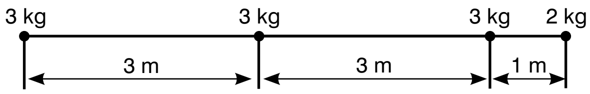
1. 9.375 cm from the centre, on the opposite side from the 250 g mass.
2. 8 cm from the 150 g mass, 12 cm from the 100 g mass.
3. 


Anticlockwise moment P = 3x

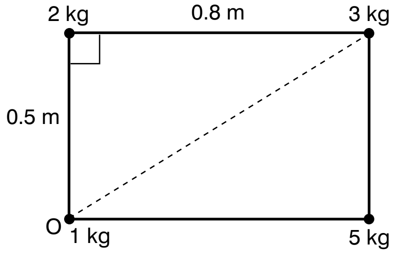
Clockwise moment = 5(1.5 – x)

$3x = 5(1.5 - x)$
$8x = 7.5$
$x = \frac{7.5}{8}$
$= 0.9375$ m

Distance is 0.9375 m

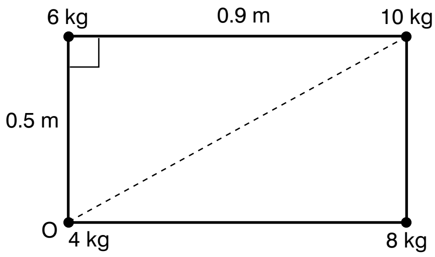
4. A 


$$x = \frac{3\times0 + 3\times3 + 3\times6 + 2\times7}{3 + 3 + 3 + 2}$$
$$= \frac{9 + 18 + 14}{11}$$
$$= \frac{41}{11} \text{ m}$$
$$= 3.73 \text{ m}$$

5. a) 


$$x = \frac{1\times0 + 0.5\times2 + 0.8\times5 + 0.943\times3}{1 + 2 + 3 + 5}$$
$$= \frac{1 + 4 + 2.829}{11}$$
$$= 0.712 \text{ m}$$

b)

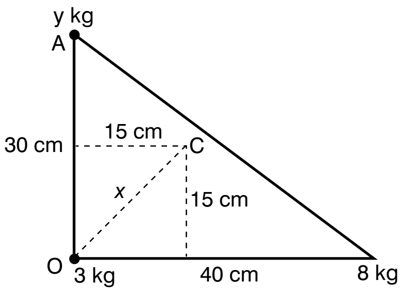



$$x = \frac{4\times0 + 0.5\times6 + 0.9\times8 + 1.03\times10}{4 + 6 + 10 + 8}$$

$$= \frac{20.5}{28}$$

$$= 0.732 \text{ m}$$

6.




With respect to corner O:

$$x = \frac{0\times3 + y\times0.3 + 8\times0.4}{3 + y + 8}$$

$$= \frac{0.3y + 3.2}{11 + y}$$

$$= 0.732 \text{ m}$$

$$x^2 = 0.15^2 + 0.15^2$$

$$= 0.045$$

$$= 0.212$$

$$0.212 = \frac{0.3y + 3.2}{11 + y}$$

$$0.212\,(11 + y) = 0.3y + 3.2$$

$$2.332 + 0.212y = 0.3y + 3.2$$

$$-0.088y = 0.868$$

$$y = 9.86 \text{ kg}$$

## 4.6 Momentum conservation in a variable mass system

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

### Learning Competencies

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

- Describe explosions and rocket propulsion in relation to momentum conservation.

### Starting off

So far, systems with constant mass have been considered in the conservation of linear momentum. Students will now look at systems where the mass is not constant.

## Teaching notes

Go through the introductory text in the Students' Book. Then ask the students to carry out Activity 4.17 in small groups. Groups should then report back their finding to the rest of the class.

Go through the worked examples in the Students' Book. Emphasise the importance of making sure that all of the quantities are in standard units. In the example, masses need to be converted to kilograms.

Students can then carry out Activity 4.18, where they investigate a balloon that is acting as a rocket. You could ask the students why this should be considered as a variable mass system (because gas is being expelled from the balloon).

**Activity 4.17: Answer**

Students should conclude that the acceleration increases because the mass is decreasing.

**Activity 4.18: Answer**

Students should find that the 'rocket' will work better when there is no board behind it – demonstrating Newton's third law.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Rockets and momentum** | |
| **SA** | Why is the mass of a rocket as it is launched not constant? Discuss in small group and feed back ideas. |
| **MA** | Activity 4.17 in a small group. |
| **CA** | Worked example 4.13 with a partner without given solution. Feed back ideas. |
| **Variable mass systems** | |
| **SA** | Why is a raindrop an example of a variable mass system? Discuss in a small group and feed back ideas. |
| **MA** | Activity 4.18 in a small group. |
| **CA** | Write a report on Activity 4.18 with a partner. |
| **Explosions** | |
| **SA** | Worked example 4.14 with a partner without given solution. Feed back ideas. |
| **MA** | With a partner, make a spidergram to summarise this topic. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Variable mass system.
- Balloon rocket.

## Where next?

The detailed mathematics involved in variable mass systems is complex and beyond the scope of this course.

## Answers to review questions

1. (18, 10.8) $m/s^2$
2. (–12.3, –0.6) m/s
3. a) 0.5 kg
   b) 5 kg

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

# 4.7 Dynamics of uniform circular motion

### Learning Competencies

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

- Interpret Newton's laws and apply these to moving objects undergoing uniform circular motion.
- Solve dynamics problems involving friction.

### Starting off

Students have already covered bodies moving in uniform circular motion in Unit 3. This section extends the coverage, introducing friction to problems.

## Teaching notes

Recap with the students what they learnt about uniform circular motion in Unit 3. Explain that they are now going to solve problems involving concepts they learned about earlier in this unit, such as friction.

Ask the students to carry out Activity 4.19.

**Activity 4.19: Answer**

This activity is designed to get the students thinking about what they have learnt so far and how they can apply this knowledge. They will need to know things like the coefficient of static friction between the riders' clothing and the inside of the drum and, the minimum speed required to keep riders 'stuck' to the inside of the drum.

Go through the worked examples on pages 93 and 94 with the students. In the second of these, the students may need to be reminded of the difference between the coefficients of static friction and kinetic friction. The coefficient of static friction is needed because the wheels are not slipping in this direction, but they are moving perpendicular to it.

Ask the students to carry out Activity 4.20.

**Activity 4.20: Answer**

They are measuring the tension in the string. They should find that the force when they are swinging the mass is constant in a horizontal circle, but varies in a vertical circle. In a vertical circle the force is lowest at the top and greatest at the bottom.

Activity 4.21 reinforces this by asking the students to look at the equations below Figure 4.46 and consider how the force varies with the angle θ.

Go through the worked example with the students. Ask the students to do Activity 4.22. Students should revisit what they did in Activity 4.19 before starting on their design.

Ask the students to carry out the project work described in the Students' Book. Students can write a report or do a presentation on their findings. They should apply as much as possible of what they have learnt in this chapter to their chosen activity.

**Activity 4.21: Answer**

In a vertical circle the force is lowest at the top of the circle and greatest at the bottom.

**Activity 4.22: Answer**

Students' own design.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Uniform circular motion** | |
| **SA** | What provides the force to keep a car moving in an arc of a circle round a bend? Discuss with a partner and feed back ideas. |
| **MA** | Activity 4.19 in a small group. |
| **CA** | Feed back on activity. |
| **Measuring circular forces** | |
| **SA** | Worked example 4.16 with a partner without given solution. Feed back ideas. |
| **MA** | Activity 4.20 with a partner. |
| **CA** | Write a report on the activity with a partner. |
| **Forces in vertical circles** | |
| **SA** | Activity 4.21 in a small group. |
| **MA** | Activity 4.22 in a small group. |
| **CA** | Project work on page 96 of Students' Book in a small group. |

## Activities

- Fairground ride parameters.
- Tension in a rope being swung in horizontal and vertical circles.
- Force towards the centre in vertical circular motion.
- Designing a fairground ride.
- Project work: applications of dynamics, e.g. seat belts, rocket ravel, sports, ball games.

## Where next?

Students will return to circular motion in Unit 6.

## Answers to review questions

1. a) 13.1 m/s
   b) 2.61 rad/s
2. a) 6.25 m/s$^2$
   b) 895 N outwards from the centre of the circle
   c) 8.85 m/s
   d) No

## Answers to end of unit questions

1. **dynamics** the study of what causes objects to move

   **kinetic friction** the frictional force between two objects sliding over each other

   **static friction** the frictional force between two objects that are trying to move against each other but are not yet moving

   **limiting friction** the maximum value of static friction

   **linear momentum** the product of the mass and velocity of a particle

   **elastic collision** a collision between two particles where kinetic energy is conserved

   **inelastic collision** a collision between two particles where kinetic energy is not conserved

   **glancing collision** a collision in two dimensions, where the objects rebound in the same plane but not necessarily the same direction as the original motion

   **head-on collision** a collision in one dimension, where the objects rebound on straight line paths that coincide with the original direction of motion

   **centre of mass** the point in a body from which the force of gravity on that body appears to be acting

   **torque** the turning effect of a force round a point

2. Total momentum of a system stays the same unless a force acts to change the momentum. Impulse is the change in momentum.
   Force is impulse ÷ time = mass × acceleartion.

3. Static friction is the friction exerted by a surface on a static body but kinetic friction is the friction exerted by a surface on a body that is moving.

4. $F_{net} = (160 - 40)\text{KN}$

   $= 120 \text{ KN}$

   $= 20\,000 \times \mathbf{a}$

   $$a = \frac{120\,000}{20\,000}$$

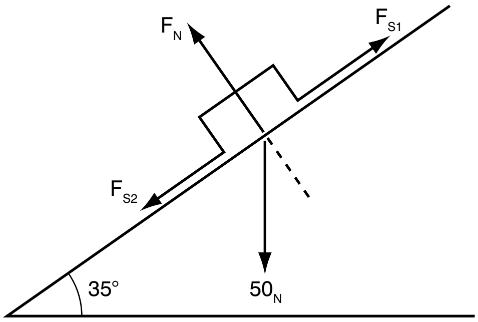
   $= 6 \text{ m/s}$

   Use v = u + at

   $$\frac{v - u}{a} = t$$

   $$\frac{33}{6} = 5.5 \text{ s}$$

5.




If $F_{S2} > F_{S1}$ crate will slide.

$F_N = 50\cos 35°$

$F_{S1} = \mu s\ F_N$

$= 0.65 \times 50 \times \cos 35°$

$= 26.6$ N

$F_{S2} = 50\sin 35°$

$= 28.7$ N

Since $F_{S2} > F_{S1}$, crate will slide down plane.

6. As a car goes round a bend it experiences a force which is proportional to its velocity squared. For the car not to slip relative to the surface, the friction must be limiting.

$\mu_s\ mg = m\omega^2 r$ so the maximum velocity is determined by the coefficient of static friction between the car and the surface.

7. $P = m_1 v_1 + m_2 v_2 + m_3 v_3 + m_4 v_4$

$= (0.5 \times 2) + (0.5 \times 4) + (0.5 \times 8) + (0.5 \times 10)$

$= 1 + 2 + 4 + 5$

$= 12$ kg m/s

8. The system is the man, the ball and the boat. All are initially at rest, so the linear momentum of the system is zero.

When the man throws the ball, no external force is acting on the system, so the linear momentum is conserved.

The man and the boat must move in a direction of travel opposite to the ball.

When thrown, the momentum of the ball is

$p = mv = 0.2 \times 50$

$= 10$ kg m/s

The man and the boat must have this momentum but in the opposite direction.

10 kg m/s $= 100 \times v$

$v = \frac{10}{100}$

$= 0.1$ m/s

The speed of the boat is 0.1 m/s.

9. The momentum depends on the velocity of the observer. We take as our frame of reference the spaceship.

   Thus, the spaceship is initially at rest, releases the satellite at a velocity of (10 000 – 1000) m/s = 9000 m/s and then moves backwards at a speed of (1000 – 910) m/s = 90 m/s.

   The momentum in this frame is initially zero. The satellite has a momentum when released of (1000 × 9000) kg m/s = 9 × 106 kg m/s.

   The spaceship moves backwards with the same momentum.

   $9 \times 10^6 = 90 \times m$

   $$M = \frac{9 \times 10^6}{9 \times 10^1}$$

   $$= 1 \times 10^5 \text{ kg}$$

10. The forces are equal and opposite so the wheel will be in equilibrium.

11. a) Forces smallest at top of loop.

    b) Forces greatest at the bottom of loop.

# Work, energy and power

Unit 5

**Learning Competencies for Unit 5**

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

- Differentiate between energy, work and force.
- Describe and explain the exchange among potential energy, kinetic energy and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.
- Identify the relationship between work and change in kinetic energy.
- Analyse and explain common situations involving work and energy, using the work–energy theorem.
- Determine the energy stored in a spring.
- Describe and explain the exchange among potential energy, kinetic energy and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.
- Predict velocities, heights and spring compressions based on energy conservation.
- Apply the law of mechanical energy conservation in daily life situations.
- Describe and explain the exchange among potential energy, kinetic energy and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.
- Solve problems involving conservation of energy in simple systems with various sources of potential energy, such as springs.
- Distinguish between conservative and non-conservative forces.
- Analyse situations involving the concepts of mechanical energy and its transformation into other forms of energy according to the law of conservation of energy.
- Define and work out power.

This unit should fill approximately **13 periods** of teaching time.

## 5.1 Work as a scalar product

This section should fill approximately **1 period** of teaching time.

### Learning Competencies

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

- Differentiate between energy, work and force.

### Starting off

Students learnt what work done is in Grade 9, but may need some revision here.

**Activity 5.1: Answer**

Students should realise that work is done pushing the box because you are overcoming friction when pushing it. There is no work done when carrying a box unless you are lifting it to a higher place. This is a concept that many students struggle with.

## Teaching notes

Remind the students of the definition of work done and go through the first worked example.

Ask the students to do Activity 5.1.

Remind students of the scalar product of two vectors, which they learnt about in Unit 2. Introduce the idea of work done as the scalar product of the force and displacement vectors. Go through Worked example 5.1 on page 99 of the Students' Book with the students. Again, emphasise the importance of drawing free-body diagrams to show the forces that are acting – it also makes it easier to see what component of the force you need to be thinking about. Also encourage the students to check answers by checking the units in them.

You could also ask the students to check what difference it would make to the answer if the force in component form was rounded to 1 decimal place rather than two.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Work** | |
| **SA** | Worked example 5.1 with a partner without given solution. |
| **MA** | Activity 5.1 in a small group. |
| **CA** | Review questions to be tackled with a partner. |

## Activity

- Discussion about work done.

## Where next?

The rest of this unit looks further at work and the links to kinetic and potential energy.

## Answers to review questions

1. 275 N
2. 675 N

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

## 5.2 Work done by a constant and variable force

### Learning Competencies

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

- Describe and explain the exchange among potential energy, kinetic energy and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.

## Starting off

Discuss the term work with the students. Check that they understand it has a different meaning in Physics to its meaning in everyday life. Discuss with students what energy, work and force are – do they understand the differences between them?

## Teaching notes

Ask the students to carry out Activity 5.2. They may need some practice at pulling the block up the slope with a steady force. Students should keep their results for Activity 5.2 later in the unit.

Discuss the idea of a variable force with the students. Can they think of other examples? Go through finding the work done by finding the area under a graph of force against displacement.

**Activity 5.2: Answer**

Students' own results.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Work done by a constant force** | |
| **SA** | With a partner, write a definition of 'work' (in the physics sense). Feed back ideas. |
| **MA** | Activity 5.2 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Work done by a variable force** | |
| **SA** | Why is the area under a force–displacement graph the work done? Discuss with a partner and feed back ideas. |
| **MA** | Draw some variable force–displacement graphs and ask your partner to find the work done in each case (you will of course have to work this out first!). |
| **CA** | Review question to be tackled with a partner. |

## Activity

- Finding the work done pulling a block up a slope.

## Where next?

Students will be revising the work–energy theorem.

## Answer to review question

1. The graph should show a force that is not constant.

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

## 5.3 Kinetic energy and the work–energy theorem

### Learning Competencies

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

- Identify the relationship between work and change in kinetic energy.
- Analyse and explain common situations involving work and energy, using the work–energy theorem.

### Starting off

Energy is a very important concept in Physics, but energy is notoriously hard to define.

Discuss with the students what they associate energy with. They may associate energy with motion, but not all forms of energy involve motion. For example, potential energy is based on the position of objects, not on their motion.

How do we measure energy? We don't directly. We measure other variables that we can then use to calculate the energy of a body. For example, we can measure most forces, e.g. the force in a spring. We can see speed, and measure time using a stopwatch. Energy is more elusive – it depends on different factors such as the mass of the object, the square of the object's speed or the position of the object.

### Teaching notes

Remind the students of the work–energy theorem, which they learnt about in Grade 9. Go through, with the students, the derivation of the work–energy theorem from Newton's second law of motion.

Go through Worked examples 5.3 and 5.4 on page 105 with the students. These are applications of the work–energy theorem. You may need to revise the concept of negative energy with the students. Discuss with them examples of where no work is done, such as the one given in the Students' Book.

Introduce the mousetrap car project. A brief description of the principles of how it works is given in the Students' Book. The students may well have built a mousetrap car in Grade 9. If they have, this is a good opportunity to revisit what they learnt – can they improve on what they did in Grade 9?

You could have a class competition, but you will need to agree what you are going for – biggest distance, highest speed or highest average speed. The design of the car depends on which parameter you are trying to maximise. For example, if you are trying to get the biggest distance, the energy needs to be transferred slowly, whereas if you are trying to get the highest speed the energy needs to be transferred quickly.

You may also need to emphasise to students that it does not matter if the car does not work properly first time – this is the way that scientists and engineers often work, by trying something out to see if it works. They then refine their designs and try again.

A mousetrap car does not need many materials – as long as you have a mousetrap. Scrap materials can be used for much of the rest of the car. The students' ingenuity will come to the fore, finding things that they can use.

If you can access the internet, there are many projects that people have done – you can get many hints and tips.

This activity could continue for the rest of this unit with students refining their designs as they go on.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Energy** | |
| **SA** | With a partner, write a list of as many types of energy as you can. Feed back ideas. |
| **MA** | Discussion activity on page 104 of Students' Book in small groups. |
| **CA** | Feed back on discussion. |
| **Energy calculations** | |
| **SA** | How is energy transferred to the ball in Figure 5.9 when it is thrown? Discuss with a partner and feed back ideas. |
| **MA** | Worked examples 5.3 and 5.4 with a partner without given solutions. Feed back ideas. |
| **CA** | Review questions to be tackled with a partner. |
| **Mousetrap car** | |
| **SA** | With a partner write down how a mousetrap car works. Feed back ideas. |
| **MA** | In a small group, build a mousetrap car. |
| **CA** | Write a report on the project with a partner. |

## Activity

- Mousetrap car race.

## Where next?

The students can have the mousetrap car as a continuing project for the rest of this unit.

## Answers to review questions

1. a) 32.4 N

   b) 12 m/s

2. 10 m

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

## 5.4 Potential energy

### Learning Competencies

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

- Determine the energy stored in a spring.
- Describe and explain the exchange among potential energy, kinetic energy and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.

### Starting off

Students first met the concept of potential energy in Grade 9, but some revision may be needed here.

### Teaching notes

Go through the first part of the text in the Students' Book, checking that the students understand the concept of potential energy and how it is stored in springs and how you gain gravitational potential energy with an increase in height.

Go through the worked example on page 108, which is revision of work the students did in Grade 9.

Ask the students to do Activity 5.3. The students will need to plan their experiment. They should draw up a plan, carry the experiment out and then write a report using the writing frame in Section 1.4. Discuss the students' results with them and introduce the concept of using a graph of force against extension to show how much energy is stored in a spring. Help them make the connection between the equation $W = Fs$, if needed. Go through the worked example.

Ask the students to do Activity 5.4.

**Activity 5.3: Answer**

Students' own results.

