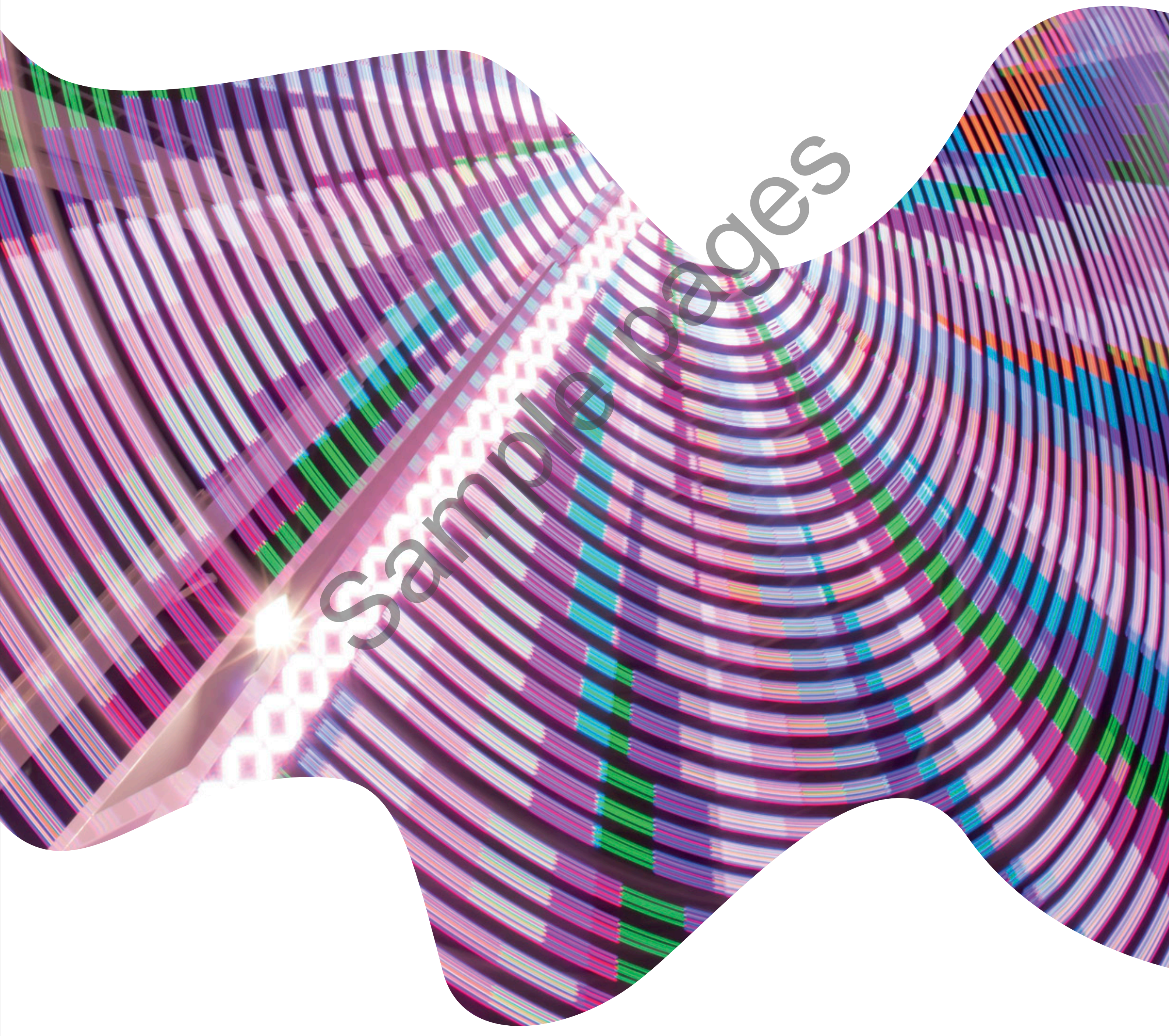
PEARSON

PHYSICS

NEW SOUTH WALES

SKILLS AND ASSESSMENT

12



Doug Bail

NSW
STAGE 6

Contents

Contents

Module 7: The nature of light

Module 8: From the universe to the atom

How to use this book

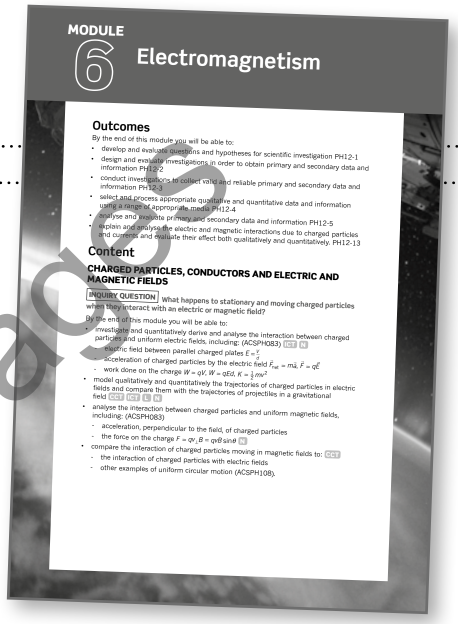
The *Pearson Physics 12 New South Wales Skills and Assessment* book takes an intuitive, self-paced approach to science education that ensures every student has opportunities to practise, apply and extend their learning through a range of supportive and challenging activities. While offering opportunities for reinforcement of key concepts, knowledge and skills, these activities enable flexibility in the approach to teaching and learning.

Explicit scaffolding makes learning objectives clear, and there are regular opportunities for student reflection and self-evaluation at the end of individual activities throughout the book. Students are also guided in self-reflection at the end of each module. There are rich opportunities to take the content further with the explicit coverage of Working scientifically skills and key knowledge in the depth studies.

This resource has been written to the new Stage 6 Syllabus for New South Wales Physics and addresses the final four modules of the syllabus. Each module consists of five main sections:

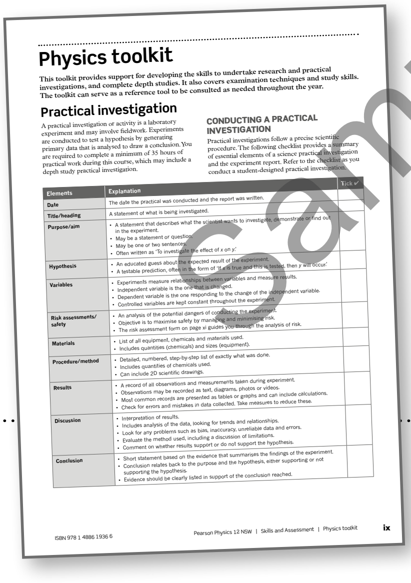
- key knowledge
- worksheets
- practical activities
- depth study
- module review questions.

Explore how to use this book below.



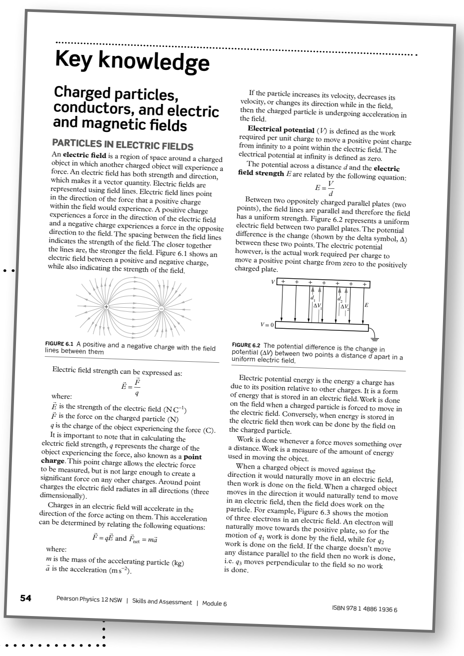
Physics toolkit

The Physics toolkit supports development of the skills and techniques needed to undertake practical investigations, secondary-sourced investigations and depth studies, and covers examination techniques and study skills. It also includes checklists, models, exemplars and scaffolded steps. The toolkit can serve as a reference tool, to be consulted as needed.



Module opener

Each book is divided to follow the four modules of the syllabus, with the module opener linking the module content to the syllabus.



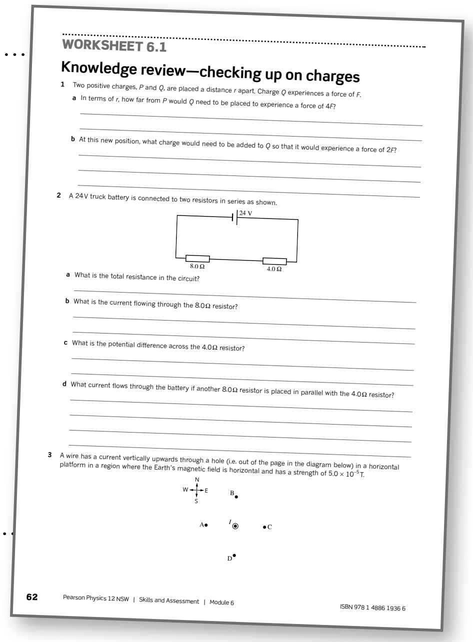
Key knowledge

Each module begins with a key knowledge section. The key knowledge consists of a set of succinct summary notes that cover the key knowledge set out in each module of the syllabus. This section is highly illustrative and written in a straightforward style to assist students of all reading abilities. Key terms are bolded for ease of navigation. It also serves as a ready reference for completing the worksheets and practical activities.

Worksheets

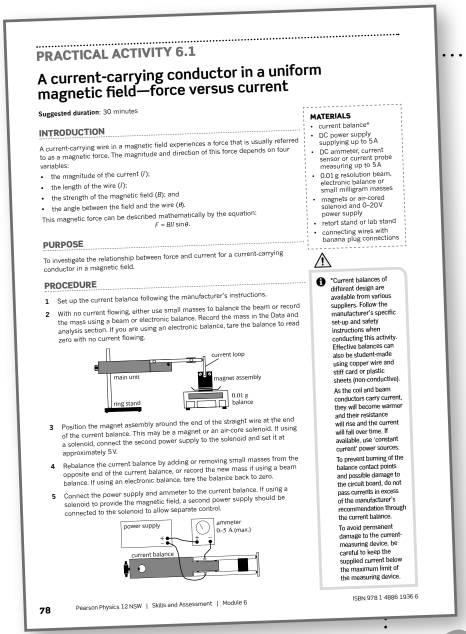
A diverse offering of instructive and self-contained worksheets is included in each module. Common to all modules are the initial ‘Knowledge review’ worksheet to activate prior knowledge, a ‘Literacy review’ worksheet to explicitly build understanding and application of scientific terminology, and finally a ‘Thinking about my learning’ worksheet, which students can use for reflection and self-assessment. Other worksheet types provide opportunities to revise, consolidate and further student understanding.

All worksheets function as formative assessment and are clearly aligned to the syllabus. A range of questions building from foundation to challenging are included within worksheets.


WORKSHEET 6.1

Knowledge review—checking up on charges

Practical activities


PRACTICAL ACTIVITY 6.1

A current-carrying conductor in a uniform magnetic field—force versus current

Practical activities give students the opportunity to complete practical work related to the various themes covered in the syllabus. All practical activities referenced in outcomes within the syllabus have been covered. Across the suite of practical activities, students have opportunities to design, conduct, evaluate, gather and analyse data, appropriately record results and prepare evidence-based conclusions. Students have opportunities to evaluate safety and risk, and identify any potential hazards.

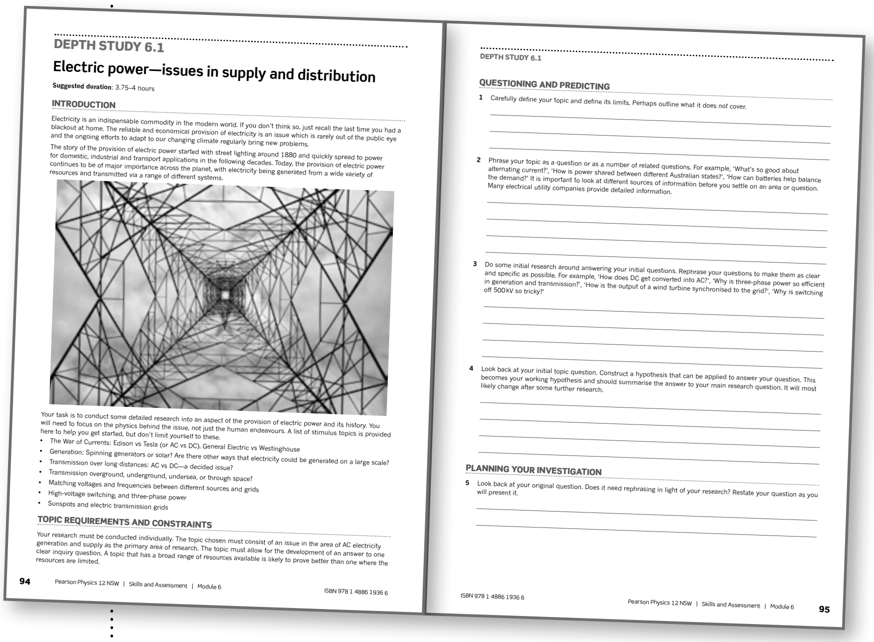
Each practical activity includes a suggested duration. Along with the depth studies, the practical activities meet the 35 hours of practical work mandated at Year 12 in the syllabus. Where there is key knowledge that will support the completion of a practical activity, students are referred back to it.