**Activity 5.4: Answer**

Students should be able to describe the energy changes in some detail. Ask them to think about the work–energy theorem. You could also ask what happens to some of the energy – they should realise that some is lost from the system to friction, particularly with the roller coaster.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Potential energy in springs** | |
| **SA** | Discussion activity at top of page 108 of Students' Book in small groups. |
| **MA** | Activity 5.3 in small groups. |
| **CA** | Write a report on the activity with a partner. |
| **More potential energy** | |
| **SA** | Discussion activity at bottom of page 108 of Students' Book in small groups. |
| **MA** | Activity 5.4 in small groups. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Using scalar product.
- Extension of a spring.
- Energy changes in a roller coaster and oscillating spring and mass.

## Where next?

This leads conveniently on to work on the law of conservation of energy.

## Answers to review questions

1. a) GPE $= m \times 9.81 \times 150$

   $= 1471.5\ m$ J where $m$ is mass.

   b) Loss in GPE $= m \times 9.81 \times 200$

   $= 1962\ m$ J where $m$ is mass.

   c) Net change GPE $= m \times 9.81 \times 50$

   $= 490.5\ m$ J where $m$ is mass.

2. $E = \frac{1}{2} \times k \times x^2$

   $= \frac{1}{2} \times 75 \times (0.2)^2$

   $= 1.5$ J

3. $F = kx$

   $x = \frac{F}{k}$

   $= \frac{40}{350}$

   $= 0.114$ m

   $E = \frac{1}{2} \times k \times (0.114)^2$

   $= \frac{1}{2} \times 350 \times 0.013$

   $= 2.275$ J

4. 5.47 m/s

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

## 5.5 Conservation of energy

### Learning Competencies

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

- Predict velocities, heights and spring compressions based on energy conservation.
- Apply the law of mechanical energy conservation in daily life situations.
- Describe and explain the exchange among potential energy, kinetic energy and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.
- Solve problems involving conservation of energy in simple systems with various sources of potential energy, such as springs.

### Starting off

Students first came across the law of conservation of energy in Grade 9, so some of this will be revision. Note that only the conservation of mechanical energy is covered here. Other forms of energy such as thermal energy and electrical energy need not be considered.

## Teaching notes

**Activity 5.5: Answer**

Bob oscillates about central point. Energy converted from potential to kinetic to potential, etc.

Revise the law of conservation of energy – go through the first part of the text in the Students' Book. Then ask the students to do Activity 5.5.

Go through Worked examples 5.7 and 5.8 on page 112 with the students. Emphasise the importance of not substituting values into equations until you have to. The mass of the ball is given in the example, but it becomes clear that the mass cancels out on both sides of the equation. So we could still solve this problem if we had not been given it.

Remind students of the work they did on collisions in Unit 4 and go through Worked example 5.9 on page 113.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Energy changes** | |
| **SA** | With a partner, write down the law of conservation of energy. Feed back ideas. |
| **MA** | Activity 5.5 in small groups. |
| **CA** | Write a report on the activity with a partner. |
| **Energy calculations** | |
| **SA** | With a partner, write down the formulae you use to calculate potential energy and kinetic energy. Feed back ideas. |
| **MA** | Worked examples 5.7, 5.8 and 5.9 with a partner without given solutions. Feed back ideas. |
| **CA** | Review questions to be tackled with a partner. |

## Activity

- Motion of a pendulum.

## Where next?

Students can apply the law of conservation of energy and other principles in this unit to things happening in their environment, e.g. sports.

## Answers to review questions

1. (15.34, 15.34) m/s or 21.69 m/s at an angle of 45° to the horizontal.
2. a) 0.77 m/s

   b) 0.62 rad/s
3. No, kinetic energy is not conserved.

## 5.6 Conservative and dissipative forces

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

### Learning Competencies

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

- Distinguish between conservative and non-conservative forces.
- Analyse situations involving the concepts of mechanical energy and its transformation into other forms of energy according to the law of conservation of energy.

### Starting off

Students learned about friction in Unit 4.

## Teaching notes

Ask students to carry out Activity 5.6 and then report the results of their discussion back to the rest of the class.

Explain to the students that the force, gravity, is a conservative force and that the work done does not depend on the path taken. Go through the explanation in the Students' Book, showing examples of conservative and dissipative forces.

Ask the students to do Activity 5.7. You could also ask students to work out the coefficient of kinetic friction between the block and the ramp.

### Activity 5.6: Answer

Students should have come to the conclusion that the amount of work done on the two books is the same.

### Activity 5.7: Answer

Students should find that the work done on pulling the block is greater than the gravitational potential energy gained by the block.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Conservative and dissipative forces (1)** | |
| **SA** | With a partner, list examples of where mechanical energy is lost from a system. Feed back ideas. |
| **MA** | Activity 5.6 in small groups. |
| **CA** | Report and discussion on activity. |
| **Conservative and dissipative forces (2)** | |
| **SA** | Discussion activity on page 115 of Students' Book in small group. |
| **MA** | Activity 5.7 in small group. |
| **CA** | Review question to be tackled with partner. |

## Activities

- Gravity as a conservative force.
- Friction as a dissipative force.

## Where next?

Students could look back at other things they have done so far in Grade 11 and identify what conservative and dissipative forces they have been observing.

## Answer to review question

1. Conservative forces are forces that do not do any work when a body moves on a closed path. Dissipative forces are forces that do work when a body moves on a closed path.

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

# 5.7 Power

### Learning Competencies

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

- Define and work out power.

### Starting off

Students learned about power in Grade 9.

## Teaching notes

Revise what the students know about power. Discuss with them the meaning of the word in everyday life and its meaning in Physics. Go through Worked example 5.10 on page 116. Discuss the effects of mechanical energy in the system – is the kinetic energy of the load significant in comparison to the total amount of energy supplied? If the engine is rated at 2500 W, will this affect the engine's capacity to lift the load? (The answer is no, as the kinetic energy is about 1% of the total gravitational energy supplied to the load.)

Before doing Activity 5.8 discuss with the students how you are going to find their power. They could do any activity where a force, distance and time can be measured, e.g. repeatedly lifting masses to a set height.

You may need to remind students that weight is given in newtons, mass is in kilograms.

If students have been building and refining their mousetrap cars that they started in Section 5.3, you could now race them. You could also ask the students to analyse their mousetrap cars in terms of work done, power, mechanical energy. Can they measure enough of the quantities to work these out?

The students should then do the project described in the Students' Book, finding out about the major sources of energy in your area.

**Activity 5.8: Answer**

Students' own results.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Power** | |
| **SA** | Activity 5.8 with a partner. |
| **MA** | Project on page 116 of Students' Book with a partner. |
| **CA** | Review questions to be tackled with a partner.<br>End of unit questions to be tackled with a partner. |

## Activity

- Finding your own power.

## Where next?

The energy in a mousetrap spring is stored as torsional potential energy – students will learn more about this in Unit 6.

## Answers to review questions

1. a) 1764 W

   b) Because weightlifters usually pause when they get the masses halfway up.

2. Power = $\frac{\text{work done}}{\text{time taken}}$

   Work done = force × distance

   $= 200 \times 9.81 \times 7$

   $= 13\,734$ J

   Power $= \frac{13\,734}{6}$

   $= 2289$ W

3. Work done = 275 N

   Power $= \frac{275}{4}$

   $= 68.75$ W

4. Work done = 675 N

$$\text{Power} = \frac{675}{12}$$

$$= 56.25 \text{ W}$$

5. $E = \frac{1}{2} \times kx^2$

$$= \frac{1}{2} \times 275 \times (0.2)^2$$

$$= 5.55$$

$$\text{Power} = \frac{5.5}{2}$$

$$= 2.75 \text{ W}$$

## Answers to end of unit questions

1. **work** the product of displacement and the force in the direction of the displacement. It is measured in joules.

   **energy** the amount of work that can be performed by a force; it is a scalar quantity and is measured in joules

   **kinetic energy** the energy that a moving object has. The faster an object is moving, the more energy it has.

   **potential energy** the energy possessed by an object because of its position or configuration. Its units are joules.

   **conservative force** a force that does no work when a body moves on a closed path

   **dissipative force** a force that does work when a body moves on a closed path

   **power** the rate at which work is done or energy is expended. Its units are watts.

2. a) The ball will move from X to Y and then oscilate from one side of Y to the other until all its kinetic energy has been dissipated.

   b) Potential energy →kinetic energy→potential energy→kinetic energy and so on.

   c) Friction would act on the ball and so some energy would be needed to overcome friction.

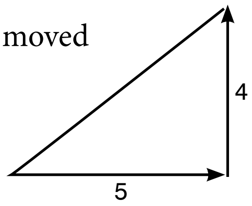
3. Both have lost some amount of GPE. However, child who moves from base of slide to base of ladder has done work in moving this distance which the other child has not done.

4. Work is force × distance.

   Energy has the same units as work but takes various forms. It can be stored.

5. The stone has GPE which is then converted to kinetic energy as the stone falls.

6. The box moved




5 m moved horizontal, work = force × distance
= 5 × 9.81 × 5
= 245.25 J

4 m moved vertically, work = force × distance
= 5 × 9.81 × 4
= 196.2 J

This is where Dahnay gets his figure: 245.25 + 196.2 = 441.45 J.

7. Work done = area under graph.

8. $W = \Delta E_k = E_{k2} - E_{k1} = \frac{1}{2} m (V_2^2 - V_1^2)$

$F = ma$

$V_2^2 = V_1^2 + 2\,as$

$2\,as = V_2^2 - V_1^2$

$a = \frac{V_2^2 - V_1^2}{2\,s}$

$F = \frac{m(V_2^2 - V_1^2)}{2\,s}$

$W = Fs = \frac{m(V_2^2 - V_1^2)}{2\,s} \times 5 = \frac{1}{2} mv_2^2 - \frac{1}{2} mv_1^2$

# Rotational motion

# Unit 6

This unit should fill approximately **17 periods** of teaching time.

**Learning Competencies for Unit 6**

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

- Describe the motion of a rigid body about a pivot point.
- Give the angular speed and angular velocity of a rotating body.
- Determine the velocity of a point in a rotating body.
- Solve problems involving net torque and angular acceleration.
- Determine the velocity and acceleration of a point in a rotating body.
- Express torque as a cross product of $r$ and $F$.
- Apply the cross product definition of torque to solve problems.
- Solve problems involving the moment of inertia.
- Apply the concepts of rotation dynamics and kinetic energy to solve problems.
- Identify factors affecting the moment of inertia of a body.
- Derive equations of motion with constant angular acceleration.
- Use equations of motion with constant angular acceleration to solve related problems.
- State the parallel axis theorem.
- Use it to solve problems involving the moment of inertia.
- Express angular momentum as a cross product of r and $p$.
- Derive an expression for angular momentum in terms of $I$ and $\omega$.
- Use the relationship between torque and angular momentum, according to Newton's second law.
- Apply the relationship between torque and angular momentum to solve problems involving rigid bodies.
- State the law of conservation of angular momentum.
- Apply the law of conservation of angular momentum in understanding various natural phenomena, and solving problems.
- Determine the location of centre of mass of a uniform rigid body.

## 6.1 Rotation about a fixed axis

This section should fill approximately **1 period** of teaching time.

### Learning Competencies

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

- Describe the motion of a rigid body about a pivot point.
- Give the angular speed and angular velocity of a rotating body.
- Determine the velocity of a point in a rotating body.

### Starting off

Students have already learned about circular motion and angular velocity in Unit 4.

## Teaching notes

Revise with students what they already know about circular motion – how there is a radial force that keeps a body moving in a circle. Activity 6.1 can help to consolidate what they already know.

Introduce the term of axis of rotation and that any object moving in a circle moves about the axis of rotation. Extend this to rotating bodies such as CDs and DVDs. Go on to introduce angular velocity and go through Worked example 6.1 on page 119. Help students make the link between linear and angular velocity.

Go through the second worked example. You may wish to introduce other spinning objects and ask the students to calculate the angular velocity at a point. You could use a spinning football to help demonstrate that angular velocity at any point on the surface of the football is independent of distance from the axis of rotation.

**Activity 6.1: Answer**

The students should make the link to speed of rotation and size of radial force.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Rotation about a fixed axis** | |
| **SA** | With a partner, write down the formula for the relation between linear speed and angular speed of a point on a rotating body. Feed back ideas. |
| **MA** | Activity 6.1 in small groups. |
| **CA** | Review questions to be tackled with a partner. |

## Activity

- Rotating object.

## Where next?

Students will look at rotational motion in more detail later in the unit.

## Answers to review questions

1. 314 rad/s

2. 52.2 rad/s, 20.7 rad/s

3. $v = r\omega$

$\omega = \frac{v}{r}$

$= \frac{16}{0.7}$

$= 22.9$ rad/s

4. a) $\frac{3000 \text{ rev}}{1 \text{ min}} = \frac{300\cancel{0} \times \cancel{2}\pi}{36\cancel{0} \text{ s}}$

$= 100\pi$ rad/s

b) At end of blade

$v = r\omega$

$= 0.4 \times 100\pi$

$= 40\pi$ m/s

At mid point of blade

$v = r\omega$

$= 0.2 \times 100\pi$

$= 20\pi$ m/s

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

## 6.2 Torque and angular acceleration

### Learning Competencies

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

- Solve problems involving net torque and angular acceleration.
- Determine the velocity and acceleration of a point in a rotating body.
- Express torque as a cross product of *r* and *F*.
- Apply the cross product definition of torque to solve problems.

### Starting off

Students have already been introduced to torque in Unit 4. Torque and moments are essentially the same thing, but moments are to do with linear motion and torque with rotational motion. Encourage the students to see the links between the two.

### Teaching notes

**Activity 6.2: Answer**

Students' own results.

Revise with the students what they already know about torque and go through Worked example 6.3 on page 121. To demonstrate torque and how it depends on both the force and the perpendicular distance, ask students to carry out Activity 6.2. If the spanners have eyes in the end, you could attach newtonmeters and measure the force required to move each spanner.

Check that the students understand the torque on a spanner. Remind them of what they learned in Unit 2 about the vector product of two vectors and the right-hand rule. They should be able to demonstrate the direction of movement of the nut in Figure 6.4 using the right-hand rule.

Go through Worked example 6.4 on page 122. Help the students to see the link between sin θ in the vector product definition with the sin θ they need to work out the component of the force that is perpendicular to the displacement. Discuss the units of torque.

Ask the students in small groups to carry out the discussion. They should conclude that it is the action of force that can change the angular velocity. Rotational kinetic energy is related to a body's angular velocity – students will cover this in more detail in the next section. Then go through Worked example 6.5 on page 123.

Introduce angular acceleration and go through Worked example 6.5. Again encourage students to make the link with its linear counterpart.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Torque** | |
| **SA** | With a partner, write a definition of a torque. Feed back ideas. |
| **MA** | Activity 6.2 in small groups. |
| **CA** | Worked example 6.4 with a partner without given solution. Feed back ideas. |
| **Rotational work done** | |
| **SA** | With a partner, write down the work done by a linear force. Try and apply this formula to find the rotational equivalent – work done by a torque. Feed back ideas. |
| **MA** | Discussion activity on page 122 of Student Books in small groups. |
| **CA** | Report on discussion. |
| **Summary of learning** | |
| **SA** | With a partner, write down one thing you have learnt in this topic. Feed back ideas. |
| **MA** | With a partner, make a spidergram to summarise this topic. |
| **CA** | Review questions to be tackled with a partner. |

## Activity

- Spanners and torque.

## Where next?

Students will go on to the law of conservation of angular momentum in Section 6.7.

## Answers to review questions

1. 52.4 rad/s$^2$
2. a) 30 cm spanner (450 N m – 20 cm spanner produces 400 N m)
   b) 30 cm spanner, 707 J; 20 cm spanner, 628 J
3. 17 N m

4. $\frac{5400 \text{ rev}}{60 \text{ s}} = \frac{90 \times 2\pi}{\text{s}}$

$= 180\pi \text{ rad/s}$

Change in speed $= 180\pi$ rad/s
time $= 2$ s

Angular acceleration $= 90\pi \text{ rad/s}^2$

5. a) Torque = force × perpendicular distance
$= 25 \times 0.25$
$= 6.25$ Nm

b) Work done $= \tau \times \theta$
$= 6.25 \times \frac{\pi}{2}$
$= 3.125\pi$ J

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

## 6.3 Rotational kinetic energy and rotational inertia

### Learning Competencies

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

- Solve problems involving the moment of inertia.
- Apply the concepts of rotation dynamics and kinetic energy to solve problems.
- Identify factors affecting the moment of inertia of a body.

### Starting off

Students have already learned about the centre of mass. This is extended in this section to moments of inertia. Students were first introduced to moments of inertia in Grade 10.

### Teaching notes

**Activity 6.3: Answer**

Students' own results.

**Activity 6.4: Answer**

Students' own results.

**Activity 6.5: Answer**

Students' own results.

Revise what the students know about Newton's second law of motion. Redefine this for rotational motion as shown in the Students' Book and encourage the students to see that moment of inertia is the rotational equivalent of mass. Introduce angular acceleration and go through Worked example 6.7 on page 125.

Ask the students to carry out Activity 6.3. You may need to go through the principles with them to make sure they understand what it is they are trying to do. Ask them to plan their experiments and then write a report using the writing frame in Section 1.4 of the Students' Book.

Discuss with the students rotational kinetic energy and the fact that it is linked to the angular velocity of the object and its moment of inertia. The Students' Book provides the proof of how the expression for the moment of inertia and its units are obtained by considering the kinetic energy of a rotating body. Go through Worked example 6.8 on page 129 with the students.

Ask the students to carry out Activities 6.4 and 6.5. They should have access to a range of objects with different mass distributions. Rolling the objects down the inclined plane should help to demonstrate the concept of the moment of inertia.

Rolling the objects with solid and liquid bodies should help demonstrate that the motion of an object with a solid body makes its motion much more predictable.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Rotational inertia** | |
| **SA** | With a partner, write a definition of 'inertia'. Feed back ideas. |
| **MA** | Activity 6.3 in small groups. |
| **CA** | With a partner, write a report on the activity. |
| **Rotational kinetic energy** | |
| **SA** | Activity 6.4 in small group. |
| **MA** | Activity 6.5 in small group. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Finding rotational inertia.
- Rolling objects down an inclined plane.
- Can race.

## Where next?

The moment of inertia of an object can be found using integral calculus – students will learn about integral calculus in Grade 12.

## Answers to review questions

1. (b) because it has a bigger moment of inertia – mass is further away from axis of rotation.
2. a) $7.3 \times 10^{-5}$ rad/s

   b) $2.6 \times 10^{29}$ J
3. a) 500 N m

   b) 2000 J

## 6.4 Rotational dynamics of a rigid body

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

### Learning Competencies

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

- Derive equations of motion with constant angular acceleration.
- Use equations of motion with constant angular acceleration to solve related problems.

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## Starting off

Students should already be very familiar with the linear equations of motion. Here they are introduced to their rotational counterparts.

## Teaching notes

Check that the students know what the linear equations of motion are. Draw up a list of linear quantities and ask the students to name the rotational counterparts. You could then ask them to rewrite the linear equations of motion with the rotational quantities. A table of them is given in the Students' Book on page 129. Ensure that the students are familiar with what a frame of reference is and the one that is applied to rotational motion.

Ask the students to carry out Activity 6.6 – this is a very good starting point for a discussion on moment of inertia.

You can come back to this later on in Section 6.7 when the law of conservation of angular momentum is discussed.

Go through the worked examples with the students. Take them through the steps involved in solving problems – first identify the known values and then the values which are being asked for. Check that the students know that sketching a diagram is often very helpful in trying to solve a problem. The second step is to find the equation that includes only one unknown – the value they are being asked for – and all the other values are known, or can be calculated. The third step is manipulating the equations and rearranging them before substituting any values in – very often the equation can be simplified before you do this, making the subsequent calculation simpler.

Ask the students to carry out Activity 6.7. You will need a variety of discarded metal spools and other things from which students can construct a yo-yo.

Ask the students to carry out Activity 6.8. This is a useful exercise in applying the rotational equations of motion and linking to concepts such as friction that they learnt about in Unit 4.

### Activity 6.8: Answer

The order in which the shapes will get to the bottom of the inclined plane is sphere, then disc and finally ring. The ring has the greatest moment of inertia and hence greatest resistance to changes in motion.