Like the worksheets, the practical activities include a range of questions, building from foundation to challenging.

Depth study

Each module contains one suggested depth study. The depth studies allow further development of one or more concepts found within or inspired by the syllabus. They allow students to acquire a depth of understanding and take responsibility for their own learning, and promote differentiation and engagement.

Each depth study allows for the demonstration of a range of Working scientifically skills, with all depth studies addressing the Working scientifically outcomes of Questioning and predicting, and Communicating. A minimum of two additional Working scientifically skills and at least one Knowledge and understanding outcome are also assessed.

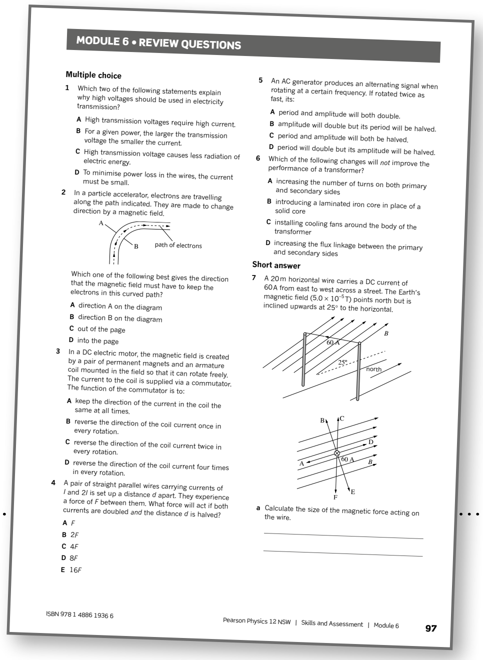

DEPTH STUDY 6.1

Electric power—issues in supply and distribution

 ISBN 978 1 4886 1936 6

Module review questions

Each module finishes with a comprehensive set of questions, consisting of multiple choice and short answer, which helps students to draw together their knowledge and understanding and apply it to these styles of question.



MODULE 6 • REVIEW QUESTIONS

Multiple choice

1 Which two of the following statements explain why high voltages should be used in electricity transmission?

- **A** High transmission voltages require high current.
- **B** For a given power, the larger the transmission voltage the smaller the current.
- **C** High transmission voltage causes less radiation of electric energy.
- **D** To minimise power loss in the wires, the current must be small.

2 In a particle accelerator, electrons are travelling along the path indicated. They are made to change direction by a magnetic field.

A B path of electrons

Which one of the following best gives the direction that the magnetic field must have to keep the electrons in this curved path?

- **A** direction A on the diagram
- **B** direction B on the diagram
- **C** out of the page
- **D** into the page

3 In a DC electric motor, the magnetic field is created by a pair of permanent magnets and an armature coil mounted in the field so that it can rotate freely. The current to the coil is supplied via a commutator. The function of the commutator is to:

- **A** keep the direction of the current in the coil the same at all times.
- **B** reverse the direction of the coil current once in every rotation.
- **C** reverse the direction of the coil current twice in every rotation.
- **D** reverse the direction of the coil current four times in every rotation.

4 A pair of straight parallel wires carrying currents of I and $2I$ is set up a distance d apart. They experience a force of F between them. What force will act if both currents are doubled *and* the distance d is halved?

- **A** F
- **B** $2F$
- **C** $4F$
- **D** $8F$
- **E** $16F$

5 An AC generator produces an alternating signal when rotating at a certain frequency. If rotated twice as fast, its:

- **A** period and amplitude will both double.
- **B** amplitude will double but its period will be halved.
- **C** period and amplitude will both be halved.
- **D** period will double but its amplitude will be halved.

6 Which of the following changes will *not* improve the performance of a transformer?

- **A** increasing the number of turns on both primary and secondary sides
- **B** introducing a laminated iron core in place of a solid core
- **C** installing cooling fans around the body of the transformer
- **D** increasing the flux linkage between the primary and secondary sides

Short answer

7 A 20 m horizontal wire carries a DC current of 60 A from east to west across a street. The Earth's magnetic field (5.0×10^{-5} T) points north but is inclined upwards at 25° to the horizontal.

a Calculate the size of the magnetic force acting on the wire.

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Rating my learning

This feature is an innovative tool that appears at the bottom of the final page of most worksheets and all practical activities. It provides students with the opportunity for self-reflection and self-assessment. It encourages them to look ahead to how they can continue to improve, and it helps them to identify focus areas for further skill and knowledge development.

The teacher may choose to use student responses to the 'Rating my learning' feature as a formative assessment tool. At a glance, teachers can assess which topics and which students need intervention for improvement.

RATING MY LEARNING	My understanding improved	Not confident ○ ○ ○ ○ ○ Very confident	I answered questions without help	Not confident ○ ○ ○ ○ ○ Very confident	I corrected my errors without help	Not confident ○ ○ ○ ○ ○ Very confident

Icons and features

The 2018 New South Wales Physics Stage 6 Syllabus Learning Across the Curriculum content is addressed and identified.

AHC A CC CCT DD EU ICT
IU L N PSC S WE

The **safety icon** highlights significant hazards, indicating caution is needed.

The **safety glasses icon** highlights that protective eyewear is to be worn during the practical activity.

Highlight boxes focus students' attention on important information such as key definitions, formulae and summary points.

> Consult the manuals for your electronic equipment or see your teacher for the options to set these values with your equipment and software.

Teacher Support

Comprehensive answers and fully worked solutions for all worksheets, practical activities, depth studies and module review questions are provided via the *Pearson Physics 12 New South Wales Teacher Support*. An editable suggested assessment rubric for depth studies is also provided.