Go through Worked example 6.11 on finding power (page 132 of the Students' Book).

Students could start on the project described in the Students' Book. This could be done over a couple of weeks. They could do their presentations at the end of the work in this unit.

### Activity 6.6: Answer

The cat tucks in the part of its body it wants to rotate and counters this by sticking out the parts of the body it does not want to rotate. These parts will still rotate, but by much less.

### Activity 6.7: Answer

Students should find that the best yo-yo has a small radius for the central spindle and that the outer part will have a reasonable amount of mass so that the yo-yo gains the maximum amount of rotational kinetic energy when you spin it.

| SA = starter activity  MA = main activity  CA = concluding activity | |
|---|---|
| **Equations of motion for rotational motion** | |
| **SA** | With a partner, write down the equations of motion for linear motion. Feed back ideas. |
| **MA** | With a partner, make a poster to compare the equations of motion for linear and rotational motion. |
| **CA** | Worked example 6.9 with a partner without given solution. Feed back ideas. |
| **Applying rotational motion** | |
| **SA** | Activity 6.6 with a partner. |
| **MA** | Activity 6.7 in small group. |
| **CA** | Report on activity 6.7 with a partner. |
| **Rotational motion and friction** | |
| **SA** | Worked example 6.10 with a partner and without given solution. |
| **MA** | Activity 6.8 with a partner. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Falling cat.
- Making a yo-yo.
- Ring, sphere and disc race.

## Where next?

Students will go on to apply some of these principles in electromagnetics in Grade 12.

## Answers to review questions

1. a) 1.2 rad/s
   b) 1.8 rad
2. a) 5.0 rad/s
   b) 6.1 s
3. a) 0.24 kg m$^2$
   b) angular acceleration of 28 rad/s$^2$
4. a) $9.0 \times 10^5$ J
   b) 2900 rev/min
   c) sensible suggestions
5. a) Use movement of inertia for thin cylindrical shell

$$\begin{aligned} I &= MR^2 \\ &= 1500 \times 5^2 \\ &= 1500 \times 25 \\ &= 37\,500 \text{ kg m}^2 \end{aligned}$$

b) $v = r\omega$

$= \frac{v}{r}$

$= \frac{3}{5}$

$= 0.6$ rad/s

c) rotational kinetic energy $= E_k = \frac{1}{2} IW^2$

$= \frac{1}{2} \times 37\,500 \times 0.6^2$

$= 6750$ J

d) power $= \frac{\text{work done}}{\text{time}}$

$= \frac{6750}{10}$

$= 675$ W

## 6.5 Parallel axis theorem

This section should fill approximately **1 period** of teaching time.

### Learning Competencies

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

- State the parallel axis theorem.
- Use it to solve problems involving the moment of inertia.

### Starting off

Students will be familiar with moments of inertia. Ask them what happens to the moment of inertia if you change the axis of rotation.

## Teaching notes

Go through the parallel axis theorem with the students, and how it can be applied to a rod rotating from its end. Go through Worked example 6.12 on page 134. You could extend this to finding the moment of inertia of objects of which they already know the moment of inertia.

**Activity 6.9: Answer**

Students' own results.

Ask the students to carry out Activity 6.9. If necessary, you could ask them to carry out this in conjunction with Activity 6.3 in Section 6.3 and hold the discussion on the results and applying the parallel axis theorem until now. Or you could ask the students to calculate the moment of inertia about another axis using the parallel axis theorem and then compare with their results from Activity 6.9.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **The parallel axis theorem** | |
| **SA** | With a partner, define 'parallel'. Feed back ideas. |
| **MA** | With a partner, discuss how you can find the moment of inertia when the axis of rotation goes through the body's centre of mass. |
| **CA** | Feed back from discussion. |

| Using the parallel axis theorem | |
|---|---|
| **SA** | With a partner, write down the parallel axis theorem. Feed back ideas. |
| **MA** | Activity 6.9 in small groups. |
| **CA** | Discuss whether results of activity show that the parallel axis theorem is true. |
| **Summary of learning** | |
| **SA** | Worked example 6.12 with a partner without given solution. Feed back ideas. |
| **MA** | With a partner, make a poster to summarise this topic. |
| **CA** | Review questions to be tackled with a partner. |

## Activity

- Demonstration of parallel axis theorem.

## Where next?

The parallel axis theorem is useful in solving more complex rotational dynamics problems, e.g. in astrophysics.

## Answers to review questions

1. 67 kg $m^2$
2. $I_p = I_{cm} + Md^2$

$$= \frac{2}{5}MR^2 + MR^2$$

$$= \frac{7}{5}MR^2$$

## 6.6 Angular momentum and angular impulse

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

### Learning Competencies

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

- Express angular momentum as a cross product of r and *p*.
- Derive an expression for angular momentum in terms of *I* and ω.
- Use the relationship between torque and angular momentum, according to Newton's second law.
- Apply the relationship between torque and angular momentum to solve problems involving rigid bodies.

### Starting off

Students were introduced to angular momentum in Grade 10 and so should already be familiar with the concept.

**Activity 6.10: Answer**

Students' own results.

**Activity 6.11: Answer**

Students should be able to explain that the raw egg starts rotating again because the yolk never stopped rotating. It does not happen in a hard-boiled egg because the egg is solid.

## Teaching notes

Revise what the students already know about angular momentum. If possible, show them a gyroscope in action to act as a trigger for a discussion on angular momentum.

Ask the students to carry out Activity 6.10. You may need to carry this out as a demonstration. The activity should help to demonstrate the independence of axes of rotation.

Go through Worked example 6.13 on page 136 of the Students' Book. You could also use the example of a roundabout on a playground – how much angular momentum does it have? You could also relate this to worked examples earlier in the book: for example Section 4.7 – what angular momentum does each body have?

Introduce the angular impulse, relating it to Newton's second law of motion and the linear impulse. Then go through Worked example 6.14 on page 137.

Ask students to carry out Activity 6.11.

Ask the students to use the right-hand rule to predict the direction of angular momentum.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Angular momentum and angular impulse** | |
| **SA** | Activity 6.10 in small group. |
| **MA** | Activity 6.11 in small group. |
| **CA** | Project work on page 137 of Students' Book with a partner. |

## Activities

- Rotating platform and bicycle wheel.
- Rotating egg.

## Where next?

Angular momentum, along with all the equations of rotational motion, are used to design things like fairground rides, and plan missions into space.

## Answers to review questions

1. a) 9.8 N m

   b) 24.5 kg $m^2/s$

## 6.7 Conservation of angular momentum

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

### Learning Competencies

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

- State the law of conservation of angular momentum.
- Apply the law of conservation of angular momentum in understanding various natural phenomena, and solving problems.

### Starting off

Students have already met the law of conservation of angular momentum in Grade 10.

## Teaching notes

Revise what the students know about the law of conservation of angular momentum. You could ask them to look again at the photo of the falling cat and try to explain what is happening in terms of the conservation of angular momentum.

Also ask the students to look at the photo of the skateboarder. Help them to see how the twisting movements relate to Newton's third law – they are the same. If you try to push one part of your body in one direction, the other part will be pushed in the opposite direction.

Ask the students to carry out Activity 6.13 as described in the Students' Book.

You may need to prevent the students from being over-enthusiastic when carrying out this activity.

**Activity 6.12: Answer**

Since no external forces are acting on the car, the law of conservation of angular momentum can be applied.

**Activity 6.13: Answer**

Students should be able to explain that your velocity increases when you bring your arms close to your chest because your moment of inertia decreases. As angular momentum has to be conserved, your speed increases.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Conservation of angular momentum** | |
| **SA** | With a partner, write down the law of conservation of linear momentum. Feed back ideas. |
| **MA** | Activity 6.12 with a partner. |
| **CA** | Why is angular momentum conserved by skateboarders turning in mid–air? Discuss with a partner and feed back ideas. |
| **Applying conservation of angular momentum** | |
| **SA** | Discussion activity on page 139 of Students' Book with a partner. Feed back ideas. |
| **MA** | Activity 6.13 in small group. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Falling cat.
- Rotating person.

## Where next?

Applying the law of conservation of angular momentum is key to analysing many problems in astrophysics.

## Answer to review question

1. 2 kg $m^2$

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

## 6.8 Centre of mass of a rigid body (circular ring, disc, rod and sphere)

### Learning Competencies

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

- Determine the location of centre of mass of a uniform rigid body.

### Starting off

Students have already come across the concept of the centre of mass. Here the concept is defined more mathematically.

## Teaching notes

Revise with the students the concept of centre of mass – what do they know or remember about it? Ask them to carry out Activity 6.14. This is a fun exercise to demonstrate that the centre of mass need not be inside an object. Discuss with the students the results of their discussions.

Guide the students through the mathematical proof of the position of the centre of mass given in the Students' Book. They do not need to know this, but it is helpful to see how you can find the centre of mass of a simple system mathematically.

In Unit 4, the students found the centre of mass of a uniform planar object. Activity 6.15 extends this. Provide the students with a mixture of rigid and non-rigid bodies.

### Activity 6.14: Answer

If necessary guide students to the conclusion that the centre of mass is somewhere below the pivot point on the edge of the glass.

### Activity 6.15: Answer

Students should conclude that for a rigid body the centre of mass is fixed, but for a non-rigid body the centre of mass can move depending on the orientation of the object.

### Activity 6.16: Answer

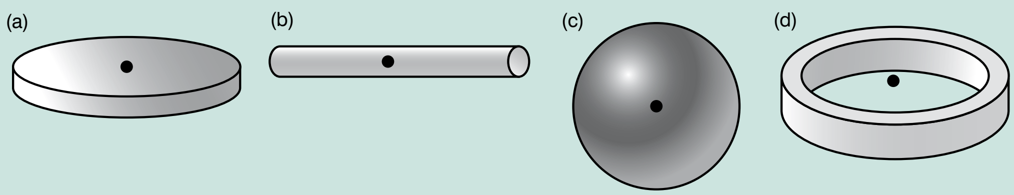



***Figure 6.32*** *Position of centre of mass for (a) disc, (b) rod, (c) sphere and (d) ring*

Ask the students to carry out Activity 6.16. It is worth spending some time here on this as the students will be using these objects in the rest of the chapter – finding moments of inertia and solving problems involving them. If possible, have examples that students can use to find the centre of mass. You could use everyday objects such as coins, tubes, solid balls, etc.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **How the centre of mass of an object helps it balance** | |
| **SA** | With a partner, write down the law of conservation of linear momentum. Feed back ideas. |
| **MA** | Activity 6.14 with a partner. |
| **CA** | Report on activity with a partner. |
| **Finding centres of mass** | |
| **SA** | With a partner, write down how to find the centre of mass of an object. Feed back ideas. |
| **MA** | Activity 6.15 in a small group.<br>Activity 6.16 in a small group. |
| **CA** | Review questions to be tackled with a partner.<br>End of unit questions to be tackled with a partner. |

## Activities

- Finding the centre of mass of objects.
- Finding the centre of mass of a disc, rod, sphere and ring.

## Where next?

The students will extend the concept of centre of mass to moments of inertia in Section 6.4.

## Answers to review questions

1. a) With reference to (3, 0)

$$\frac{0 + 0.5 + 1\times0.5 + 2\times0.5 + 3\times0.5 + 4\times0.5 + 5\times0.5}{6 \times 0.5}$$

$$= \frac{0.5 + 1 + 1.5 + 2 + 2.5}{3}$$

$$= \frac{7.5}{3}$$

$$= 2.5$$

cm at (3, 2.5)

b) With reference to (0, 0)

| Point | Distance from reference | |
|---|---|---|
| (−2, 4) | $\sqrt{(2)^2 + (4^2)}$ | = 4.47 |
| (−1, 7) | $\sqrt{(-1)^2 + (7)^2}$ | = 7.07 |
| (3, 8) | $\sqrt{(3)^2 + (8)^2}$ | = 8.54 |
| (7, 7) | $\sqrt{(7)^2 + (7)^2}$ | = 9.9 |
| (8, 4) | $\sqrt{(8)^2 + (4)^2}$ | = 8.9 |
| (6, 0) | 6 | |
| (3, −2) | $\sqrt{(3)^2 + (4)^2}$ | = 5 |

$$\frac{0.5\,(4.47 + 7.07 + 8.54 + 9.9 + 8.9 + 5)}{6 \times 0.5}$$

= 7.31 from 0

2. a) rod

   b) ring

## Answers to end of unit questions

1. **axis of rotation** the axis about which a body rotates

   **torque** the turning effect of a force round a point; it is also a force

   **angular acceleration** the rate of change of angular velocity

   **rotational inertia** a measure of an object's resistance to changes in its speed of rotation over a certain time. Also known as moment of inertia

   **rotational kinetic energy** the amount of kinetic energy a rigid body has from its rotational movement

   **angular momentum** momentum of a body due to its angular velocity

   **angular impulse** the change in angular momentum of a rotating body caused by a torque acting over a certain time

2. a) The equations of motion take similar forms.

   Linear speed and angular speed are related by $v = r\omega$

   Angular and linear momentum are both conserved.

   b) Mass is replaced by momentum of inertia.

   Angular velocity replaces velocity

   Angle replaces distance.

3. The rotational laws of motion are the same as linear laws of motion except that linear quantities are replaced by rotational quantities.

4. $I = \frac{2}{5}MR^2$

$= \frac{2}{5} \times 7.27 \times (0.09)^2$

$= 0.0236 \text{ kg m}^2$

$\omega = \frac{v}{r}$

$= \frac{4.55}{0.09}$

$= 50.6 \text{ rad/s}$

$KE_{Total} = KE_{translational} + KE_{rotational}$

$= \frac{1}{2}mv^2 + \frac{1}{2} I\omega^2$

$= \frac{1}{2} \times 7.27 \times (4.55)^2 + \frac{1}{2} \times 0.0236 + (50.6)^2$

$= 75.3 + 30.2$

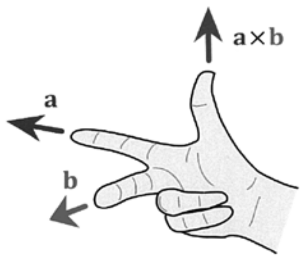
$= 105.5 \text{ J}$

5. Parallel axis theorem states that if you know the moment of inertia about the centre of mass, you can find it about any pivot point provided that the axes of rotation are parallel.

   $I_p = I_{cm} + Md^2$

6. Angular momentum does not change unless the system is acted on by a resultant torque.

7. Torque is found by using the vector product. The directions of vectors are found using the right hand rule.




8. If the system is isolated, not net torque acts on the object. Thus, the angular momentum of the object must remain constant. Since L = Iω, if I is doubled, then ω must be halved. The final angular velocity is equal to one half of its original value.

9. Use the principle of conservation of angular momentum.

   The initial angular momentum

   $L_o = I\omega = 10I_o$ where $I_o$ is the moment of inertia of the rotating disk.

   When the second disk is added, it has the same amount of inertia as the first one.

   The final inertia

   $I_f = 2I_o$

   Using conservation of angular momentum

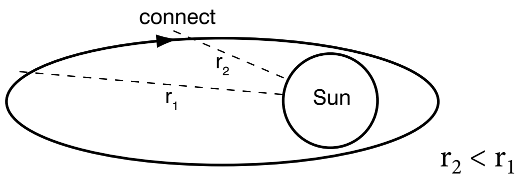
   $L_o = L_f$

   $10I_o = 2I_o\omega f$

   $\omega_f = 5$

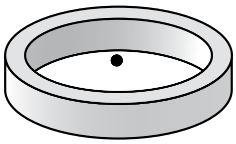
   The final angular velocity of the two disks is 5 rad/s.

10. Comets travel in elliptical paths as shown below. The radius decreases as they approach the Sun.




To calculate angular momentum, take the Sun as the origin. As the comet approaches the Sun, its radius, and therefore its moment of inertia, decreases. To conserve angular momentum, the angular velocity of the comet increases. The velocity therefore increases as it approaches the Sun.

11. A centre of mass can be outside a body, as it is in a ring, for example.



12. To find the centre of mass of a rigid body, find the geometric centre of the shape.
13. There are no external forces acting on the cat so the law of conservation of angular momentum can be applied.
14. Since angular momentum is a vector product, the right hand rule can be used to find the direction of the resultant vector.

# Equilibrium

## Unit 7

**Learning Competencies for Unit 7**

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

- Find the resultant of two or more concurrent forces acting at a point.
- Define the term equilibrium.
- State the first condition of equilibrium.
- Identify and label the forces and torques acting in problems related to equilibrium.
- Apply the first condition of equilibrium to solve equilibrium problems.
- Distinguish between coplanar and concurrent forces.
- Draw free body diagrams to show all the forces acting.
- Differentiate static equilibrium from dynamic equilibrium.
- State the second condition for equilibrium.
- Verify the second condition for equilibrium is valid about any arbitrary axis of rotation.
- Describe the difference among the terms stable, unstable and neutral equilibrium.
- Explain why objects are stable, unstable and neutral.
- Explain methods of checking stability, instability and neutrality of rigid bodies.
- Describe the equilibrium conditions for a body acted on by coplanar forces.
- Verify by experiment the conditions necessary for the equilibrium of a set of non-concurrent forces.
- State the conditions for rotational equilibrium.
- Define the term couples.
- Describe the rotational effects of couples on the rigid body.
- Solve problems involving the equilibrium of coplanar forces.

This unit should fill approximately **10 periods** of teaching time.

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

## 7.1 Equilibrium of a particle

### Learning Competencies

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

- Find the resultant of two or more concurrent forces acting at a point.
- Define the term equilibrium.
- State the first condition of equilibrium.
- Identify and label the forces and torques acting in problems related to equilibrium.
- Apply the first condition of equilibrium to solve equilibrium problems.

### Starting off

Start by revising what the students know about equilibria. They will have covered this briefly in Grade 10.

### Teaching notes

**Activity 7.1: Answer**

Students' own results.

Go through the first part of Section 7.1 in the Students' Book, which links equilibria to Newton's first law of motion. You may also need to revise vector addition, which the students covered in Unit 2. Check that they remember the various techniques – drawing them to scale head to tail, working out the components and adding the components together.

Check that the students understand what concurrent forces are.

Go through Worked example 7.1 on page 145 of the Students' Book, which deals with finding the components of the forces. Then ask students to carry out Activity 7.1. This is similar to Activity 2.3 in Unit 2, but is much more open ended. It is also designed so that many different angles and forces can be explored – it does not rely on the students having to hang on to newtonmeters!

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Concurrent forces** | |
| **SA** | With a partner, state Newton's first law of motion. Feed back ideas. |
| **MA** | With a partner, summarise Student Book pages 144–145. |
| **CA** | Worked example 7.1 with a partner without given solution. Feed back ideas. |
| **Investigating forces in equilibrium** | |
| **SA** | With a partner, write down the first condition of equilibrium. Feed back ideas. |
| **MA** | Activity 7.1 in a small group. |
| **CA** | Review questions to be tackled with a partner. |

### Activity

- Equilibrium of concurrent forces.

## Where next?

Students will look at equilibrium conditions when forces are not concurrent in Section 7.3.

## Answers to review questions

1. a) Yes, vectors form a closed shape.
   b) No, vectors do not form a closed shape.
2. Net force is zero, so they are in equilibrium.
3. Net force is (0.11, −0.19) so they are not in equilibrium.

# 7.2 Moment of torque or force

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

### Learning Competencies

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

- Distinguish between coplanar and concurrent forces.
- Draw free body diagrams to show all the forces acting.

### Starting off

Students have already come across torque and moment in units 4 and 6 of this book. However, here, a slightly different approach is taken – starting with concurrent forces and asking what happens when the forces are not concurrent.

## Teaching notes

Go through Worked example 7.2 on page 147 and then ask the students to carry out Activity 7.2 in small groups. Groups should then report back to the class.

Go through Worked example 7.3 on page 147, emphasising that we take both clockwise and anti-clockwise moments about an axis and that the axis is perpendicular to the plane of the paper. You may need to remind the students of the convention they learned in Unit 6: anti-clockwise is positive and clockwise is negative with regard to torque and rotational motion.

Emphasise that even though two forces may be equal and opposite, they do not necessarily cancel each other out and lead to an equilibrium. If the forces are not concurrent, they will have a turning effect. Check that students know the difference between concurrent and coplanar forces.

Ask students to carry out Activity 7.3.

### Activity 7.3: Answer

Students should be able to explain that as the stack gets taller the centre of mass moves upwards and that a small force acting at the top can push the centre of mass outside the base of the stack, which means that it becomes unstable and falls over.

### Activity 7.2: Answer

The students should be able to think of many examples – wherever there is a force that causes some kind of rotational movement, e.g. opening doors that have hinges, using a can opener, pencil sharpener, undoing a bottle top or jam jar.

Go through Worked example 7.4 on page 148. Check that the students understand that when taking moments about an axis, they do not need to consider any force that is acting on that axis. Emphasise that when taking moments, the torque varies according to which axis is chosen.

Ask the students to do Activity 7.4.

**Activity 7.4: Answer**

This is a good exercise in combining many of the things they have learnt. In Activity 5.6 in Unit 5, they described the energy changes taking place as a pendulum swings. They should be able to combine this knowledge with what they now know about centre of mass and equilibria.

You could introduce the project here – this is something that students could work on for the rest of this chapter. Ask the students to research one or more of the items given in the Students' Book and prepare a report or presentation. They will need to come back to this project as they learn more in the rest of the unit. Students could do their presentations when you come to the end of this unit.

| **SA = starter activity MA = main activity CA = concluding activity** | |
|---|---|
| **Examples of moments and torque** | |
| **SA** | With a partner, define 'moment' and 'torque'. Feed back ideas. |
| **MA** | Activity 7.2 in a small group. |
| **CA** | Worked example 7.2 with a partner without given solution. |
| **Investigating equilibrium** | |
| **SA** | Worked example 7.3 with a partner without given solution. |
| **MA** | Activity 7.3 in a small group. |
| **CA** | Write report on activity with partner. |
| **Experimentally determining equilibrium** | |
| **SA** | Review questions 1–4 to be tackled with a partner. |
| **MA** | Activity 7.4 in a small group. |
| **CA** | Project work on page 149 of Students' Book with a partner. |

## Activities

- Examples of torque in everyday life.
- Stack of small objects.
- Describing motion of a balancing toy.

## Where next?

In the next section, students will learn about the conditions of equilibrium.

## Answers to review questions

1. a) 14.5 N m anti-clockwise

   b) 10 N m anti-clockwise

2. a) i) 13 N m clockwise

      ii) 10 N m clockwise

   b) 22.5 N upwards

3. a) Use $\tau = Fd$ d is perpendicular displacement

   About A:

   net torque = 12 N × 0.55 + 0 × 18 sin40 – 20 sin50 × 0.25

   = 6.6 + 0 – 3.83

   = 2.77 Nm

   b) About B:

   net torque = 12 × 0 + 18 sin40 × 0.55 – 20 sin50 × 0.3

   = 0 + 6.36 – 4.596

   = 1.76 Nm

4 a) About A:

   net torque = F × 0 + 10 sin65 × 0.9 – 25 sin55 × 0.4

   = 0 + 8.157 – 8.19

   = –0.033 Nm

   b) About B:

   net torque = 0 – 10 × 0 + F sinθ × 0.9 – 25 sin55 × 0.5

   = 0 + 0.9 F sinθ – 25 sin55 × 0.5

   0.9 F sinθ = 25 sin 55 × 0.5

   $$F \sin\theta = \frac{25 \sin 55 \times 0.5}{0.9}$$

   = 11.4 N

   c) Do not have enough information to calculate F as do not know value of θ.

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

## 7.3 Conditions of equilibrium

### Learning Competencies

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

- Differentiate static equilibrium from dynamic equilibrium.
- State the second condition for equilibrium.
- Verify the second condition for equilibrium is valid about any arbitrary axis of rotation.
- Describe the difference among the terms stable, unstable and neutral equilibrium.
- Explain why objects are stable, unstable and neutral.
- Explain methods of checking stability, instability and neutrality of rigid bodies.
- Describe the equilibrium conditions for a body acted on by coplanar forces.
- Verify by experiment the conditions necessary for the equilibrium of a set of non-concurrent forces.
- State the conditions for rotational equilibrium.

### Starting off

This section builds on the previous two sections. Start by revising what students have learnt so far about concurrent and coplanar forces and moments about an axis.

## Teaching notes

**Activity 7.5: Answer**

Students' own results.

Discuss with the students what they think the conditions for equilibrium are. Go through Worked example 7.6 on page 151 of the Students' Book, showing that not only is there no net force but also no net torque. Show how when taking moments of a system in equilibrium it does not matter which axis is chosen – and that this only happens when a system is in equilibrium.

Emphasise to students that for an object to be in static equilibrium it needs to be stationary as well as satisfying the other two conditions of equilibrium – sum of force vectors is zero and sum of torque vectors is zero. Ensure that students also understand that an object moving with a constant velocity that is not accelerating either linearly or angularly is also in equilibrium.

Ask the students to carry out Activity 7.5. They will need to plan their experiment. The metre stick should be placed with its centre of mass over the pivot – this means that its mass can be ignored when students are trying out different combinations of weight and distance. Encourage them to put two different weights at different distances from the pivot on the same side of the pivot and balance it with a single weight on the other side.

Go through the three types of equilibrium using the example of the bottle shown in the Students' Book.

Ask the students to carry out Activity 7.6 – this is more of a thought experiment, looking at how the size of *F* changes when you alter its position, and then fix it and change the size of the angle. They could investigate it using numbers, for the force, and length and mass of bar.

Go through Worked example 7.7 on page 153 of the Students' Book. Again, this applies some of the principles that they learnt earlier in this book. This is also a classic equilibrium problem – question 2 in the review questions is another.

Figure 7.21 can be used as the basis for a discussion – are the balconies on Fasilidas's palace in equilibrium? What happens when someone walks on them. The answer is, of course, that they are in equilibrium, but if they are overloaded and collapse, they are not!

Finally, go through the conditions of rotational equilibrium with the students.

**Activity 7.6: Answer**

The students should conclude that as the force is moved towards the right-hand end of the bar, the force needed decreases. When they change the angle, they should conclude that vertical component of the force stays the same.

| | |
|---|---|
| **SA = starter activity  MA = main activity  CA = concluding activity** | |
| **Static and dynamic equilibrium** | |
| **SA** | With a partner, write definition of 'static' and 'dynamic'. Feed back ideas. |
| **MA** | Activity 7.5 in a small group. |
| **CA** | Report on activity with a partner. |
| **Equilibrium of a bar and a ladder** | |
| **SA** | Worked example 7.6 with a partner without given solution. Feed back ideas. |
| **MA** | Activity 7.6 in small group. |
| **CA** | Worked example 7.7 with a partner without given solution. Feed back ideas. |
| **Design a toy** | |
| **SA** | What characteristics does a child's toy need if it is to bounce back to the vertical when it is pushed? Discuss with a partner and feed back ideas. |
| **MA** | Activity 7.7 in small groups. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Demonstrating conditions for equilibrium.
- How forces change for a system to stay in equilibrium.
- Designing a small child's toy that doesn't fall over.

## Where next?

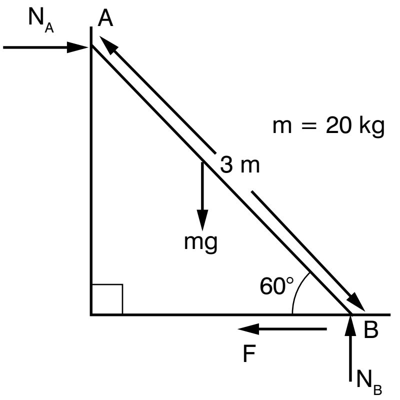
Equilibrium of forces is an important concept in the design of buildings, bridges etc. Engineers analyse the equilibrium to see how a structure will behave when a load is added to it, for example when a truck drives across a bridge.

## Answers to review questions

1. a) 16.7 cm from right-hand end of bar.

   b) 28 cm from left-hand end of bar.

2. 19.6 N along the wire.

3. 


Ladder equlibrium so $\Sigma F = 0$

Vertical components: $N_B - mg = 0$

$N_B = mg$

$= 20 \times 9.81$

$= 196.2$ N

Horizontal components: $N_A - F = 0 \quad N_A = F$

Similarly, moments about any axis $\Sigma\tau = 0$

Use B, and take anticlockwise as positive:

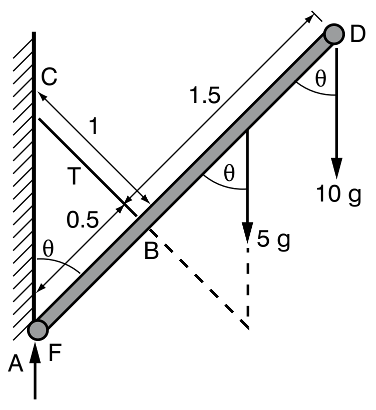
$mg \times 1.5 \times \cos 60 - N_A \times 3 \times \sin 60 = 0$

$15 = 2.598\ N_A$

$N_A = \dfrac{15}{2.598}$

$= 5.77$ N

$N_A = F$ so $F = 5.77$ N

4. 


a) Rod in equilibrium

$T = 15\ g \sin\theta$

$\theta = \tan^{-1}\left(\dfrac{1}{0.5}\right)$

$= 63.4°$

$T = 15 \times 9.81 \times \sin 63.4$

$= 131.6$ N

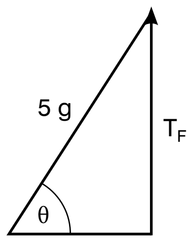
b) Rod in equlibrium

F – 15 g + component of T indirect[1] of F, $T_F = 0$

$T_F \sin\theta = 5\text{ g}$

$$T_F = \frac{5\text{ g}}{\sin\theta}$$

$= 5.59\text{ g}$




F – 15 g + 5.59 g = 0

F = 9.41 g

= 9.41 × 9.81

= 92.3 N

## 7.4 Couples

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

### Learning Competencies

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

- Define the term couples.
- Describe the rotational effects of couples on the rigid body.
- Solve problems involving the equilibrium of coplanar forces.

### Starting off

Check that the students understand the conditions for rotational equilibrium.

## Teaching notes

Go through the Students' Book introducing a couple and compare the direction of the forces in a couple with the direction of the forces in rotational equilibrium shown in Figure 7.25.

Guide students through Worked example 7.9 on page 156 to demonstrate the independence of the axis for taking moments when considering a couple. Go through the properties of a couple.

Ask the students to do Activity 7.8. This could lead into a discussion on when the torque applied by a spanner becomes a couple, e.g. when using a socket set that you use like a screwdriver.

Go through Worked example 7.10 on page 156 with the students.

### Activity 7.8: Answer

Students should be able to think of examples such as using a screwdriver (the force exerted by your hand on the screwdriver and the force exerted by the blade of the screwdriver on the head of the screw).

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Couples in everyday life** | |
| **SA** | Why are the forces used to turn the handle of a tap a couple? Discuss with a partner and feed back ideas. |
| **MA** | Activity 7.8 in small group. |
| **CA** | Report results of activity. |

| Summary of learning | |
|---|---|
| **SA** | Review question to be tackled with a partner. |
| **MA** | With a partner, make a poster to summarise this unit. |
| **CA** | End of unit questions to be tackled with a partner. |

## Activity

- Examples of couples.

## Where next?

Students will learn more about couples when they learn more about electromagnetism in Grade 12.

## Answers to review question

1. a) 40 N m

   b) 12 N m

## Answers to end of unit questions

1. **equilibrium** a body is in equilibrium when the net force and net moment on the particle are zero

   **concurrent forces** forces that all pass through the same point

   **moment of a force** the force multiplied by the perpendicular distance from the point about which the moment is being measured

   **coplanar forces** a set of forces that act in the same plane

   **static equilibrium** type of equilibrium that occurs when a body is at rest and there is no net force or net torque acting on it

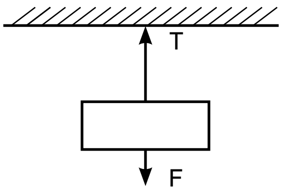
   **dynamic equilibrium** type of equilibrium that occurs when a body is moving at a steady velocity and there is no net force or net torque acting on it

   **couples** a set of forces with a resultant moment but no net force

2. Torque is a turning effect.

3. a) The net force (or the sum of the force vectors) must be zero. The net torque must be zero.

   b) A body may be in dynamic equilibrium where it is moving but there are no forces or torque acting on it. In this case it is not in static equilibrium.

4. 


The box is in equilibrium.

T = F = ma

= (20 + 1) × 9.8

= 205.8 N

5. Resolve horizontally

$P \cos 30 - 4 \cos 45° = 0$ **1**

Resolve vertically

$P \sin 30 + 4 \sin 45 - \theta = 0$ **2**

Solve

$$P = \frac{4 \cos 45}{\cos 30}$$

= 3.27 N (3 s. f.)

Ø = P sin 30 + 4 sin 45

= 4.46 N ( 3 s. f.)

6. a) Resolve along plane and take direction up plane as positive.

$P \cos a - 8 - 5 \sin 30 = 0$

$P \cos a = 8 + 5 \sin 30$ **1**

Resolve perpendicular to plane.

$P \sin a + 2 - 5 \cos 30 = 0$

$P \sin a + 2 = 5 \cos 30 - 2$ **2**

Divide **2** by **1**.

$$\tan a = \frac{5 \cos 30 - 2}{8 + 5 \sin 30} = \frac{2.330}{10.5} = 0.222$$

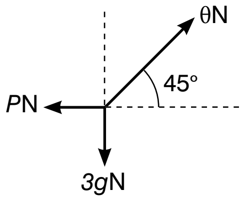
a = 12.5° (3 s. f.)

b) Substitute into equation **1**.

P cos 12.5 = 10.5

P = 10.8 N (3 s. f.)

7.




a) Resolve vertically

$\theta \sin 45 - 3g = 0$

$\theta = \dfrac{3g}{\sin 45}$

$= 3\sqrt{2}\, g$

$= 42$ N (2 s. f.)

b) Resolve horizontally

$\theta \cos 45 - P = 0$

$P = 3\sqrt{2}\, g \cos 45°$

$= 3\, g$

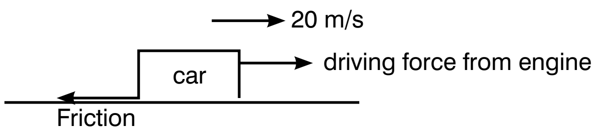
$= 29$ N (2 s. f.)

8. If a body is in rotational equilibrium, the sum of all the external torques acting on the body must be zero.

9. Concurrent forces all pass through the same point. Coplanar forces act in the same plane.

10. If a body is not moving and there are no net forces or torque on the body, it is in static equilibrium. If a body is moving and there are no net forces or net torque acting on the body, there is no net acceleration. The body will continue to move at the same velocity. The body is in dynamic equilibrium.

11. a)




b) If car is in dynamic equilibrium, then driving force from engine = friction. To determine whether car is in dynamic equilibrium, we need to know values of driving force and friction.

# Properties of bulk matter

# Unit 8

**Learning Competencies for Unit 8**

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

- Define the terms elastic limit, stress, strain, Young's modulus, shear modulus.
- State Hooke's law.
- Carry out calculations involving stress, strain, Young's modulus and the energy stored in a stretched material.
- Define the terms density, atmospheric pressure, absolute pressure, pressure, volume.
- Describe the concepts related to hydraulic and pneumatic systems.
- State and apply Archimedes's principle.
- Define surface tension and surface energy.
- Define the angle of contact and account for the shapes of the surfaces of liquids.
- Determine the relationship for capillary rise and use it to solve problems.
- Define the terms laminar and turbulent flow, flow rate.
- Identify factors affecting laminar flow and give examples.
- Identify factors that affect the streamlining of cars, boats and planes.
- Define the Reynolds number.
- State Bernoulli's principle.
- Explain applications of Bernoulli's principle.
- Use Bernoulli's equation to solve problems.
- State Stokes's law and use it to solve problems.
- Use the equation of continuity to solve problems.
- Define the terms calorimetry, phase, phase change, phase diagram, state variable, critical point, triple point, latent heat, heat capacity, specific heat capacity.
- Distinguish between heat, temperature, internal energy and work.
- State the units for heat, heat capacity, specific heat capacity and latent heat.
- Explain the factors that determine the rate of heat flow through a material.
- Describe the thermal expansion of solids in terms of the molecular theory of matter.
- Carry out calculations involving expansivity.
- Solve problems involving thermal conductivity.
- Describe experiments to measure latent heat.

This unit should fill approximately **30 periods** of teaching time.

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

## 8.1 Elastic behaviour

### Learning Competencies

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

- Define the terms elastic limit, stress, strain, Young's modulus, shear modulus.
- State Hooke's law.
- Carry out calculations involving stress, strain, Young's modulus and the energy stored in a stretched material.

### Starting off

Revise work that the students have already done on forces. Question them as follows. What are Newton's three laws? Why do we need two equal but opposite forces to cause a body to deform? (Think about Newton's first and third laws.) Why would a body that was subject to a single force start to move with increasing speed? (Newton's second law.)

## Teaching notes

**Activity 8.1: Answer**

Students' own results.

Activity 8.1 gives students an opportunity to experience deforming forces. Discuss the various types of deforming forces carefully. If possible, demonstrate them using modelling clay (or better still, give each student a small piece of clay and ask them to subject it to the various forces as you work through the text).

Explain the difference between elasticity in metals and non-metals carefully. You could use two rulers to represent layers of atoms in a metal sliding over each other. You could ask a small group of students to link arms to represent the molecules in a non-metal such as rubber. As 'the material' is stretched, the distance between the 'molecules' increases, but the bonds do not break. When the stretching force is removed, the distance decreases again.

**Activity 8.2: Answer**

Students' own results.

**Activity 8.3: Answer**

Students' own results.

**Activity 8.4: Answer**

Students' own results.

Activity 8.2 gives students a chance to explore tensile deformation. Note that the apparatus for this activity is also used for Activities 8.3 and 8.4.

Go through the worked examples carefully – you may wish to present students with the problems without the solution initially so that you can assess understanding by seeing how they tackle it. This is a general principle for using worked examples and ensures that students are actively learning rather than passively reading the text but not really internalising it.

We then move on to consider concepts that follow from the students' experience of Activity 8.2. Hooke's law applies to the straight part of the graph they obtained, the elastic limit is indicated by the graph, and Young's modulus can be found by considering the straight line part of the graph.

Activity 8.3 gives students an opportunity to find the elastic limit for the wire and Activity 8.4 is a chance for them to measure Young's modulus.

Make sure that the students are clear about the difference between bulk modulus and shear modulus. Ask them to describe these two concepts in their own words. The formula for strain energy is derived by considering the average force exerted on the wire. (This derivation has parallels with the derivation for the energy stored in a charged capacitor, which students met in Grade 10.)

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Deforming forces** | |
| **SA** | Why would a single force cause a body to start moving with increasing speed? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.1 in a small group. |
| **CA** | Report on the activity with a partner. |
| **Exploring tensile deformation** | |
| **SA** | Why do you think steel has a lower elastic limit than rubber? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.2 in a small group. |
| **CA** | Report on the activity with a partner. |
| **Hooke's law and the elastic limit** | |
| **SA** | What is happening to the atoms of the material at the yield point? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.3 in a small group. |
| **CA** | Report on the activity with a partner. |
| **Ductile and brittle materials** | |
| **SA** | With a partner, write a definition of 'ductile' and 'brittle'. Feed back ideas. |
| **MA** | With a partner, carry out some research into ductile and brittle materials. Present your findings in a form of your choice. |
| **CA** | Presentation of research. |
| **Young's modulus** | |
| **SA** | Worked example 8.3 with a partner without given solution. Feed back ideas. |
| **MA** | Activity 8.4 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Bulk modulus, shear modulus and strain energy** | |
| **SA** | With a partner, write definitions of 'bulk modulus', 'shear modulus' and 'strain energy'. Feed back ideas. |
| **MA** | With a partner, summarise the learning in this unit. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Experiencing deforming forces.
- Exploring tensile deformation.
- Finding the elastic limit.
- Measuring Young's modulus.

## Where next?

Having considered solids in this unit, the next unit moves on to consider statics of fluids.