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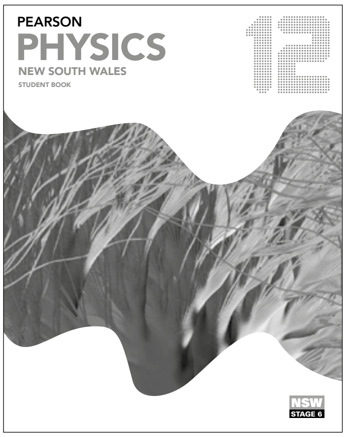
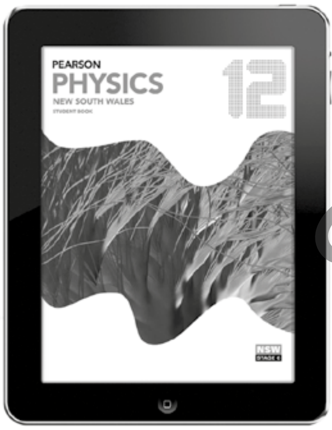


Student Book

Pearson Physics 12 New South Wales has been written to fully align with the 2018 New South Wales Physics Stage 6 Syllabus. The Student Book includes the very latest developments and applications of physics and incorporates best-practice literacy and instructional design to ensure the content and concepts are fully accessible to all students.

Skills and Assessment Book

The Skills and Assessment Book gives students the edge in preparing for all forms of assessment. Key features include a toolkit, key knowledge summaries, worksheets, practical activities, suggested depth studies and module review questions. It provides guidance, assessment practice and opportunities to develop key skills.



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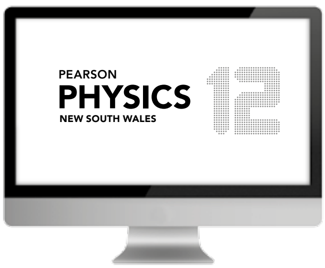
Pearson Reader+ lets you use your Student Book online or offline on any device. Pearson Reader+ retains the look and integrity of the printed book. Practical activities, interactives and videos are available on Pearson Reader+ along with fully worked solutions to the Student Book questions.



Teacher Support

Online teacher support for the series includes syllabus grids, a scope and sequence plan, and three practice exams per year level. Fully worked solutions to all Student Book questions are provided, as well as teacher notes for the chapter inquiry tasks. Skills and Assessment book resources include solutions to all worksheets, practical activities, depth studies and module review questions; teacher notes, safety notes, risk assessments and lab technician's checklists and recipes for all practical activities; and assessment rubrics and exemplar answers for the depth studies.

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Access your digital resources at **pearsonplaces.com.au**
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MODULE 5 Advanced mechanics

Outcomes

By the end of this module you will be able to:

- select and process appropriate qualitative and quantitative data and information using a range of appropriate media PH12-4
- analyse and evaluate primary and secondary data and information PH12-5
- solve scientific problems using primary and secondary data, critical thinking skills and scientific processes PH12-6
- communicate scientific understanding using suitable language and terminology for a specific audience or purpose PH12-7
- describe and analyse qualitatively and quantitatively circular motion and motion in a gravitational field, in particular, the projectile motion of particles PH12-12.

Content

PROJECTILE MOTION

INQUIRY QUESTION **How can models that are used to explain projectile motion be used to analyse and make predictions?**

By the end of this module you will be able to:

- analyse the motion of projectiles by resolving the motion into horizontal and vertical components, making the following assumptions:
  - a constant vertical acceleration due to gravity
  - zero air resistance
- apply the modelling of projectile motion to quantitatively derive the relationships between the following variables:
  - initial velocity
  - launch angle
  - maximum height
  - time of flight
  - final velocity
  - launch height
  - horizontal range of the projectile (ACSPH099)
- conduct a practical investigation to collect primary data in order to validate the relationships derived above
- solve problems, create models and make quantitative predictions by applying the equations of motion relationships for uniformly accelerated and constant rectilinear motion. ICT N

Module 5 • Advanced mechanics

CIRCULAR MOTION

INQUIRY QUESTION **Why do objects move in circles?**

By the end of this module you will be able to:

- conduct investigations to explain and evaluate, for objects executing uniform circular motion, the relationships that exist between:
  - centripetal force
  - mass
  - speed
  - radius
- analyse the forces acting on an object executing uniform circular motion in a variety of situations, for example:
  - cars moving around horizontal circular bends
  - a mass on a string
  - objects on banked tracks (ACSPH100) CCT ICT
- solve problems, model and make quantitative predictions about objects executing uniform circular motion in a variety of situations, using the following relationships:
  - $a_c = \frac{v^2}{r}$
  - $v = \frac{2\pi r}{T}$
  - $F_c = \frac{mv^2}{r}$ ICT N
  - $\omega = \frac{\Delta\theta}{t}$
- investigate the relationship between the total energy and work done on an object executing uniform circular motion
- investigate the relationship between the rotation of mechanical systems and the applied torque
  - $\tau = r_{\perp}F = rF\sin\theta$ ICT N

MOTION IN GRAVITATIONAL FIELDS

INQUIRY QUESTION **How does the force of gravity determine the motion of planets and satellites?**

By the end of this module you will be able to:

- apply qualitatively and quantitatively Newton's law of universal gravitation to:
  - determine the force of gravity between two objects $F = \frac{GMm}{r^2}$
  - investigate the factors that affect the gravitational field strength $g = \frac{GM}{r^2}$
  - predict the gravitational field strength at any point in a gravitational field, including at the surface of a planet (ACSPH094, ACSPH095, ACSPH097)

- investigate the orbital motion of planets and artificial satellites when applying the relationships between the following quantities: CCT ICT N
  - gravitational force
  - centripetal force
  - centripetal acceleration
  - mass
  - orbital radius
  - orbital velocity
  - orbital period
- predict quantitatively the orbital properties of planets and satellites in a variety of situations, including near the Earth and geostationary orbits, and relate these to their uses (ACSPH101) ICT N
- investigate the relationship of Kepler's laws of planetary motion to the forces acting on, and the total energy of, planets in circular and non-circular orbits using: (ACSPH101)
  - $v = \frac{2\pi r}{T}$
  - $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$ ICT N
- derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to a variety of situations, including but not limited to: ICT N
  - the concept of escape velocity $v_{esc} = \sqrt{\frac{2GM}{r}}$
  - total potential energy of a planet or satellite in its orbit $U = -\frac{GMm}{r}$
  - total energy of a planet or satellite in its orbit $U + K = -\frac{GMm}{2r}$
  - energy changes that occur when satellites move between orbits (ACSPH096)
  - Kepler's laws of planetary motion (ACSPH101).