## Answers to review questions

1. a) The elastic limit is the load at which elastic behaviour ceases.

   b) Stress $= \dfrac{\text{force}}{\text{area}}$

   c) Strain $= \dfrac{\text{extension}}{\text{original length}}$

   d) Young's modulus $= \dfrac{\text{force} \times \text{original length}}{\text{extension} \times \text{cross-sectional area}}$

   e) Shear modulus $= \dfrac{\text{shear stress}}{\text{shear strain}}$

2. The extension in a wire is proportional to the applied force up to the elastic limit of the material.

   a) Stress = force/area

   $= \dfrac{20}{\pi \times (1 \times 10^{-3})^2} = 6{,}366{,}198 \text{ N m}^2$

   b) Strain = extension/original length

   $= \dfrac{0.24 \times 10^{-3}}{4} = 0.00006$

   c) Young's modulus = force × original length/extension × cross-sectional area

   $= \dfrac{20 \times 4}{0.24 \times 10^{-3} \times \pi \times (1 \times 10^{-3})^2}$

   $= \dfrac{80}{7.54 \times 10^{-10}}$

   $= 1.06 \times 10^{11}$

   d) Strain energy = ½ × force × extension = ½ × 20 × 0.24 × $10^{-3}$ = 0.0024 J

3. a) Young's modulus = force × original length/extension × cross-sectional area so

   force = Young's modulus × extension × cross sectional area/original length

   $= \dfrac{2.0 \times 10^{11} \times 1 \times 10^{-3} \times \pi \times (0.8 \times 10^{-3})^2}{6}$

   = 402.12/6

   = 67.02

   = 6.702 kg

   b) Strain energy = ½ × force × extension = ½ × 67.02 × 1 × $10^{-3}$ = 0.034 J

## 8.2 Fluid statics

This section should fill approximately **8 periods** of teaching time.

### Learning Competencies

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

- Define the terms density, atmospheric pressure, absolute pressure, pressure, volume.
- Describe the concepts related to hydraulic and pneumatic systems.
- State and apply Archimedes's principle.
- Define surface tension and surface energy.
- Define the angle of contact and account for the shapes of the surfaces of liquids.
- Determine the relationship for capillary rise and use it to solve problems.

### Starting off

Show students a column of liquid such as water. Ask them to consider an object at various depths in the column. Where do they think the object will feel the greatest force from the water above? (This may seem trivial but it is important that students realise that pressure is related to depth in a liquid.) Discuss the key terms for the first section: can the students define them in their own words? (They will have met density and volume in mathematics, for example.)

## Teaching notes

Work through the derivation of the pressure at height $h$ in a column of fluid carefully, if possible with a column of fluid for the students to look at as a visual aid. Activity 8.5 (the Cartesian diver) demonstrates the transmission of pressure by fluids. Students should work in small groups and be encouraged to discuss and try to explain their observations.

Pascal's law states that pressure exerted anywhere in a liquid is transmitted equally and undiminished in all directions. You may wish students to carry out Activity 8.6 as a home assignment. This would be an opportunity for the students to practise carrying out an investigation independently and writing a report so that you can follow what happened during the investigation. A writing frame for reports is provided in Unit 1. This skill is an important one for students to develop and is how scientific ideas are communicated worldwide.

Activity 8.7 gives students an opportunity to carry out some research into applications of hydraulics; they should also look at applications of pneumatics. They are asked to present their findings in a form of their choice: ideas could be posters or presentations with visual aids.

Archimedes's principle is simple but has wide implications and uses. Activity 8.8 asks students to find the density of an object by applying Archimedes's principle.

Activity 8.9 is more open ended and you may wish the students to begin it in class and complete it as a home assignment, again writing a report as for Activity 8.6.

**Activity 8.5: Answer**

Students' own results.

**Activity 8.6: Answer**

Students' own results.

**Activity 8.7: Answer**

Students' own research.

**Activity 8.8: Answer**

Since density = mass/volume, they should measure the volume of liquid displaced by the object and find its mass and then substitute these values into the density equation to find the density.

**Activity 8.9: Answer**

Students' own results.

**Activity 8.10: Answer**

Students' own results.

**Activity 8.11: Answer**

Students' own presentation.

**Activity 8.12: Answer**

Students' own results.

**Activity 8.13: Answer**

Students' own results.

**Activity 8.14: Answer**

Students' own presentation.

We move on now to consider surface tension. Begin by asking the students where they have observed the phenomena in everyday life: insects on water are one example, but when you heat milk it forms a 'skin' on the top onto which you can pour a certain amount of powder before it starts to break through the skin. Activity 8.10 gives students an opportunity to explore surface tension before you work through the theory. As you work through the theory, if you can demonstrate the trivial experiment with the block coming out of water, this will help students.

We move on to consider pressure difference across a surface film, which refers back to the observations in Activity 8.10.

Activity 8.11 gives students an opportunity to consolidate their understanding by producing a presentation on the applications of surface tension ideas.

When considering angle of contact and capillary action, the theory will be much more accessible for the students if you have a tube or tubes and invert them as described in Activity 8.12. The equation for the height *h* of a liquid column looks complicated but could be rewritten in words as:

$$\text{height of column} = \frac{2 \times \text{surface tension} \times \cos \text{contact angle}}{\text{density} \times g \times \text{radius of tube}}$$

Some students find words more memorable than symbols and you should take account of this in your teaching.

Work through the worked example as suggested in Section 8.1 – again, this gives students a chance to consolidate their understanding by applying the equation in a different context.

Activities 8.13 and 8.14 explore capillary action and examples of applications of capillary action.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Pressure due to a fluid column** | |
| **SA** | With a partner, work through the formula for pressure at depth *h*. |
| **MA** | Activity 8.5 in small groups. |
| **CA** | Discuss the results of the activity. |
| **Pascal's law and its applications** | |
| **SA** | With a partner, describe how hydraulic brakes work. Feed back ideas. |
| **MA** | Activity 8.6 in small groups. |
| **CA** | Worked example 8.5 with a partner without given solution. Feed back ideas. |
| **Other applications of hydraulics** | |
| **SA** | With a partner, write down one thing you learnt in the last lesson. Feed back ideas. |
| **MA** | Activity 8.7 in small groups. |
| **CA** | Present research from activity. |
| **Archimedes's principle** | |
| **SA** | In a small group, drop a small stone into a measuring jug half full of water. What happens to the level of the water? |
| **MA** | Activity 8.8 in a small group. |
| **CA** | Activity 8.9 in a small group. |

| Surface tension (1) | |
|---|---|
| **SA** | With a partner, write a definition of 'surface tension'. Feed back ideas. |
| **MA** | Activity 8.10 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Surface tension (2)** | |
| **SA** | With a partner, list some instances where you observe surface tension in everyday life. Feed back ideas. |
| **MA** | Activity 8.11 in small group. |
| **CA** | Presentation from activity. |
| **Demonstrating capillary action** | |
| **SA** | Why must all forces balance where two surfaces meet? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.12 in a small group. |
| **CA** | Activity 8.13 in a small group. |
| **Applications of capillary action** | |
| **SA** | Activity 8.14 in a small group. |
| **MA** | Presentations of research. |
| **CA** | Review questions to be tackled with a partner. |

## Activities

- Demonstrating the transmission of pressure by fluids (Cartesian diver).
- Demonstrating Pascal's law.
- Other applications of hydraulics.
- Finding the density of an object using Archimedes's principle.
- Exploring Archimedes's principle.
- Exploring the effects of surface tension.
- Applications of surface tension ideas.
- Demonstrating capillary action in a tube.
- Exploring capillary action.
- Exploring applications of capillary action.

## Where next?

The next section moves on to consider fluids in motion, which includes types of flow.

## Answers to review questions

1. a) density = mass/volume
   b) atmospheric pressure is the pressure exerted by the air around us
   c) absolute pressure = force applied/perpendicular area
   d) pressure = force/area
   e) volume = cross-sectional area × height

2. a) Archimedes's principle states that any object, wholly or partially immersed in a fluid, is buoyed up by a force which is equal to the weight of the fluid displaced by the object.

   b) Archimedes's principle is used when working out the rotational stability of vessels. Designers need to ensure that any angular displacement of the vessel will move the line of action of the forces on the vessel so that a righting moment is set up. Archimedes's principle is also used as airships rise and submarines dive.

3. a) Surface tension is the force per unit length on the surface of the liquid.

   b) The surface energy is the energy created by the disruption to the molecules at the surface of the liquid, which appear to be pulled inwards.

4. a) The angle of contact is the angle formed when two surfaces meet.

   b) Where a water surface meets a glass container, the glass pulls some of the water to it and the angle of contact creates a meniscus.

5. a) $h = \dfrac{2 \times \text{surface tension} \times \cos \text{contact angle}}{\text{density} \times g \times \text{radius of tube}}$

   b) $h = \dfrac{2 \times 0.26 \times \cos 29}{2.28 \times 9.81 \times 20 \times 10^{-3}}$

   $= \dfrac{0.4548}{0.447336}$

   $= 1.02$

This section should fill approximately **8 periods** of teaching time.

## 8.3 Fluid dynamics

### Learning Competencies

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

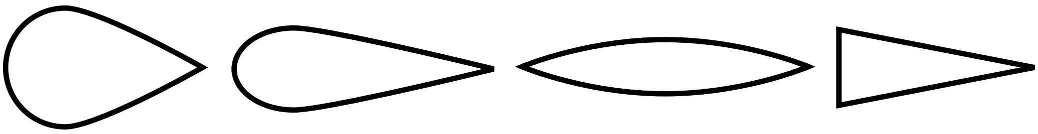
- Define the terms laminar and turbulent flow, flow rate.
- Identify factors affecting laminar flow and give examples.
- Identify factors that affect the streamlining of cars, boats and planes.
- Define the Reynolds number.
- State Bernoulli's principle.
- Explain applications of Bernoulli's principle.
- Use Bernoulli's equation to solve problems.
- State Stokes's law and use it to solve problems.
- Use the equation of continuity to solve problems.

### Starting off

This topic has plenty of applications in real life which will motivate students. Find out whether students have experienced travelling by air – have they ever experienced 'turbulence'? Do any students follow motor sports (or indeed any sports which involve streamlined vehicles such as cycling)? Explain that this topic explores some of the Physics behind such sports.

## Teaching notes

Study the diagram showing laminar flow carefully with the students. You could give some further examples of shapes such as these and ask students to draw laminar flow around them.



When you are discussing Bernoulli's principle and how it relates to flight, it would be helpful if you had a model of an aircraft to show students and point out where pressure reduces above the wing and where there is normal pressure below the wing, and how this lifts the aeroplane upwards.

When you discuss turbulent flow, talk about the eddy currents and point out that these are observed in everyday life when water flows down a drain.

Make sure that students do not miss the definition of flow rate.

The section on factors which affect laminar flow should be studied carefully, as should the section on factors affecting streamlining. Activities 8.15 and 8.16 give students opportunities to explore streamlining, first by comparing a streamlined vehicle with an ordinary vehicle, and then by experimenting with making their own shapes and trying to make them as streamlined as possible.

The equation of continuity looks very complicated but its effects are observed readily, as described in Activity 8.17. The summary statement, that the rate of fluid going into the system has to be the same as the rate of fluid coming out of the system, is also fairly readily understood. The worked example is an important step: in this instance it would be worth working through the steps with the students and then giving them another example based on this one to see that they have understood the method. (A further question of this type is given as question 9 in the review questions.)

We then move on to explore Bernoulli's equation. Again, the equation looks complicated, but the simplified version is very much easier for students to grasp, as demonstrated in the worked example. Activities 8.18 and 8.19 are two ways to demonstrate Bernoulli's principle: you might consider half the class doing Activity 8.18 while the other half do Activity 8.19, and then swap over. This reduces the amount of equipment required. Alternatively you could set Activity 8.18 as a home assignment, with students being required to produce a written report.

Students may like to research more applications of Bernoulli's principle and produce a presentation for the rest of the class.

We move on to discuss viscosity. Activity 8.20 gives students the opportunity to devise an investigation. They should check their proposal with you before they begin – you should check that they are not proposing to do anything hazardous. Again, they should be expected to produce a written report.

The coefficient of viscosity links with Stokes's law and terminal velocity. Activity 8.21 gives students an opportunity to measure terminal velocities.

**Activity 8.15: Answer**

Shape: race car streamlined. Height above ground.

**Activity 8.16: Answer**

Students' own results.

**Activity 8.17: Answer**

Students' own results.

**Activity 8.18: Answer**

Students' own results.

**Activity 8.19: Answer**

Students' own results.

**Activity 8.20: Answer**

Students' own results.

**Activity 8.21: Answer**

Students' own results.

The final section talks about Reynolds number, which determines whether flow will be laminar or turbulent.

| **SA = starter activity  MA = main activity  CA = concluding activity** | |
|---|---|
| **Streamlining (1)** | |
| **SA** | With a partner, write a definition of 'streamlining'. Feed back ideas. |
| **MA** | Activity 8.15 in small groups. |
| **CA** | Feed back from activity. |
| **Streamlining (2)** | |
| **SA** | With a partner, write down the factors that affect streamlining. Feed back ideas. |
| **MA** | Activity 8.16 in small groups. |
| **CA** | With a partner, report on activity. |
| **The equation of continuity** | |
| **SA** | Why is $V_{in} = V_{out}$? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.17 in a small group. |
| **CA** | Explain the activity results. |
| **Bernoulli's principle (1)** | |
| **SA** | With a partner, write a definition for 'incompressible'. Feed back ideas. |
| **MA** | Activity 8.18 in small groups. |
| **CA** | Write a report on the activity with a partner. |
| **Bernoulli's principle (2)** | |
| **SA** | With a partner, write down one thing that you learnt from the last lesson. Feed back ideas. |
| **MA** | Activity 8.19 in a small group. |
| **CA** | With a partner, research further applications of Bernoulli's principle. Write a report on your findings. |
| **Viscosity** | |
| **SA** | With a partner, write a definition of 'viscosity'. Feed back ideas. |
| **MA** | Activity 8.20 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Terminal velocities** | |
| **SA** | Will a ball fall faster in water or in oil? Why? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.21 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Summarising learning** | |
| **SA** | In pairs, devise a question based on this topic for other students to answer. (You must know the answer yourselves!) |
| **MA** | With a partner, summarise this topic in the form of your choice. |
| **CA** | Review questions with a partner. |

## Activities

- Identifying streamlining features on motorsport vehicles.
- Exploring streamlining.
- Application of the equation of continuity.
- Demonstrating Bernoulli's principle 1.
- Demonstration Bernoulli's principle 2.
- Comparing viscosity of various liquids.
- Measuring terminal velocities.

## Where next?

The next topic moves to consider heat, temperature and thermal expansion.

## Answers to review questions

1. Examples of laminar flow are flows around streamlined objects such as motorsport vehicles.
2. Factors that affect the streamlining of cars, boats and planes are reducing the surface area of the front of the vehicle so that it travels faster, making the vehicle lower slung so that its centre of mass is lower, and making the edges curved so that air can flow over them easily.
3. The Reynolds number is the variable in equations that describe whether flow conditions lead to laminar or turbulent flow. In a pipe that is straight and has a circular cross section, if the Reynolds number is less than 2300 the flow is generally considered to be laminar.
4. Bernoulli's principle says that a fluid travelling over a surface of an object exerts less pressure than if the fluid were still.
5. static pressure + dynamic pressure = total pressure

   9 Pa + 3 Pa = 12 Pa
6. Stokes's law is the viscous drag force $F$ which acts on a sphere of radius $r$ travelling at a velocity $v$ through a fluid of viscosity $\eta$ is given by:

   $F = 6\pi\eta rv$
7. The equation of continuing states that the volume flow rate of an ideal fluid flowing through a closed system is the same at every point.

This section should fill approximately **8 periods** of teaching time.

## 8.4 Heat, temperature and thermal expansion

### Learning Competencies

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

- Define the terms calorimetry, phase, phase change, phase diagram, state variable, critical point, triple point, latent heat, heat capacity, specific heat capacity.
- Distinguish between heat, temperature, internal energy and work.
- Give the units for heat, heat capacity, specific heat capacity and latent heat.
- Explain the factors that determine the rate of heat flow through a material.
- Describe the thermal expansion of solids in terms of the molecular theory of matter.
- Carry out calculations involving expansivity.
- Solve problems involving thermal conductivity.
- Describe experiments to measure latent heat.

### Starting off

Once again, this topic explores the Physics behind many phenomena that students will experience every day. Start by talking about boiling water: do the students think it would take longer to boil one cup of water or one jug of water? Ask them to explain their reasoning. Talk about ice cubes and why they are used in drinks. What effect do they have on the drink? Talk about heat conduction: what happens if you have a pan with a metal handle as the pan heats up?

## Teaching notes

We begin by exploring the amount of heat energy needed to heat water. Students have met this concept in Grade 9, Unit 7.3, so this should be revision for them, but their responses to the starting off questions may have given you some indication about how much they actually recall and how much will have to be retaught. Go through the initial theory, asking questions to check understanding. Set the worked example as a problem for students to solve before revealing the given solution – again, this will give you valuable feedback about students' existing knowledge.

**Activity 8.22: Answer**

Students' own results.

Activity 8.22 has various points that need to be stressed. The first is that the heater needs to be fully submerged under the water and the second is that the container needs to be as insulated as possible. Ask students why this is and check that they realise that they need to minimise heat loss. We give sample readings and the steps in the calculation in case the students' readings are not usable, but do encourage students to use their own readings and follow the steps in the calculation if at all possible.

Calorimetry is a term students need to know but is simply the science of measuring the heat of chemical reactions or physical changes such as changing from ice to water.

We then move on to discuss changes of state and phase-change diagrams. Students need to be clear about the different states of matter and the arrangement of atoms or molecules in the various states: put simply, solids have atoms or molecules that are close together and usually arranged in a lattice of some form, liquids have atoms or molecules that are further apart and have more kinetic energy, and the atoms or molecules in gases are some distance apart and have considerable kinetic energy.

It is important that you discuss the various terms carefully and question students to ensure understanding of the phase-change diagram. Activity 8.23 is an opportunity to consolidate this learning.

Latent heat is the heat involved when there is a change of state. Activities 8.24 and 8.25 give students the opportunity to measure the specific latent heat of vapourisation of water and the specific latent heat of melting ice.

We then move on to discuss the specific latent heat of fusion, which is then explored further in Activity 8.26, where students measure the specific latent heat of fusion of ice. Again, we give sample data but students should be encouraged to use their own data if at all possible. Give examples to give students the opportunity to use the formula to find the specific latent heat of vapourisation.

We discuss the distinction between heat, temperature, internal energy and work. The distinction between heat and temperature is clear as long as students remember that heat is a form of energy. Temperature is related to the internal energy of the molecules in the substance – students will learn more about this when they cover kinetic theory. Work is the energy that is fed into the system.

The next sections cover heat transfer by conduction. Activity 8.27 gives students an opportunity to explore the conduction of heat in copper, while Activity 8.28 gives them the chance to look at heat transfer in insulators. You could ask them to compare the two situations. In each case, they should write a report on their investigation.

Go through the section on thermal conductivity carefully and ensure that students are able to manipulate the formulae. The worked examples should be gone through carefully and then you should give further examples for practice. Questions 6 and 7 of the review questions are examples you could use as the basis for your own questions.

The Stefan–Boltzmann law applies to black body radiation. Again, make sure that students are comfortable with manipulating the equation.

Newton's law of cooling is used in forensic science to establish the length of time an object has been at a crime scene. Activity 8.30 gives students the opportunity to choose an investigation into cooling.

The final section talks about the expansion of solids in terms of the molecular theory of matter – put simply, as a material is heated, the distance between the molecules increases and so the solid expands. Students will learn more about this when they cover the kinetic theory of matter.

**Activity 8.23: Answer**

Students need to be able to define triple point and critical point (see Students' Book page 187)

**Activity 8.24: Answer**

Students' own results.

**Activity 8.25: Answer**

Students' own results.

**Activity 8.26: Answer**

Students' own results.

**Activity 8.27: Answer**

Students' own results.

**Activity 8.28: Answer**

Students' own results.

**Activity 8.29: Answer**

Students' own results.

**Activity 8.30: Answer**

Students' own results.

| SA = starter activity MA = main activity CA = concluding activity | |
|---|---|
| **Specific heat capacity** | |
| **SA** | Worked example 8.13 with a partner without given solution. Feed back ideas. |
| **MA** | Activity 8.22 in small groups. |
| **CA** | Write a report on the activity with a partner. |
| **Change of state** | |
| **SA** | Activity 8.23 in a small group. |
| **MA** | Activity 8.24 in a small group. |
| **CA** | Write a report on activity 8.24 with a partner. |
| **Specific latent heat of fusion** | |
| **SA** | With a partner, write a definition of 'specific latent heat of fusion'. Feed back ideas. |
| **MA** | Activity 8.25 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Specific latent heat of vapourisation of water** | |
| **SA** | With a partner, write a definition of 'vapourisation'. Feed back ideas. |
| **MA** | Activity 8.26 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Conduction in copper** | |
| **SA** | Why does copper conduct heat? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.27 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Heat transfer in insulators** | |
| **SA** | What is an insulator? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.28 in a small group. |
| **CA** | Write a report on the activity with a partner. |
| **Convection** | |
| **SA** | How does a kettle heat water to boiling point? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.29 in a small group. |
| **CA** | Review questions to be tackled with a partner. |
| **Investigating cooling** | |
| **SA** | What factors would reduce the rate of cooling of some hot water in a beaker? Discuss with a partner and feed back ideas. |
| **MA** | Activity 8.30 in a small group. |
| **CA** | End of unit questions to be tackled with a partner. |

## Activities

- Measuring the specific heat capacity of a liquid by electrical heating.
- The phase diagram.
- Measuring the specific heat of vapourisation of water.
- Determining the amount of heat necessary to convert a known quantity of ice at 0°C to water at 0°C.
- Measuring the specific latent heat of fusion of ice.
- Conduction in copper.
- Heat transfer in insulators.
- Investigating cooling.

## Where next?

This unit lays foundations for later study of the kinetic theory of matter and the gas laws.

## Answers to review questions

1. a) Calorimetry is the science of measuring the heat of chemical reactions or physical changes.

   b) A phase is a state of matter, e.g. solid, liquid or gas.

   c) A phase change is where a substance changes phase from solid to liquid, for example.

   d) A phase diagram summarises the phase changes for a substance.

   e) A state variable is a property such as temperature, pressure and internal energy.

   f) Latent heat is the heat energy required or released when a substance changes state.

   g) Heat capacity is the heat energy needed to change from one state to another.

   h) Specific heat capacity is the heat energy needed to change 1 kg of a substance from one state to another.

2. Heat is a form of energy. Temperature is related to the internal energy of the molecules in the substance and is a measure of hotness. Work is the energy that is fed into the system.

3. The units for heat are J, the units for heat capacity are J $K^{-1}$, the units for specific heat capacity are J $kg^{-1}K^{-1}$ and the units for latent heat are J $kg^{-1}$.

4. The factors that determine the rate of heat flow through a material are: the material itself, the area of cross section, the temperature gradient across the material.

5. $450 \times A \times (100 - \theta)/2.0 = 150 \times A \times (\theta - 30)/1.2$

   $450 \times (100 - \theta)/2.0 = 150 \times (\theta - 30)/1.2$

   $450 \times (100 - \theta) \times 1.2 = 150 \times (\theta - 30) \times 2.0$

   $(45000 - 450\,\theta) \times 1.2 = (150\,\theta - 4500) \times 2.0$

   $54000 - 540\,\theta = 300\,\theta - 9000$

   $63000 = 840\,\theta$

   $75 = \theta$

   So for bar B, rate of flow of heat = $450 \times 1.0 \times 10^{-4} \times (100 - 75)$

   = 1.125 W = rate of flow of heat for C

6. In principle the method is straightforward. You must take some water at its boiling point, and find out how much energy has to be supplied so that 1 kg (or 1 g) shall be boiled away. In practice, how can this be done?

   A method using a Bunsen burner is depicted in Figure 8.36.

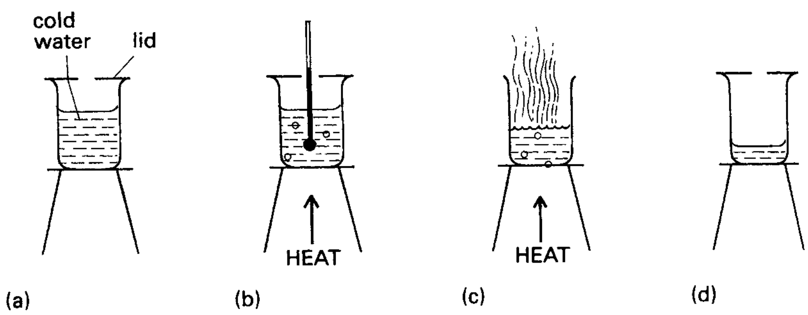



*Figure 8.36* *a) The mass of the cold water is known. b) The water is brought to the boil, using a Bunsen burner whose flame is not altered. Readings of temperature and time are taken. c) Still keeping the flame constant, the water is boiled for 10 minutes. d) The lid is replaced and the apparatus weighted to find out how much water has been boiled away.*

Set up the apparatus as shown. The thermometer is there to measure how quickly the Bunsen burner heats the water. This enables you to work out how many joules of heat energy the Bunsen burner is supplying every second, so the flame must not be altered throughout the experiment.

Take readings and work out how much energy is needed to turn 1 g of water to steam.

## Answers to end of unit questions

1. **elastic deformations** deformations where, when forces that caused deformation are removed, body goes back to its original dimensions

   **plastic deformations** deformations where irreversible changes occur when the body is being deformed

   **elastic limit** point beyond which all materials are permanently deformed

   **tensile stress** tensile force F divided by the cross-section area A of the wire tensile stress = $\frac{F}{A}$

   **tensile strain** extension x divided by the wire's original length, L tensile strain = $\frac{F}{A}$

   **Hooke's law** the force applied to a material is directly proportional to its extension, up to the elastic limit

   **limit of proportionality** point at which extension and applied force are no longer proportional

   **yield point** point where there is a sudden increase in extension

   **Young's modulus** the ratio of tensile stress to tensile strain up to the material's limit of proportionality

   **bulk modulus** a measure of the ability of a substance to resist changes in volume when under increasing pressure from all sides

   **shear modulus** a measure of the ability of a substance to resist deformation caused by a force parallel to one of its surfaces

   **shear stress** the force divided by the cross-sectional area which is being sheared

   **shear strain** $\frac{\Delta x}{L}$

   **atmospheric pressure** the pressure exerted by weight of air against a surface

   **density** the mass per unit volume of a substance

   **pressure** the amount of force acting per unit area

   **volume** the amount of space filled by an object or substance

   **absolute pressure** the actual pressure at a given point

   **Pascal's law** the pressure applied to an enclosed fluid is transmitted to every part of the fluid without reducing in value

   **Archimedes's principle** the buoyant force on an object wholly or partially immersed in a fluid is equal to the weight of the fluid displaced by the object

   **surface tension** a property of a liquid's surface that causes it to act like a stretched elastic skin; it is caused by the forces of attraction between the particles of the liquid and the other substances with which it comes into contact

   **surface energy** a measure of the disruption of intermolecular bonds caused by a surface

   **contact angle** the angle at which a liquid surface meets a solid surface

   **capillary action** the movement of a liquid along the surface of a solid caused by the attraction of molecules of the liquid to molecules of the solid

**meniscus** a curve in the surface of a liquid caused by the relative attraction of the liquid molecules to the solid surfaces of the container

**Bernoulli's principle** principle stating that as the velocity of a fluid increases, the pressure exerted by that fluid decreases

**streamline/laminar flow** type of fluid flow where the fluid travels smoothly in regular layers; the velocity and pressure remain constant at every point in the fluid

**turbulent flow** type of fluid flow where there is disruption to the layers of fluid; the speed of the fluid at any point is continuously changing both in magnitude and direction

**flow rate** the volume of liquid flowing past a given point per unit time

**equation of continuity** the mass flow rate of fluid flowing into a system is equal to the mass flow rate of fluid leaving the system

**viscosity** the internal resistance of a fluid to flow and a measure of 'thickness' of a fluid

**terminal velocity** the maximum constant velocity reached by a falling body when the drag force acting on it is equal to the force of gravity acting on it

**specific heat capacity** the heat energy required to raise the temperature of 1 kg of a given substance by 1 K

**heat capacity** the heat capacity, C, of a body of mass m is given by heat capacity + m × specifc heat capacity

**calorimetry** the experimental approach to measuring heat capacities and heat changes during chemical and physical processes

**critical point** the temperature and pressure at which the liquid and gas phases of a substance become identical

**phase** the distinct form of a substance under different conditions, e.g. solid, liquid, gas

**phase change** a change from one state of matter to another without a change in chemical composition

**phase change diagram** a graph of pressure against temperature which can be used to show the conditions under which each phase of a substance exists

**state variable** a variable that describes the state of a dynamic system. In thermodynamics, this may include properties such as temperature, pressure or internal energy

**triple point** the temperature and pressure at which the three phases of a substance coexist

**latent heat** the amount of energy released or absorbed by a substance during a change of state that occurs without a change in temperature

**internal energy** energy possessed by the molecules of a substance

**conduction** the transfer of heat energy through a material from molecule to molecule without any movement of the material itself

**insulation** use of a material that does not conduct heat energy and hence can prevent heat gain or loss

**thermal conductivity** a measurement of the ability of a material to conduct heat

**black body** a theoretical object that absorbs all electromagnetic radiation that hits it

**Newton's law of cooling** the rate of change of the temperature of an object is proportional to the difference between its own temperature and the temperature of its surroundings

2. Hooke's law states the force applied to a material is directly proportional to its extension, up to the elastic limit.

3. a) Young's modulus = force × original length/extension × cross sectional area

   Extension = force × original length/Young's modulus × cross sectional area

   $= \frac{5 \times 1.5}{1.0 \times 1011 \times \pi \times (0.15 \times 10^{-3})^2}$

   $= \frac{7.5}{7068.6}$

   = 0.001 m

   b) Strain energy = ½ × force × extension = ½ × 5 × 0.001 = 0.0025 J

4. In hydraulic systems, liquids transmit pressure from one point to another, such as in vehicle brake systems. In pneumatic systems, air is used to transmit pressure from one point to another.

6. Factors affecting laminar flow are density, compressibility, temperature and viscosity.

5. $h = \frac{2 \times \text{surface tension} \times \cos\theta}{egr}$

   $= \frac{2 \times 0.26 \times \cos 29}{2.28 \times 9.81 \times 20 \times 10^{-3}}$

   $= \frac{0.454}{0.447}$

   = 1.02 m

7. Bernoulli's principle applies to aeroplanes in flight: the pressure below the wing is greater than that above the wing. The carburettor in engines has a region of low pressure where the air is moving at its fastest speed to draw fuel into the carburettor and mix it thoroughly with air.

8. Consider healthy artery

| Flow rate ($cm^3$/min) | $\Delta p$ (mm Hg) | $r$ (cm) | η(kg/m/s) | $L$ (cm) |
|---|---|---|---|---|
| 100 | 120 | r | η | 10 |

Consider diseased artery

| Flow rate ($cm^3$/min) | $\Delta p$ (mm Hg) | $r$ (cm) | η(kg/m/s) | $L$ (cm) |
|---|---|---|---|---|
| 100 | ? | $\frac{1}{2}$r | η | 10 |

Use

$$\text{flow rate} = \frac{\pi \times \Delta p \times r^4}{8 \times \eta \times L}$$

$$\frac{\pi \times 120 \times r^4}{8 \times \eta \times L} = \frac{\pi \times \Delta p \times (\frac{1}{2}r)^4}{8 \times \eta \times L}$$

$$120 \times r^4 = \frac{\Delta p \times r^4}{16}$$

$$120 \times 16 = \Delta p$$

$$= 1920 \text{ mm Hg}$$

9. $F = 6\pi\eta rv = 6\pi \times 0.985 \times 5 \times 10^{-3} \times 0.35 = 0.032$ N

10. Using equation (2) the velocity in the 150 mm pipe can be calculated as

$(20\ m^3/h) \times (1/3600\ h/s) = v_{150} \times (3.14 \times (0.15\ m)^2/4)$

or

$v_{150} = (20\ m^3/h) \times (1/3600\ h/s) / (3.14\ (0.15\ m)^2 / 4) = 0.0055/0.0177$

$= 0.31$ m/s

Using equation (2) the velocity in the 120 mm pipe can be calculated

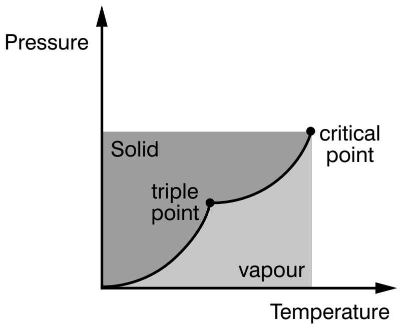
$(20\ m^3/h)(1 / 3600\ h/s) = v_{80}\ (3.14\ (0.12\ m)^2 / 4)$

or

$v80 = (20\ m^3/h)(1 / 3600\ h/s) / (3.14\ (0.12\ m)^2 / 4) = 0.0055/0.011$

$= 0.5$ m/s

11. a)

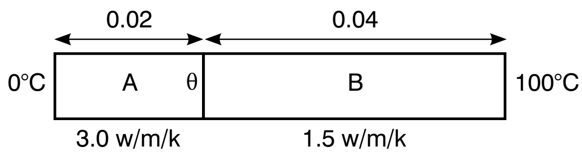



b) i) critical point – point at which liquid and gas phases become indistinguishable.

ii) triple point – point at which all three states coexist together.

12. a) rate of flow of heart

b)




$$\frac{3 \times \cancel{A} \times (\theta)}{0.02} = \frac{1.5 \times \cancel{A} \times (100 - \theta)}{0.04}$$

$$\frac{3\,\theta}{0.02} = \frac{1.5\,(100 - \theta)}{0.04}$$

$$\frac{3\theta}{0.02} = \frac{1.5 - 1.5\theta}{0.04}$$

$$0.04\,(3\theta) = (150 - 1.5\theta)\,0.02$$

$$0.12\theta = 3 - 0.03\theta$$

$$0.12\theta + 0.03\theta = 3$$

$$0.15\theta = 3$$

$$\theta = 20°$$

c) Consider bar A

$$\text{rate of flow} = \frac{3 \times A \times 20}{0.02}$$

$$= \frac{60\ A}{0.02}$$

$$= 3000\ A\ W$$

where A is area of cross section.

13. Copper is a particularly good conductor of heat, and Figure 8.37 shows a demonstration of this.

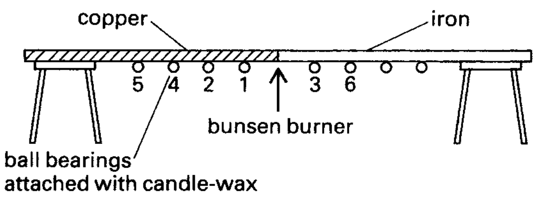



***Figure 8.37*** *How to show that copper is a better conductor of heat than iron*

Take a long bar made of copper at one end and iron at the other, joined together with a rivet. At regular intervals along it attach ball bearings with candle wax. Heat the bar strongly at its midpoint with a Bunsen burner. Record your observations. Try to explain them before reading on.

As heat is conducted along the bar in both directions, the wax melts and the ball bearings drop off. The iron conducts the heat, but not as well as the copper: the numbers on Figure 8.37 indicate a likely order in which the balls will fall.

# Minimum learning competencies

Grade 11

| Area of Competency | Grade 11 |
|---|---|
| **Measurement** | **1. Measurement and practical work**<br>• Explain the importance of measurement in life<br>• Explain about sources of errors and their types<br>• Differentiate between accepted and experimental values<br>• Add and subtract scientific notation, keeping significant figures properly<br>• Multiply scientific figures keeping significant figures properly.<br>• Define the term scientific method and state the steps of scientific methods<br>• Explain the possible sources of errors and state the types of errors<br>• Distinguish between systematic and random error |
| **Vectors** | **2. Vector quantities**<br>• Distinguish between vector and scalar quantities, and give examples of each<br>• Determine the resolved part of a vector in any given direction<br>• Add vectors by graphical representation to determine a resultant<br>• Determine graphically a resultant of two vectors<br>• Add/subtract two or more vectors by the vector addition rule<br>• Determine the magnitude and direction of the resolution of two or more vectors using Pythagoras theorem and trigonometry<br>• Solve problems related to scalar and vector products of two vectors in a plane<br>• Explain properties of vector operations<br>• Identify vectors<br>• Represent the real quantities |
| **Kinematics** | **3. Kinematics**<br>• Use the scientific terms: speed, velocity, distance, displacement, acceleration, instantaneous velocity and acceleration correctly and state their SI units<br>• Explain the difference between average speed (or velocity) and instantaneous speed (or velocity)<br>• Solve numerical problems involving average velocity, instantaneous velocity and acceleration<br>• Explain uniform circular motion in the horizontal and vertical planes with reference to the forces involved<br>• Explain uniform circular motion in the horizontal and vertical planes with reference to the forces involved<br>• Identify circular motion requires the application of a constant force directed toward the centre of the circle<br>• Solve problems involving objects moving in two dimensions<br>• Describe the behaviour of motion of a freely falling body |

| | |
|---|---|
| **Energy** | **4. Work, energy and power**<br>• Define and use the terms work, energy, and power<br>• Use the principle of conservation of energy in the solution of problems<br>• Distinguish between elastic and inelastic collisions and solve problems involving such collisions<br>• Identify the relationship between work and change in kinetic energy<br>• Distinguish between conservative and non conservative forces<br>• Explain the energy transformation occurring during oscillations<br>• Solve problems involving elastic and inelastic collisions in one and two dimension by using the principles of conservation of momentum and energy |
| **Dynamics** | **5. Dynamics**<br>• State and use Newton's laws<br>• State Newton's 2nd law interims of momentum<br>• Apply Newton's laws of motion to explain and predict the behaviour of bodies acted uponby external forces<br>• Use the principle of momentum conservation<br>• Explain qualitatively how frictional forces depend on the nature of surfaces and normal contact force<br>• Use free body diagram representing forces on a point mass to solve problems<br>• Solve numerical problems involving Newton's laws of motion<br>• Determine the forces needed to keep an object moving in horizontal and vertical circles<br>• Define the centre of mass of a body and that of a system of particles |
| **Mechanics** | **6. Rotational motion**<br>• Define and use the terms: angular displacement, angular velocity, angular acceleration, moment of inertia, angular momentum, angular impulse and torque<br>• Use the equations for uniformly accelerated angular motion<br>• Use the equations relating linear and angular motions<br>• State the similarities and differences between the behaviour of rotating bodies and bodies travelling with linear velocity<br>• Identify the factors which determine the moment of inertia of a body<br>• State and apply the law of conservation of angular momentum<br>• Determine the velocity and acceleration of a point in the rotating body<br>• Demonstrate the direction of angular velocity, angular acceleration and angular momentum using the right-hand rule |

| | |
|---|---|
| **Static** | **7. Equilibrium**<br>• Distinguish between coplanar and concurrent forces<br>• Find the resultant of a number of concurrent forces acting at a point<br>• Solve problems involving the equilibrium of coplanar forces<br>• State the conditions for there to be no rotation of a body<br>• State the equilibrium conditions for a body acted on by coplanar forces |
| **Mechanics** | **8. Properties of bulk matter**<br>• Define the scientific terms: elastic limit, stress, strain, Young modulus, Shear modulus, viscous flow, viscosity, stream line flow, turbulent flow<br>• Use equation of continuity to solve numerical problems<br>• Describe the application of Bernoulli's principle in everyday life situation<br>• State and use Bernoulli's equation to solve problems<br>• Define surface tension and surface energy<br>• Define the angle of contact and account for the shapes of liquid surfaces<br>• Determine the relationship for the capillary rise and use it in problems<br>• Define the terms: calorimetry, change of phase, latent heat, heat capacity, specific heat capacity<br>• Distinguish between the concepts: heat, temperature, internal energy, work<br>• Identify the units for heat, heat capacity, specific heat capacity, latent heat<br>• Solve problems involving thermal conductivity, change of state and expansivity<br>• Describe properties that can be used for temperature measurement<br>• Explain the methods used for the measurement of specific heat capacities<br>• Relate latent heat to intermolecular forces |

# Physics syllabus

## General objectives of Grade 11 physics

After completing Grade 11 physics lessons students will be able to:

- Understand the basic concepts of measurement and practical work, vector quantities, kinematics, dynamics, the law of conservation of energy, and the way energy is transformed and transmitted, the concepts and units related to energy, work, and power and the laws of conservation of momentum for objects moving in one and two dimensions, properties of bulk matter
- Develop manipulative skills in solving problems related to kinematical and dynamical problems related to translational and rotational motions, the laws of conservation of momentum and energy
- Develop scientific-inquiry skills as they verify accepted laws and solve both assigned problems and those emerging from their investigations
- Analyse the interrelationships between physics and technology, and consider the impact of technological applications of physics on society and the environment
- Solve the problems using a variety of problem-solving skills.