Key knowledge

Vectors can be represented using a variety of different notations. Throughout this book you will see some vectors written with an arrow above the variable, i.e. $\vec{F}$. This is known as vector notation. There are different sorts of vector notation; for example, the same vector can be represented as $\tilde{F}$, $\boldsymbol{F}$ or F. Regardless of the way a vector is represented, it is important for you to understand that the same rules apply when completing any calculation involving vectors. A vector is a variable which has both a magnitude and a direction. Being able to understand when a variable is described by a vector is an important skill for a physicist to develop.

Projectile motion

A **projectile** is any object that is thrown or projected into the air and has no power source driving it. If air resistance is ignored, the only force acting on a projectile is its **weight**, i.e. the force of gravity, F_g. This force can be assumed to be constant and is always directed vertically downwards with an **acceleration** of $9.8\,\mathrm{m\,s^{-2}}$. Projectiles move in parabolic paths that can be analysed by considering the horizontal and vertical components of their motion (shown in Figure 5.1). The two factors that affect a projectile's motion are the angle at which it is launched and its initial **velocity**.

FIGURE 5.1 The motorcycle and rider are travelling in a parabolic path as they fly through the air.

PROJECTILE LAUNCHED HORIZONTALLY

Projectiles can be launched at any angle. The launch velocity needs to be resolved into vertical and horizontal components using trigonometry to complete most problems. For projectiles launched horizontally, the horizontal velocity is constant if air resistance is ignored and is equal to the horizontal launch velocity; the initial vertical velocity is zero and will increase during the flight. A parabolic path is traced by an object accelerating only in the vertical direction while moving at constant velocity in the horizontal direction. The following equations of motion for uniform acceleration must be used for the vertical component of the motion:

$$v = u + at$$

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

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

where:

s is the **displacement** (m)

u is the initial velocity ($\mathrm{m\,s^{-1}}$)

v is the final velocity ($\mathrm{m\,s^{-1}}$)

a is the acceleration ($\mathrm{m\,s^{-2}}$)

t is the time (s).

As the horizontal velocity of a projectile remains constant throughout its flight, the following equation for average velocity can be used for this component of the motion:

$$v_{\mathrm{av}} = \frac{s}{t}$$

To solve a projectile motion problem, a diagram should be constructed where the direction convention is clearly specified (whether up or down is the positive or negative direction). The information supplied for the horizontal and vertical components should be drawn separately.

For example, a ball is hit horizontally from the top of a 10.5 m cliff with a speed of $5.0\,\mathrm{m\,s^{-1}}$ (Figure 5.2). Use acceleration due to gravity of $9.80\,\mathrm{m\,s^{-2}}$ and ignore air resistance. To calculate the time it takes the ball to land and the distance it has travelled from the base of the cliff, there are a few steps you should take.

By first writing out the variables that are known, you can then decide on the equations of motion that are best suited to finding the answers. Remember to keep the horizontal and vertical components of motion separate.

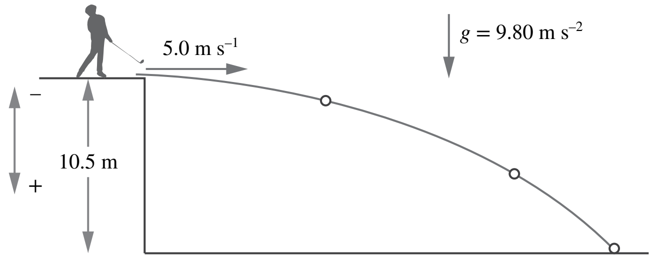

FIGURE 5.2 Parabolic motion with initial horizontal velocity only

The time can then be found using the vertical components of motion and the equation: $s = ut + \frac{1}{2}at^2$.

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$$10.5 = 0 + \tfrac{1}{2} \times 9.80 \times t^2$$

$$t = \sqrt{\frac{10.5}{4.9}}$$

$$= 1.46\,\text{s}$$

Similarly, to calculate the horizontal displacement (i.e. how far the ball travelled from the base of the cliff), you can use the equation: $v_{av} = \frac{s}{t}$.

$$5.0 = \frac{s_H}{t}$$

$$s = 5.0 \times 1.46$$

$$= 7.3\,\text{m}$$

Generally, vector answers need both their magnitude and direction, so pay close attention to how a question is written to know what information is needed in your solution. In the example given above, you were asked for the distance travelled, not the horizontal displacement, so the answer is given as a scalar.

PROJECTILES LAUNCHED OBLIQUELY

The previous section looked at projectiles that were launched horizontally. A more common situation is projectiles that are launched obliquely (at an angle), by being thrown forwards and upwards at the same time (like in Figure 5.3). For objects initially launched at an angle to the horizontal, it is useful to calculate the initial horizontal and vertical velocities using trigonometry. The initial velocity can be broken down into its perpendicular horizontal (u_H) and vertical (u_V) components using the trigonometric relationships below:

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{u_V}{u} \qquad u_V = u\sin\theta$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{u_H}{u} \qquad u_H = u\cos\theta$$

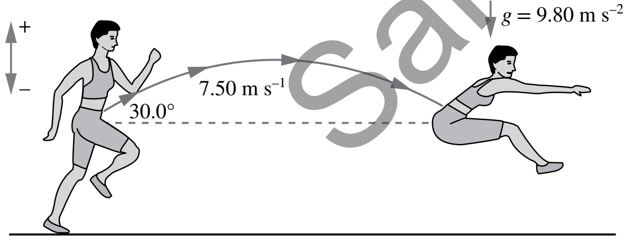

FIGURE 5.3 Projectiles can also be launched obliquely (at an angle).

As with projectiles launched horizontally, if air resistance is negligible, the only force that is acting on a projectile is gravity, F_g. Therefore, the horizontal velocity of a projectile remains constant throughout its flight, i.e. $v_{av} = \frac{s}{t}$ is used. At its highest point, the projectile is only moving horizontally so the vertical component of the velocity is zero at this point. Overall, the assumptions that must be made when analysing a projectile problem are as follows.

- Air resistance is negligible.
- If an object is dropped, $u = 0\,\text{m s}^{-1}$.
- At the highest point of a projectile's path, $v_V = 0\,\text{m s}^{-1}$.
- Final velocity = negative initial velocity, i.e. $u = -v$.

In the example given in Figure 5.3, in order to find the maximum height reached, you would first need to break the initial velocity into its vertical and horizontal components.

$$u_V = u \times \sin\theta$$

$$u_V = 7.50 \times \sin 30 = 3.75\,\text{m s}^{-1}$$

The vertical displacement can then be calculated using the formula $v^2 = u^2 + 2as$:

$$0^2 = 3.75^2 + 2 \times -9.8 \times s$$

$$s = 0.717\,\text{m upwards}$$

This means that the centre of mass of the person jumping will travel upwards to a maximum of 0.7 m above their starting height. If the centre of mass is originally 1 m off the ground, then the maximum height reached will be 1.7 m.

Circular motion

Circular motion involves the movement of an object along a circular path. It can be uniform (with a constant rate of rotation and speed), or non-uniform (with a changing rate of rotation).

CIRCULAR MOTION IN A HORIZONTAL PLANE

Uniform circular motion is motion along a circular path in which there is no change in speed, only a change in direction. For example, consider an athlete in a hammer throw event, swinging a steel ball in a horizontal circle with a constant speed (Figure 5.4). The velocity of the hammer at any instant is tangential (at a tangent) to its path. At one instant (point A), the hammer is travelling at $25\,\text{m s}^{-1}$ north, then an instant later (point B) at $25\,\text{m s}^{-1}$ west, then $25\,\text{m s}^{-1}$ south (point C), and so on.

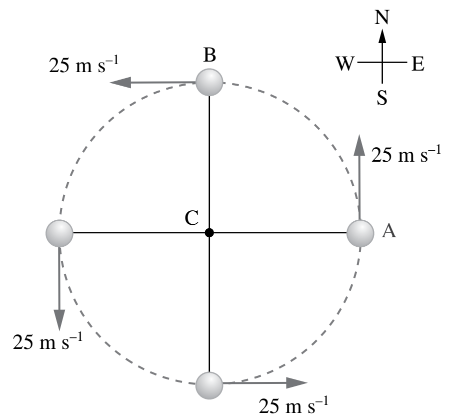

FIGURE 5.4 The velocity of the hammer (steel ball) at any instant is tangential to its path and is continually changing even though it has constant speed. This changing velocity means that the hammer is accelerating.

Period, T, is the time for one revolution and is measured in seconds. **Frequency**, f, is the number of revolutions each second and is measured in hertz (Hz). The relationship between T and f is:

$$f = \frac{1}{T} \text{ and } T = \frac{1}{f}$$

An object moving with a uniform speed in a circular path of radius, r, and with a period, T, has an average speed that is given by:

$$v = \frac{2\pi r}{T}$$

Sometimes it is more convenient to measure the angle of rotation, denoted by the angular velocity, ω. The **angular velocity** decribes the angle an object travels through, $\Delta\theta$, over a time t:

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

The angle can be found in either degrees or radians so that the angular velocity has units of either $° \text{ s}^{-1}$ or rad s^{-1}.

In a unit circle, the circumference is 2π units. Because of this, angles (in degrees) can be related to the arc length (in radians) on a unit circle. In a complete circle, the angle 360° is equal to 2π radians.

Therefore degrees can be converted to radians by multiplying by $\frac{\pi}{180}$, and radians can be converted to degrees by multiplying by $\frac{180}{\pi}$.

Because an object moving in a circular path is always changing its direction of motion, even if it is travelling with a constant speed it must have a non-zero acceleration. This acceleration is directed towards the centre of the circular path and is called **centripetal acceleration**, a_c:

$$a_c = \frac{v^2}{r}$$

Centripetal acceleration is a consequence of a **centripetal force** acting to make an object move in a circular path. Centripetal forces are directed towards the centre of the circle and their magnitude can be calculated by using Newton's second law for the net force of the object:

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

By substituting the relationship between speed and period into the equations for acceleration and the net force, you can also find the following: $a_c = \frac{4\pi^2 r}{T^2}$ and $F_c = \frac{4\pi^2 rm}{T^2}$.

Centripetal force is always supplied by a real force, the nature of which depends on the situation. The real force is commonly friction, gravitation or the tension in a string or cable.

CIRCULAR MOTION ON BANKED TRACKS

This section focuses on circular motion on a surface that is not horizontal. On many road bends, the road is not horizontal, but is at a small angle to the horizontal. This is called a banked track, and it enables vehicles to travel at higher speeds when cornering, without skidding, than they could travel on a horizontal curved path. Banked tracks reduce a vehicle's dependence on friction to safely navigate a curve. An example of this effect can be seen at a cycling velodrome like that shown in Figure 5.5, where the banked corners allow cyclists to travel at much higher speeds than if the track were flat.

FIGURE 5.5 The Australian women's pursuit track cycling team in action on a banked velodrome track during the London Olympics in 2012

Banking a track eliminates the need for a sideways frictional force to turn. When cars travel in circular paths on horizontal roads, they are relying on the force of friction between the tyres and the road to provide the sideways force that keeps the car turning on a circular path. Both the normal force, F_N, and weight of the car are balanced, so the only force allowing the car to turn is friction. A banked track means that the normal force has an inwards component, enabling the car to turn the corner (Figure 5.6).

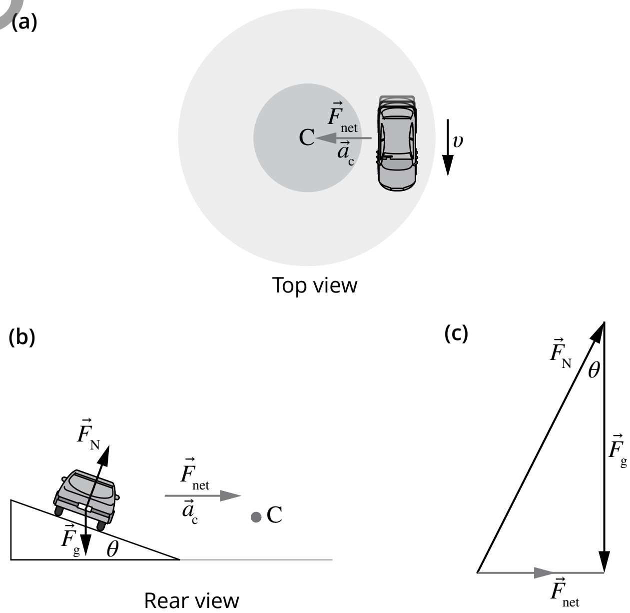

FIGURE 5.6 (a) The car is travelling in a circular path on a banked track. (b) The acceleration and net force are towards the centre of the circular motion, C. The banked track means that the normal force ($\vec{F}_N$) has an inwards component. This is what enables the car to turn the corner. (c) Vector addition gives the net force ($\vec{F}_{net}$) as acting horizontally towards the centre.

When the speed and angle are such that there is no sideways frictional force, the speed is known as the **design speed**. The forces acting on a vehicle travelling

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at the design speed on a banked track are gravity and the normal force from the track. These forces are unbalanced and add to give a net force directed towards the centre of the circular motion.