## Unit 1: Measurement and practical work (8 periods)

### Unit outcomes: Students will be able to:

- Demonstrate knowledge and understandings in the science of measurement, errors in measurement
- Develop skills in experimenting and report writing
- Understand a systematic and random errors in the measurement of a physical quantity
- Communicate the procedures and results of investigations and research for specific purposes using data tables, laboratory reports, and account for discrepancies between theoretical and experimental values with reference to experimental uncertainty
- Express the result of any calculation involving experimental data to the appropriate number of decimal places or significant figures
- Identify and describe science- and technology-based careers related to the subject area under study
- Select and use appropriate SI units (units of measurement of the International System of Units).

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Identify the orders of magnitude that will be appropriate and the uncertainty that may be present in the measurement of data<br>• Identify and use appropriate units for data that will be collected | **1. Measurement & practical work**<br>**1.1 Science of measurement**<br>(1 period)<br>**1.2 Errors in measurement**<br>(2 periods)<br>**1.3 Precision, accuracy and significance**<br>(3 periods) | The purposes of this unit are to introduce measurement, precision and accuracy as well as reporting experimental results. Initiate discussion on what measurement is and what it is not. Distinguish between different types of errors. Illustrate significant digits using actual measurements. Students should be taught to estimate the last digit rather than to ignore it.<br>Calculators provide more digits than are significant, especially when performing multiplication and division. If students recognise this and report the correct number then the major objective of this unit is achieved. |
| • Use terminology and reporting styles appropriately and successfully to communicate information and understanding<br>• Distinguish between precision and accuracy<br>• State what is meant by the precision of a measuring instrument<br>• State what is meant by the degree of precision of a measuring instrument<br>• Distinguish between random uncertainties and systematic errors | **1.4. Experiment and report writing**<br>(2 periods) | • Appropriate calculations on errors<br>• Let the students say something on how error in measurement arises. After listening to their response, give an explanation on measurement and uncertainty. The point is that error is attributed to a process, not the individual. Measurements in science are conducted many times, sometimes hundreds, to get accurate values.<br>Activity: students will make a measurement of an object: say the volume of a box, or the volume of a soccer ball.<br>• Assist students in becoming familiar with metric units by identifying various units with parts of human body. Approximately 1 cm is width of small fingernail; 1m is 'reach' from tip of chin to tip of outstretched hand. Substitution of units in equations in algebra will provide preliminary check on correctness of equation format.<br>• Show glass beakers of various sizes up to 1 litre. Use food colouring in water to improve visibility. Also show several common liquid measures and ask students to estimate volumes in SI units. Have students bring cardboard box from grocery store for which they have calculated volume in litres.<br>• Measure precisely 100 cc alcohol (ethanol) and pour into graduated cylinder. Add precisely 100 cc of water and observe final volume is not 200 cc! Discuss conservation of mass vs volume.<br>• Teachers need to make sure students use the correct units when solving physics problems. If a problem presents information about a quantity like time in different units, they need to convert that information to the same units. You convert units by:<br>1. Knowing the conversion factor (say, 12 inches to a foot; 2.54 centimetres to an inch).<br>2. Multiplying by the conversion factor (such as 3.28 feet/1.00 metre) so that you cancel units in both the numerator and denominator. For example, to convert metres to feet, you multiply by 3.28 ft/m so that the metre units cancel.<br>In conversions, it is easy to make mistakes so it is good to check your work. To make sure you are applying conversions correctly, make sure the appropriate units cancel. To do this, you note the units associated with each value and each conversion factor. |

## 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

Students working at the minimum requirement level will be able to: define and describe concepts related to vectors, scalars, representation of vectors, addition and subtraction of vectors, condition of equilibrium; apply mathematical concepts such as the Pythagorean Theorem and trigonometric relationships in solving vector problems; resolve a vector into its two independent component vectors; determine the resultant vector of two or more non-perpendicular vectors acting in two dimensions using the vector component method.

### Students above minimum requirement level

A student working above the minimum requirement level will be able to: define the terms precision, uncertainty, error, magnitude of order; state the types of errors, distinguish between random and systematic error, use the appropriate units for the given measurements, convert from one unit of measurement to another, describe the procedures of report writing of the experiment, state the uncertainty in a single measurement of a quantity, explain the importance of measurement in life, explain about sources of errors and their types, differentiate between accepted and experimental values, add and subtract scientific notation, keeping significant figures properly, multiply scientific figures keeping significant figures properly, define the term scientific method and state the steps of scientific methods, explain the possible sources of errors.

### 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: Vector quantities (18 periods)

### Unit outcomes: Students will be able to:

- Familiarise themselves with basic principles of operations of vectors
- Acquire knowledge and understandings in nature, and properties of vectors
- Apply the knowledge of vectors in interpreting physical phenomena
- Develop skills in using vector concepts in the solution of problems
- Analyse experimental data, using vectors, graphs, trigonometry, and the resolution of vectors into perpendicular components, to determine the net force acting on an object and its resulting motion
- Appreciate the use of vector algebra in treating physical concepts.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Demonstrate an understanding of the difference between scalars and vectors and give common examples<br>• Add vectors by graphical representation to determine a resultant<br>• Explain what a position vector is<br>• Use vector notation and arrow representation of a vector<br>• Specify the unit vector in the direction of a given vector<br>• Add/subtract two or more vectors by the vector addition rule<br>• Determine the magnitude and direction of the resolution of two or more vectors using Pythagoras theorem<br>• Use the geometric definition of the scalar product to calculate the scalar product of two given vectors<br>• Use the scalar product to determine projection of a vector onto another vector<br>• Test two given vectors for orthogonality<br>• Use the vector product to test for collinear vectors | **2. Vector quantities**<br>Definition of vectors.<br>**2.1. Types of vectors**<br>(3 periods)<br>**2.1.1. Position vector**<br>**2.1.2. Unit vectors**<br>**2.1.3. Collinear and coplanar vectors**<br>**2.2. Resolution of vectors**<br>(2 periods)<br>**2.3. Vector addition and subtraction**<br>(7 periods)<br>**2.3.1. graphical methods**<br>**2.3.2. Analytic methods (Triangle and Parallelogram laws)**<br>**2.3.3. Component method**<br>**2.4. Multiplication of vectors** (6 periods)<br>**2.4.1. Multiplication of vector by a scalar**<br>**2.4.2. Scalar product**<br>**2.4.3. Vector product** | There are many practical examples of vector addition, and several should be discussed in class. Some of these include the motion of a boat in water, an airplane in wind, and a sled in snow. Statics, the equilibrium condition of point objects, also has many common examples.<br>The need for vector, rather than scalar, addition of forces is best displayed by means of a demonstration.<br>• Use arrows, drawn to scale, "heads to tail" to show triangle law (i.e. the resultant of two vectors completes the triangle formed by the two).<br>• Commutative law of vector addition can be demonstrated by producing same resultant when varying order of vector addition.<br>• Help students to show how three non-zero vectors can be added up to be zero.<br>• Draw an example<br>• Appropriate calculations<br>**Experiments**<br>Find resultants using Newton balances or pulleys.<br>**Project Work(s)**<br>Investigation of the laws of equilibrium for a set of co-planar forces |

## 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: give the definitions of the terms: position vector, unit vectors, collinear, coplanar, non-coplanar vectors; add and subtract vectors by using graphical and analytical methods, use the triangle and parallelogram law of addition of vectors, define the scalar and vector product of vectors, apply the definitions of vector products to find the result of two or more vectors, resolve vectors into their rectangular components and along any given line, explain some of the applications of vectors. Distinguish between vector and scalar quantities, and give examples of each, determine the resolved part of a vector in any given direction, add vectors by graphical representation to determine a resultant, determine graphically a resultant of two vectors, add/subtract two or more vectors by the vector addition rule, solve problems related to scalar and vector products of two vectors in a plane, explain properties of vector operations.

### 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: Kinematics (20 periods)

### Unit outcomes: Students will be able to:

- Gain an understanding of the fundamental principles of kinematics in one and two dimensions
- Develop skills in applying equations of motions to solve practical problems
- Recognise the effect of air resistance and force of gravity on motion of a body in a plane
- Analyse the motion of objects in horizontal, vertical, and inclined planes, and predict parameters of the motion
- Investigate motion in a plane, through experiments
- Analyse 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
- Describe technological advances related to motion; and identify the effects of societal influences on transportation and safety issues.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Present information in tabular, graphical, written and diagrammatic form<br>• Report concisely on experimental procedures and results<br>• Use scientific calculators efficiently. Solve numerical kinematics problems<br>• Relate scientific concepts to issues in every day life<br>• Explain the science of kinematics underlying familiar facts, observations, and related phenomena<br>• Describe motion using vector analysis<br>• Analyse and predict, in quantitative terms, and explain the motion of a projectile with respect to the horizontal and vertical components of its motion<br>• Analyse and predict, in quantitative terms, and explain uniform circular motion in the horizontal and vertical planes with reference to the forces involved<br>• Describe Newton's law of universal gravitation, apply it quantitatively, and use it to explain planetary and satellite motion<br>• Identify circular motion requires the application of a constant force directed toward the centre of the circle | **3. Kinematics**<br>**3.1. Motion in a straight line** (10 periods)<br>**3.1.1. Frame of reference**<br>**3.1.2. Average and instantaneous velocity**<br>**3.1.3. Average and instantaneous acceleration**<br>**3.1.4. Motion with constant acceleration**<br>**3.1.5. Freely falling bodies**<br>**3.1.6. Graphical representation of motion**<br>**3.2. Motion in a plane** (10 periods)<br>**3.2.1. Projectile motion**<br>**3.2.2. Uniform circular motion**<br>**3.2.3. Motion in a vertical circle**<br>**3.2.4. Motion of a satellite**<br>**3.2.5. Relative velocity** | The content and approach to problem solving in this section are fundamental in the study of Physics. Encourage students to develop the habit of selecting the fundamental equation, solve for the unknown before substituting any numerical value and dimensional checks as necessary.<br>The section on Motion in a plane extends the concepts of linear motion to curvilinear motion. Activities should help students recognise that the motion of projectiles is the result of an object having linear motions in two directions at the same time.<br>The concept of the independence of the velocities, in the two directions, gives students considerable difficulty. One of the simplest and most effective means of demonstration the independence of velocities involves the use of a flexible ruler and two marbles or steel balls. Both balls, when flipped with the ruler, will leave the edge of the table at the same time. If students listen carefully, they will hear only one 'click' as both balls strike the floor simultaneously.<br>**Demonstration**<br>A long ramp along one side of a classroom can be used to illustrate accelerated motion. Distance travelled at the end of equal intervals of time can be marked with chalk. The acceleration equations should then be demonstrated by plotting distance versus time, and distance versus $(\text{time})^2$.<br>• Galileo's thought experiment that compares the time of two balls falling separately or tied together can be used to support the idea that acceleration due to gravity is constant.<br>• 'Monkey and Hunter' demonstration gives a more elaborate method of demonstrating the independence of velocities.<br>• Measurement of velocity and acceleration<br>• Measurement of g<br>• Investigation of relationship between period and length for a simple pendulum and hence calculation of g.<br>• Use ruler at edge of a table, with pencil as a pivot, to cause one coin to drop vertically while other coin is propelled horizontally. Both hit level floor simultaneously showing time of fall is independent of any horizontal motion. Test by changing height of fall and initial horizontal velocity.<br>• Use knife to punch two holes on opposite sides of Styrofoam cup near bottom. Fill with water and drop from height of several metres. During free fall, in accelerated frame of cup, water exerts no weight on cup; hence no pressure and stream ceases.<br>• Let students act out motions represented on graphs. Practice until they can do this without any pauses that are not shown on the graph. When they are able to execute the motions let them explain how they knew to move as they did. |

| | | |
|---|---|---|
| | | • Stress the fact that the object is speeding up if the velocity and acceleration have the same sign, whether positive or negative. If the velocity and acceleration have different signs, then the object is slowing down. Negative acceleration does not necessarily mean slowing down. Positive acceleration does not necessarily mean speeding up.<br>• Students often confuse a graph of motion with the trajectory of an object (e.g., a thrown ball) when viewing distance vs. time graphs. They are not the same thing. The path of an object moving through space can look completely different from a plot of the object's motion over time. For example, the trajectory of a coin tossed straight up in the air looks very different from a graph of its motion. A graph that plots variables such as money vs. time is not so confusing because there is no motion involved – there is only a variable changing over time. To break the habit of associating the path of the motion with the graph of the motion, it is helpful to ask students to compare distance vs. time graphs with similar graphs that represent entirely different situations. |

## 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 the terms reference frame, average velocity, instantaneous velocity, average acceleration, instantaneous acceleration, projectiles, relative velocity, uniform circular motion, radial force; derive kinematics equations and apply them to solve numerical problems, describe the motion of freely falling bodies, motion of satellites and motion of a body in horizontal and vertical circles, describe Newton's law of universal gravitation and use it to explain planetary and satellite motion, interpret graphs, draw graphs from the kinematical equations, derive equations for maximum height, range and total time of flight of a projectile, determine the relative velocities of bodies moving at an angle relative to each other, explain the difference between average speed (or velocity) and instantaneous speed (or velocity), solve numerical problems involving average velocity, instantaneous velocity and acceleration, explain uniform circular motion in the horizontal and vertical planes with reference to the forces involved, explain uniform circular motion in the horizontal and vertical planes with reference to the forces involved, identify circular motion requires the application of a constant force directed towards the centre of the circle, solve problems involving objects moving in two dimensions, describe the behaviour of motion of a freely falling body.

## 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: Dynamics (20 periods)

## Unit outcomes: Students will be able to:

- Realise that momentum is an inherent property of moving objects
- Demonstrate an understanding of the relationship between net force and the acceleration of an object in linear motion
- Analyse the effect of a net force in quantitative terms, using graphs, free-body diagrams, and vector diagrams
- Describe the contributions of Galileo and Newton to the understanding of dynamics
- Describe technological advances related to motion; and identify the effects of societal influences on transportation and safety issues
- Analyse ways in which an understanding of the dynamics of motion relates to the development and use of technological devices.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Interpret Newton's laws and apply these to moving objects<br>• Define, and when appropriate give examples of, such concepts as gravity, Newton's law of universal gravitation<br>• Describe how Newton's laws of motion and his law of universal gravitation explain the phenomenon of gravity and necessary conditions of 'weightlessness'<br>• Define and describe the concepts and units related to force, coefficients of friction, torque, and work<br>• Explain the conditions associated with the movement of objects at constant velocity | **4. Dynamics**<br>**4.1. The force concept**<br>(1 period)<br>**4.2. Basic laws of dynamics**<br>(3 periods)<br>**4.3. Law of conservation of linear momentum and its applications**<br>(5 periods)<br>**4.4. Elastic and inelastic collisions in one and two dimensions**<br>(3 periods)<br>**4.5. Centre of mass**<br>(2 periods) | The simplicity of Newton's laws makes them difficult for students to appreciate. Students must understand that Newton's laws govern all motion. Emphasise that the result of a net force is the acceleration of a body, and if no net force exists, the body will remain in equilibrium. Equilibrium includes moving with constant velocity.<br>Momentum and energy conservation are concepts that are equivalent to Newton's laws, but are more powerful and at the same time, more abstract. Forces can be felt and acceleration can be measured; momentum and energy must be calculated.<br>Citing collisions as sources of information in atomic and nuclear physics may be used to motivate students to take the content with increased interest. Most of the information known about the atomic nucleus is interpretation of collisions between subatomic particles since the famous Rutherford's alpha-scattering experiment.<br>**Experiments**<br>1. Determine static and kinetic friction by method of sliding block along an inclined surface.<br>• Demonstration of the Newton's laws using air track or tickertape timer or powder track timer, etc. If air track is unavailable a steel ball rolling across a smooth table has low enough friction to be useful as well.<br>• If available an air track or dynamics cart can be used to demonstrate collisions. Otherwise billiard balls serve very well to qualitatively observe collision between balls of equal or different masses. |

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| • Analyse, in qualitative and quantitative terms, the various forces acting on an object in a variety of situations, and describe the resulting motion of the object<br>• Solve dynamics problems involving friction<br>• Discover the relationship between impulse and momentum, according to Newton's 2nd law<br>• Apply quantitatively the law of conservation of linear momentum | **4.6. Momentum conservation in variable mass system (rocket propulsion, explosion...)**<br>(3 periods)<br>**4.7. Dynamics of uniform circular motion (banked curves)**<br>(3 periods) | Activity: determination of coefficient of friction between a given pair of surfaces.<br>• Let student standing on floor throw a ball filled with sand to demonstrator on cart. Ball provides momentum exchange. Construct carts using plywood about 60 × 100cm with hard ball bearing wheels.<br>• Persons on two carts play toss with sand jug, each receiving a reaction as result of throwing jug (action). Can also push on one another with flat outstretched palms to illustrate 3rd law. Show 2nd law by placing two persons on one cart and one on another cart. Show different accelerations for same force. Discuss other 3rd law examples including rockets, being careful to ask on what and where reaction force acts.<br>• Kneel on table with forearms flat on table and elbows touching knees. Place short object such as cigarette lighter at tips of outstretched fingers. Now place hands behind back and try to tip over object with nose without losing balance. Most women can, most men cannot because mass distribution for most men places in shoulder area, which shifts centre of mass forward of knees.<br>**Project Work(s)**<br>1. Group discussion on applications and presentation (seat belts, rocket travel, sports, all ball games, importance of friction in everyday experience, e.g. walking, use of lubricants, etc.) |

## 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 the terms dynamics, linear momentum, elastic and inelastic collision and centre of mass; state the laws of dynamics, the law of conservation of momentum; solve problems involving the basic laws of dynamics, momentum conservation and dynamics of circular motion, use Newton's laws, state Newton's 2nd law interims of momentum, apply Newton's laws of motion to explain and predict the behaviour of bodies acted by external forces, use the principle of momentum conservation, explain qualitatively how frictional forces depend on the nature of surfaces and normal contact force, use free body diagram representing forces on a point mass to solve problems, solve numerical problems involving Newton's laws of motion, determine the forces needed to keep an object moving in horizontal and vertical circles, define the centre of mass of a body and that of a system of particles.