At the design speed, the angle of bank of the track can be determined by the following formula:

$$\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$

This can therefore be rearranged to find the design speed:

$$v = \sqrt{rg\tan\theta}$$

A similar example of circular motion is the conical pendulum. A conical pendulum is a mass that travels in a horizontal circle on a string. The tension in the string supplies the force to counter the force of gravity and also supplies the centripetal force. Its construction is like an ordinary pendulum; however, instead of swinging back and forth, the mass of the conical pendulum moves at a constant speed in a circle with the string tracing out a cone. The closer the mass is to the horizontal, the more the speed increases. An example of a conical pendulum is shown in Figure 5.7.

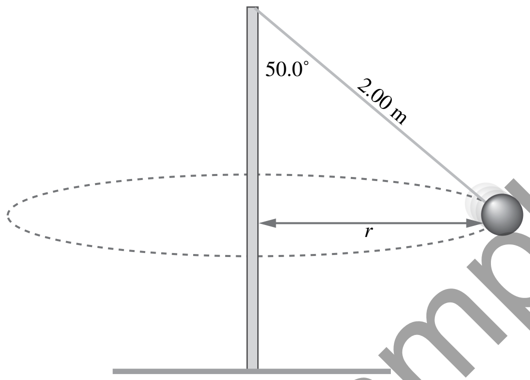

FIGURE 5.7 Conical pendulum

If both the angle and length of the string are known, the radius, r, of the circle can be found using a simple trigonometric ratio (see Figure 5.8a). Trigonometric ratios can also be used to find the other forces involved if one of the forces is known.

For example, if the mass of the ball is 0.20 kg, the weight force acting on it will be

$$F_g = mg = 0.20 \times 9.80 = 1.96\,\text{N downwards.}$$

Then as the weight of the ball (considering the string to be negligible mass) and the angle the ball is swinging at are both known, trigonometry can then be used to determine the centripetal force and tension in the string (see Figure 5.8b).

WORK AND ENERGY

Vertical circular paths (non-uniform circular motion), like horizontal circular paths, have an acceleration that is directed towards the centre of the circle. Unlike horizontal paths, however, in vertical paths the speed, as

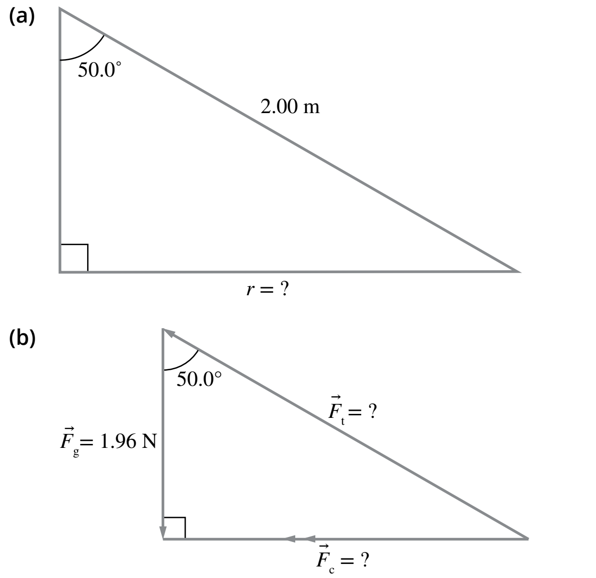

FIGURE 5.8 Trigonometry can be used to find (a) the radius of the circular motion as well as (b) the different forces acting: the weight force F_g, the tension of the string F_t and the net or centripetal force F_c.

well as the direction, of the object is constantly changing. For example, when travelling on a rollercoaster ride, strong forces would be experienced when travelling both through dips and over humps, but how these forces feel would be different. When you travel through dips, you feel as though you are getting pushed down into the seat, but when you travel over humps you feel as though you are being lifted up. This phenomenon is due to unbalanced forces between your weight and the normal force. Figure 5.9a shows the rider going through a dip. In this example, the centripetal force is upwards, which means the magnitude of the normal force is greater than the weight, and the rider will feel heavier than usual. Figure 5.9b shows the rider going over a hump. In this example, the centripetal force is downwards, so the magnitude of the normal force is less than the weight of the person and the rider will feel lighter than usual. The normal force is equal to the person's apparent weight, and this makes the person 'feel' heavier and lighter as they travel through the dips and humps respectively.

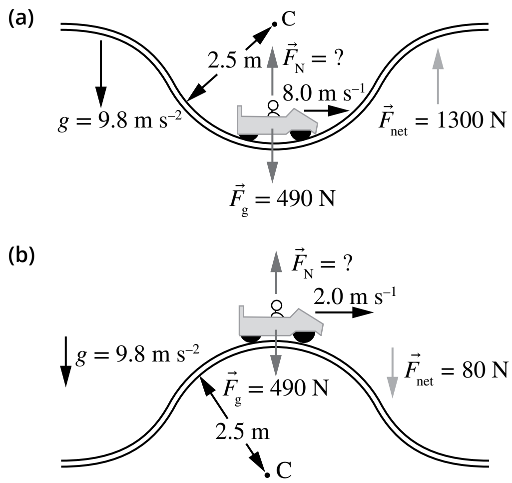

FIGURE 5.9 In (a), the centripetal acceleration is upwards towards the centre of the circle. In (b), the centripetal acceleration is downwards so the net force is also in that direction. At this point, the magnitude of the normal force $\vec{F}_N$ is less than the weight $\vec{F}_g$ of the person and the car.

As the speed is constantly changing throughout a roller coaster ride, often it is much easier to solve these types of problems using the law of **conservation of energy**. The law of conservation of energy states that energy is transferred or transformed between objects and there is always the same amount of energy at the end as there was at the start. The sum of the kinetic and potential energy (the total **mechanical energy**) of an isolated system is always conserved. This can be represented by the following:

$$(E_m)_{initial} = (E_m)_{final}$$

$$K_{initial} + U_{initial} = K_{final} + U_{final}$$

where:
E_m is the total mechanical energy
K is the kinetic energy
U is the potential energy.

Kinetic energy, K, is the energy of motion of a body:

$$K = \frac{1}{2}mv^2$$

where:
m is the mass (kg)
v is the speed ($m\,s^{-1}$).

Close to the surface of the Earth, where the force of gravity can be assumed to be constant, the change in gravitational potential energy of an object of mass m is dependent on the height from a given surface Δh and the acceleration due to gravity g:

$$\Delta U = mg\Delta h$$

The variable Δh is always given against some reference level, so gravitational potential energy can be positive or negative. A negative potential energy just means that the object will have travelled below the reference level. Ground level is often used as the reference point.