## 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: Work, energy and power (13 periods)

### Unit outcomes: Students will be able to:

- Demonstrate an understanding, in qualitative and quantitative terms, of the concepts of work, energy, energy transformations and power
- Design and carry out experiments and solve problems involving energy transformations and the law of conservation of energy
- Analyse the costs and benefits of various energy sources and energy-transformation technologies that are used around the world, and explain how the application of scientific principles related to mechanical energy has led to the enhancement of sports and recreational activities
- Demonstrate an understanding of forms of energy, energy sources, energy transformations, energy losses, and efficiency, and the operation of common energy-transforming devices
- Construct or investigate devices that involve energy sources, energy transformations, and energy losses, and assess their efficiency
- Analyse and describe the operation of various technologies based on energy transfers and transformations, and evaluate the potential of energy-transformation technologies that use sources of renewable energy.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Describe and explain the exchange among potential energy, kinetic energy, and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object<br>• Predict velocities, heights, and spring compressions based on energy conservation<br>• Determine the energy stored in a spring<br>• Differentiate between energy, work, and force | **5. Work energy and power**<br>**5.1. Work as a scalar product** (1 period)<br>**5.2. Work done by a constant and variable force** (2 periods)<br>**5.3. Kinetic energy, work-energy theorem** (3 periods)<br>**5.4. Notion of potential energy** (2 periods)<br>**5.5. Conservation of energy** (2 periods)<br>**5.6. Conservative and dissipative forces** (2 periods)<br>**5.7 Power** (1 period) | Before delving into some specific forms of energy, the teacher should address the general topic of energy. Although it is a very important concept in physics, and an important topic in general, energy is notoriously hard to define. You may associate energy with motion, but not all forms of energy involve motion. A very important class of energy, potential energy, is based on the position or configuration of objects, not their motion. Students should understand that they can measure most forces, such as the force of a spring. They can see speed and decide which of two objects is moving faster. They can use a stopwatch to measure time. Quantifying energy is more elusive, because energy depends on multiple factors, such as an object's mass and the square of its speed, or the mass and positions of a system of objects. Despite these caveats, there are important principles that concern all forms of energy. First, there is a relationship between work and energy, Second, energy can transfer between objects. Third energy can change forms.<br>The first two sections of this unit are meant to pave the way for the consideration of more unifying concept vs. energy. Students may encounter difficulties with the concept of work. Although they repeat statements of the definition they may not grasp the implications of defining work in a precise manner. |

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| • Identify the relationship between work and change in kinetic energy<br>• Apply the law of mechanical energy conservation in daily life situations<br>• Analyse situations involving the concepts of mechanical energy and its transformation into other forms of energy according to the law of conservation of energy<br>• Solve problems involving conservation of energy in simple systems with various sources of potential energy, such as springs<br>• Analyse and explain common situations involving work and energy, using the work-energy theorem | | Discuss the difference between carrying a box down a corridor and pushing the same box along the floor. Examples of this nature can be explained in terms of the definition of work<br>(W =F θS) as well as in terms of energy changes.<br>Sufficient time should be devoted to discuss energy and its conservation. Only mechanical energy is to be dealt with in this unit. Other forms (thermal, electrical, etc.) need not be considered at this point.<br>• A spring-powered toy can demonstrate that work (W =F θS) is done on a spring, stored in the form of potential energy and converted to kinetic energy.<br>• Hang a pendulum from a support bar. Mount a metre stick horizontally behind the pendulum. Demonstrate that a pendulum starting its swing from a given height on one side of its rest position will swing the same height on the other-side. Measure this with the metre stick. Discuss transformation of energy from kinetic to potential and back.<br>• Explain the effects of energy transfers and energy transformations.<br>• Estimation of average power developed (by person running upstairs; person repeatedly lifting weights to a height, etc.)<br>• Appropriate calculations.<br>• Mousetrap car race: Mouse trap has stored potential energy when set. Have students build car in which trap is sole motive power. Compete to see which design moves car through greater displacement, which runs longest or highest average speed. Teaches principles of lever, friction, angular motion, and torque and much more.<br>**Experiments**<br>1. Determination of deformation of a spring due to a weight falling on it and compare the theoretical prediction experimentally<br>**Project Work(s)**<br>1. Investigate and write on the major energy source for household use in students' locality |

## 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 the terms work, energy, power, kinetic energy, potential energy, conservative and dissipative forces; identify work as a scalar product of force and displacement, calculate the work done by constant variable force, derive work-energy theorem, state the law of conservation of energy, apply work-energy theorem and the law of conservation of energy to solve practical problems, use the principle of conservation of energy in the solution of problems, distinguish between elastic and inelastic collisions and solve problems involving such collisions, identify the relationship between work and change in kinetic energy, distinguish between conservative and non conservative forces, explain the energy transformation occurring during oscillations, solve problems involving elastic and inelastic collisions in one and two dimension by using the principles of conservation of momentum and energy.

### 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: Rotational motion (17 periods)

### Unit outcomes: Students will be able to:

- Demonstrate an understanding of the concepts of work, energy, momentum, and the laws of conservation of energy and of momentum for objects moving in two dimensions, and explain them in qualitative and quantitative terms
- Investigate the laws of conservation of momentum and of energy (including elastic and inelastic collisions) through experiments and analyse and solve problems involving these laws with the aid of vectors, graphs, and free-body diagrams
- Analyse and describe the application of the concepts of energy and momentum to the design and development of a wide range of collision and impact-absorbing devices used in everyday life.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Use the relationship between torque and angular momentum according to Newton's second law, as well as its application in solving problems involving rigid bodies<br>• Specify the angular speed, angular velocity of a rotating body | **6. Rotational motion**<br>**6.1. Rotation about a fixed axis** (1 period)<br>**6.2. Torque and angular acceleration** (2 periods)<br>**6.3. Rotational kinetic energy and rotational inertia** (3 periods)<br>**6.4. Rotational dynamics of a rigid body** (3 periods) | This unit can be developed in analogy with that of linear motion. Emphasis on the analogy between the rotational quantities and linear quantities can be used.<br>**Experiments**<br>1. Centripetal force and velocity relation may be qualitatively observed by weight suspended from a rotating object through a tube.<br>2. Spin raw egg rapidly on its side. Stop it and then quickly release it. It begins to rotate again because its yolk never stopped rotating. Hard boiled eggs will not do this.<br>**Demonstrations**<br>1. Discs of identical shape but with different mass distribution from the centre can be used to illustrate the moment of inertia concept by rolling them down an inclined plane. |

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| • Determine the velocity and acceleration of a point in the rotating body<br>• Solve problems involving moment of inertia<br>• Solve problems that relates net torque and angular acceleration | **6.5. Parallel axis theorem** (1 period)<br>**6.6. Angular momentum and angular impulse** (2 periods)<br>**6.7. Conservation of angular momentum** (2 periods)<br>**6.8. Centre of mass of a rigid body (circular ring, disc, rod and sphere)** (3 periods) | 2. Measurement of the moment of inertia of a flywheel falling weight coupled to flywheel. Demonstration using swivel chair or rotating platform (masses held close to and away from the body).<br>3. A transparency showing multiple exposure of a falling object like a cat falling, a diver etc. is a good starting point to discuss moment of inertia.<br>**Project Work(s)**<br>1. Students may be asked to search literature, internet or from any other source to find out:<br>• why it is easier to balance on a bicycle when moving than when still?<br>• why a rolling coin does not topple until it has nearly stopped rolling?<br>Assist students to apply the equations in physics problems, the first step is to identify the known values and which values are being asked for. Sketching a diagram of the situation may help them with this. The next step is to find an equation that includes both the known and the unknown (asked-for) values. When applying the rotational equations, they should remember that positive displacement and velocity represent counterclockwise motion, and negative displacement and velocity indicate clockwise motion.<br>Discuss what causes an object to rotate more or less quickly, and how this relates to rotational work, rotational energy and angular momentum. Let students discover many similarities between linear and rotational dynamics, as well as some crucial differences.<br>Use a wrench that is loosening a nut to explain the concept of torque in more detail. Discuss two of the factors that determine the amount of torque. One factor is how much force F is exerted and the other is the distance *r* between the axis of rotation and the location where the force is applied.<br>**Demonstration**<br>• Rolling a yo-yo. Let the students construct a yo-yo using discarded metal spool. Best design is one having inner and outer radii which are substantially different, the larger the better. Attach string to inner radius and wrap several turns leaving enough to pass over pulley and attach hanging mass.<br>• Two Cans Race. Let students in group select two cans of same size and mass, one filled with liquid and other mainly solid. Alternatively use two cans of identical liquids (soft drink in metal), one frozen to behave like solid and other not. Let them roll down incline together and observe the motion. |

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| | | • Bicycle wheel-mass in extended hands. Let the teacher hold a bike wheel, at rest, overhead with axle vertical while standing or sitting on platform spin wheel with the other hand without waiting too long (else table friction will reduce angular momentum), grab wheel to stop it thereby restoring entire system to initial zero angular momentum. The students should note the effect of changing axle orientation from vertical to horizontal, while spinning.<br>• A girl rotating on a turntable has arms extended. She suddenly pulls her arms inward and her rotational velocity increases dramatically. Let students discuss and explain in terms of conservation of angular momentum. |

## 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 the terms: axis of rotation, torque, angular acceleration, rotational kinetic energy, rotational inertia, angular momentum, angular impulse; describe centre of mass of a rigid body, the relation between torque and angular acceleration; state the law of conservation of angular momentum, the parallel axis theorem; solve problems involving rotational dynamics. Use the equations for uniformly accelerated angular motion; use the equations relating linear and angular motions; state the similarities and differences between the behaviour of rotating bodies and bodies travelling with linear velocity; identify the factors which determine the moment of inertia of a body; state and apply the law of conservation of angular momentum; determine the velocity and acceleration of a point in the rotating body; demonstrate the direction of angular velocity, angular acceleration and angular momentum using the right-hand rule.

### 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

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# Unit 7: Equilibrium (10 periods)

## Unit outcomes: Students will be able to:

- Acquire knowledge and understanding in equilibrium conditions
- Apply physics principles and equations in solving problems on static equilibrium
- Develop skills in applying the conditions of equilibrium in the solutions of problems.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• State the equilibrium conditions for a body acted on by coplanar forces<br>• Experimentally verify the conditions necessary for the equilibrium of a set of non-concurrent forces<br>• Distinguish between coplanar and concurrent forces<br>• Find the resultant of a number of concurrent forces acting at a point<br>• Solve problems involving the equilibrium of coplanar forces<br>• State the conditions for rotational equilibrium | **7. Equilibrium**<br>**7.1. Equilibrium of a particle** (2 periods)<br>**7.2. Moment of torque or force** (3 periods)<br>**7.3. Conditions of equilibrium** (3 periods)<br>**7.4. Couples** (2 periods) | Torque or Moment of a force can be introduced by careful observation of a turning effect of a force on a spanner or on a door. Students may be guided to conclude that the turning effect of a given force is not only dependent on the magnitude of a force but also on the perpendicular distance of the line of action of the force from the pivot point.<br>Equilibrium of a particle is either the state of rest or uniform motion of a body. This implies the condition of zero net force on the particle. In the case of extended object, two equal and opposite forces may not necessarily cancel each other and may have rotational effect. This point needs emphasis in exercises and demonstrations.<br>**Experiments**<br>1. The conditions necessary for the equilibrium of a set of non-concurrent forces can be verified by Metre stick, metre stick knife-edge clamps, weight hangers, set of weights, balances and weights.<br>2. Put a number of coins on the top of a desk and show how stability decreases as the number increases. Help students to relate this with the upward shift of the centre of mass of the system.<br>**Demonstrations**<br>Stable, unstable and neutral equilibrium of rigid bodies can be demonstrated by putting bottle along the base, top and side respectively.<br>**Project Work(s)**<br>Students may report qualitative observation about torque and equilibrium on taps, doors, handlebars on bicycles, and in reference to moving-coil metres and simple motor<br>• Stress the fact that in physics, static equilibrium also requires a threefold path. First, there is no net force acting on the body. Second, there is no net torque on it about any axis of rotation. Finally, in the case of static equilibrium, there is no motion. An object moving with a constant linear and rotational velocity is also in equilibrium, but not in static equilibrium.<br>• Encourage students in tackling equilibrium problems. However; it is not always so easy to determine the axis of rotation. In those cases, it is helpful to remember that if the net torque is zero about one axis, it will be zero about any axis, so the choice of axis is up to you. However, this trick only works for cases when the net torque is zero. In general, the torque depends on one's choice of axis. |

## 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 the terms: equilibrium, moment of a force, and couples; state conditions for equilibrium; solve problems involving equilibrium of rigid bodies. Distinguish between coplanar and concurrent forces; find the resultant of a number of concurrent forces acting at a point; solve problems involving the equilibrium of coplanar forces; state the conditions for there to be no rotation of a body; state the equilibrium conditions for a body acted on by coplanar forces.

## Students above minimum requirement level

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## Students below minimum requirement level

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# Unit 8: Properties of bulk matter (30 periods)

## Unit outcomes: Students will be able to:

- Gain comprehensive knowledge on basic properties of fluids, thermal properties of matter, phase changes, ideal-gasses, calorimetry, heat transfer mechanisms
- Realise that the principles of fluid mechanics are widely applicable to modern technology
- Demonstrate an understanding of the scientific principles related to fluid static and dynamics, and to hydraulic and pneumatic systems
- Work with different temperature scales and solve calorimetry problems
- Use specific heats and heats of transformations in the practical application of calorimetry
- Analyse and describe the social and economic consequences of the development of technological applications related to the motion of fluids
- Appreciate application of fluid mechanics to the advancement of science and technology.

| Competencies | Contents | Suggested activities |
|---|---|---|
| Students will be able to:<br>• Define the terms Hooke's law, elastic limit, stress, strain, Young modulus, Shear modulus<br>• Perform calculations involving stress, strain, Young modulus and energy stored in a stretched material<br>• Define and describe the concepts and units related to fluids and to hydraulic and pneumatic systems (e.g., density, atmospheric pressure, absolute pressure, laminar and turbulent flow, pressure, volume, flow rate)<br>• Identify factors affecting laminar flow, and describe examples of laminar flow<br>• Identify the factors affecting the streamlining of cars, boats, planes<br>• State Archimedes's principle and its application<br>• Apply equation of continuity to solve problems<br>• Describe what Reynolds's number is<br>• State Bernoulli's principle<br>• Explain the applications of Bernoulli's principle in the fields of technology<br>• Use Bernoulli's equation to solve problems<br>• State Stokes's law and use it in problems | **8. Properties of bulk matter**<br>**8.1. Elastic behaviour** (6 periods)<br>**8.1.1. Stress-strain relation**<br>**8.1.2. Hooke's Law**<br>**8.1.3. Young's modulus**<br>**8.1.4. Bulk modulus**<br>**8.1.5. Shear modulus**<br>**8.2. Fluid statics** (8 periods)<br>**8.2.1. Pressure due to a fluid column**<br>**8.2.2. Pascal's law and applications**<br>**8.2.3. Archimedes's principle and applications**<br>**8.2.4. Surface energy and surface tension**<br>**8.2.5. Pressure difference across a surface film**<br>**8.2.6. Angle of contact and capillary**<br>**8.2.7. Applications of surface tension ideas**<br>**8.3. Fluid dynamics** (8 periods)<br>**8.3.1. Streamline and turbulent flow**<br>**8.3.2. Equation of continuity**<br>**8.3.3. Bernoulli's Equation**<br>**8.3.4. Viscosity**<br>**8.3.5. Stokes's law**<br>**8.3.6. Terminal Velocity**<br>**8.3.7. Reynolds's number** | The first two sections of this unit introduce the properties of solids and fluids. Connections to the kinetic theory are stressed. Problems that deal with applications of fluids at rest (hydrostatics) and thermal expansion of solids provide interesting examples of the technological applications of physics. Qualitative properties are best understood if students can see demonstrations of these properties.<br>The section on Heat introduces the concepts of thermal physics using microscopic point of view. It expands the concept of conservation of energy, and prepares students for the study of kinetic theory and gas laws.<br>• Determination of the density of an object denser than water using Archimedes's principle<br>• Determine the amount of heat necessary to convert a known quantity of ice at 0° C to water at 0° C<br>• Calibration curve of a thermometer using the laboratory mercury thermometer as a standard<br>• Measurement of specific heat capacity, e.g. of water or a metal by a mechanical or electrical method<br>• Measurement of the specific latent heat of fusion of ice<br>• Measurement of the specific latent heat of vapourisation of water<br>• The difference in elasticity between metallic and non-metallic solids should be shown. Also show the elastic limit, the point at which the bent metal no longer returns to its original shape.<br>**Demonstration**<br>A Cartesian diver shows properties of fluids very nicely. Toys can be used or a diver can be constructed. Take a small test tube, partially filled with water, and cover the open end with part of a balloon, securely fastened with a rubber band. Wait for the tube to float in water, glass end up. Place the tube in a clear plastic squeeze bottle that is completely filled with water. Cap the squeeze bottle that is completely filled with water. Cap the squeeze bottle securely, squeeze it, and the test tube should sink. You may have to experiment with the amount of water in the tube needed to produce the dramatic effect. Explain how this demonstrates that fluids transmit pressure equally, and that liquids are much less compressible than gases.<br>Appreciate the concept of forces in equilibrium to derive the equation for pressure in a liquid. The liquid is assumed to have a uniform density $\theta$, no matter what its depth. |

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| • Define surface tension and surface energy<br>• Define the angle of contact and account for the shapes of liquid surfaces<br>• Determine the relationship for the capillary rise and use it in problems<br>• Define the terms: calorimetry, phase, phase change, phase diagram, state variable, critical point, triple point, latent heat, heat capacity, specific heat capacity<br>• Distinguish between the concepts: heat, temperature, internal energy, work<br>• Identify the units for heat, heat capacity, specific heat capacity, latent heat<br>• Explain the factors which determine the rate of flow of heat through a material<br>• Describe the thermal expansion of solids in terms of molecular theory of matter<br>• Perform calculations involving expansivity<br>• Solve problems involving thermal conductivity<br>• Describe experiments by which latent heat can be measured | **8.4. Heat, Temperature and thermal expansion** (8 periods)<br>**8.4.1. Specific heat capacity**<br>**8.4.2. Calorimetry**<br>**8.4.3. Change of state**<br>**8.4.4. Heat transfer**<br>**8.4.5. Stefan –Boltzmann law**<br>**8.4.6. Thermal conductivity**<br>**8.4.7. Newton's law of cooling** | Let a teacher turn on a hose and watch the water flow out, and then cover half the hose end with his/her thumb. The water flows faster through the narrower opening. You have just demonstrated the fluid equation of continuity: How much volume flows per unit time – the volume rate of flow – stays constant in a closed system. The increased speed of the flow at the opening balances the decreased cross sectional area there. Of course after the water leaves the hose with its new speed, it is no longer in the closed system, and you cannot apply the equation of continuity to the resulting spray of droplets. They spread out without slowing down.<br>Discuss how Bernoulli's equation is used to analyse fluid flowing at different points in a closed system.<br>**Demonstration**<br>Bernoulli's principle can be demonstrated by supporting a ping-pong ball in a stream of air blown from a hair dryer. For an alternative method, insert a pin through an empty sewing thread spool and insert a pin through an index card. Place the pin into one hole of the spool and blow into the other hole. While blowing, turn the spool over. The card will be supported by the reduced pressure between the spool and card.<br>Balloons with two cups: let students demonstrate this experiment<br>Moisten lips of two Styrofoam cups with water and press cups firmly against opposite sides of partially inflated balloon. Upon further inflation, cups stick to balloon. Students should discuss in groups the cause.<br>Discuss p-T (phase diagram) and three states separated by curves for boiling, freezing, and sublimation, meeting at triple point. Boiling curve terminates at critical point for water, mention uniqueness of freezing curve resulting in lowering of freezing point with increase of applied pressure.<br>Suspend two light bulbs from table rod. Blow sharply between bulbs so as to hear them clank together. Suspend in field of overhead projector turned on its side to produce magnified image on ceiling. |

## 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 the terms: stress, strain, modulus, pressure, surface energy, surface tension, capillarity, streamlined, turbulent flow, viscosity, terminal velocity; state Hooke's law, Pascal's law, Archimedes's principle, Stokes's law, Stefen-Boltzmann's law and Newton's law of cooling; describe the stress-strain relation, equation of continuity, Bernoulli's equation, Reynolds's number, change of state and heat transfer; identify Young's modulus, bulk modulus, shear modulus; solve problems involving elastic behaviour, fluid statics and heat, use equation of continuity and Bernoulli's principle to solve problems; describe the application of Bernoulli's principle in everyday life situation; state and use Bernoulli's equation to solve problems; define the angle of contact and account for the shapes of liquid surfaces; determine the relationship for the capillary rise and use it in problems; define the terms: calorimetry, change of phase, latent heat, heat capacity, specific heat capacity; distinguish between the concepts: heat, temperature, internal energy, work; identify the units for heat, heat capacity, specific heat capacity, latent heat; solve problems involving thermal conductivity, change of state and expansivity; describe properties that can be used for temperature measurement; explain the methods used for the measurement of specific heat capacities; relate latent heat to intermolecular forces.

## 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.

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