Consider the roller coaster ride again. There are times when the car isn't moving so that the kinetic energy is zero and you can describe the total energy of the system using only the gravitational potential energy. If the total energy in the system is known, this can be used to find the kinetic energy at other times during the ride as a change in potential energy is transformed into a change in kinetic energy, which means the speed can be found. Then the speed can be substituted into the centripetal force formula to calculate the net force.

Work is the transfer of energy from one object to another and/or the transformation of energy from one form to another (i.e. $W = \Delta U = \Delta K$). Work, W, is a scalar variable and is measured in joules (J). A force does work on an object when it acts on a body causing a displacement in the direction of the force. A centripetal force does no work on an orbiting object, as the force and displacement are perpendicular.

TORQUE

Torque is a measurement of the tendency of a force to cause an object to rotate around an axis. This axis is known as the **axis of rotation**. The object doesn't need to be circular for it to rotate around the axis of rotation. For example, torque is applied to a nut or bolt that needs to be tightened with a spanner. In this example, the pivot point is the bolt and the force is applied at right angles to the spanner (Figure 5.10). For all turning objects, there must be a **pivot point** around which the object will rotate, and there must be a force applied to the object to cause it to rotate. There also must be some distance between the **line of action of the force** (an imaginary line through the force vector) and the pivot point.

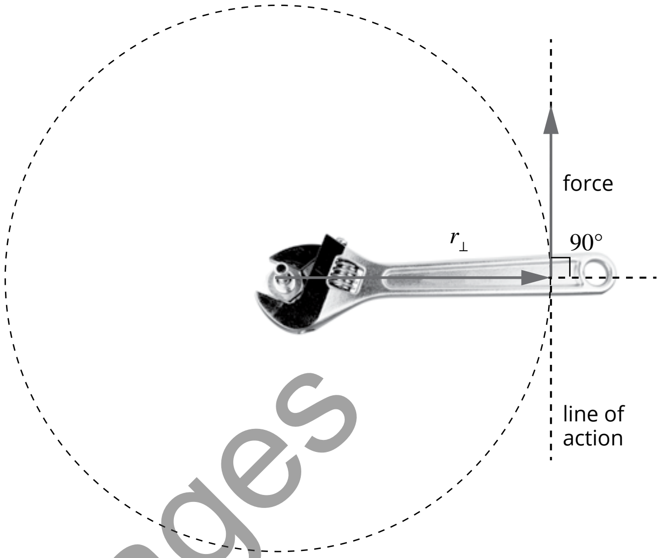

FIGURE 5.10 Although the adjustable spanner is not a wheel or circle, torque can still be applied to the nut.

The formula for calculating torque is:

$$\tau = r_\perp F$$

where:
τ is the torque (N m)
$r_\perp$ is the perpendicular force arm (m)
F is the force (N).

The amount of torque created is therefore directly proportional to the perpendicular distance between the pivot point and the line of action of the force, and magnitude of the force. This perpendicular distance is called the force arm. The force arm is given the symbol $r_\perp$ (as shown in Figure 5.10). Torque is a vector quantity. Generally the direction convention chosen describes a clockwise rotation as negative and an anticlockwise rotation as positive.

Maximum torque occurs when the acting force applied is perpendicular to a line drawn from the pivot point to the point of application. The larger the force acting on the object, the larger the torque will be. The longer the force arm, the greater the torque will be.

If torque is generated by an acting force that is not perpendicular to the lever arm of the object, then either:

- the component force perpendicular to the length of the object is used to calculate torque:

$$\tau = rF_\perp$$

or

- the distance from the pivot point perpendicular to the line of action of the force is used to calculate torque:

$$\tau = r_\perp F.$$

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Both strategies for determining torque from non-perpendicular situations equate to:

$$\tau = rF\sin\theta$$

where θ is the angle between the applied force and the radius (°).

For example, consider someone loosening a bolt with a force of 65.0 N at an angle of 68.0° to the spanner, shown in Figure 5.11. In this example, the perpendicular force could first be found: $F_{\perp} = F\sin\theta = 65.0\ \sin 68.0 = 60.3$ N. This can then be used to find the torque using $\tau = rF_{\perp}$. Alternatively, $\tau = rF\sin\theta$ can be used.

FIGURE 5.11 An acting force that is not perpendicular to the lever arm of the object will also generate a torque.

Motion in gravitational fields

Gravity is the weakest of the four fundamental forces of physics (electromagnetism, the strong nuclear force and the weak nuclear force are the others), but is still a very important force that drives the universe. For a satellite to move in an orbit around the Earth, the centripetal force is supplied by the gravitational force of attraction between the two masses. The size of this force is determined by one of Newton's laws: Newton's law of universal gravitation.

GRAVITY

All objects with mass attract one another with a gravitational force. The gravitational force acts equally on each of the masses. The magnitude of the gravitational force is given by **Newton's law of universal gravitation**:

$$F = \frac{GMm}{r^2}$$

where:

F is the gravitational force (N)

M is the mass of object 1 (kg)

m is the mass of object 2 (kg)

r is the distance between the centres of M and m (m)

G is the **gravitational constant**, $6.67 \times 10^{-11}\ \text{N}\,\text{m}^2\,\text{kg}^{-2}$.

The gravitational force is always an attractive force. Gravitational forces are usually negligible unless one of the objects is massive, e.g. a planet. For example, consider a man with a mass of 90 kg and a woman with a mass of 75 kg who have a distance of 80 cm between their centres. The force of gravitation would be:

$$F = \frac{GMm}{r^2}$$

$$= 6.67 \times 10^{-11} \times \frac{90 \times 75}{0.80^2}$$

$$= 7.0 \times 10^{-7}\ \text{N towards one another.}$$

The weight of an object on the Earth's surface is due to the gravitational attraction of the Earth. A **gravitational field** is a region in which a gravitational force is exerted on all matter within that region. Some systems like the solar system involve several objects (i.e. the Sun and planets) exerting attractive forces on each other at the same time. Every physical object has an accompanying gravitational field. A gravitational field can be represented by a gravitational field diagram, in which:

- the arrowheads indicate the direction of the gravitational force
- the spacing of the lines indicates the relative strength of the field. The closer the line spacing, the stronger the field.

For example, Figure 5.12 shows a gravitational field diagram. The arrows indicate that objects will be attracted towards the mass in the centre and the spacing of the lines shows that force will be strongest at the surface of the central mass and weaker further away.

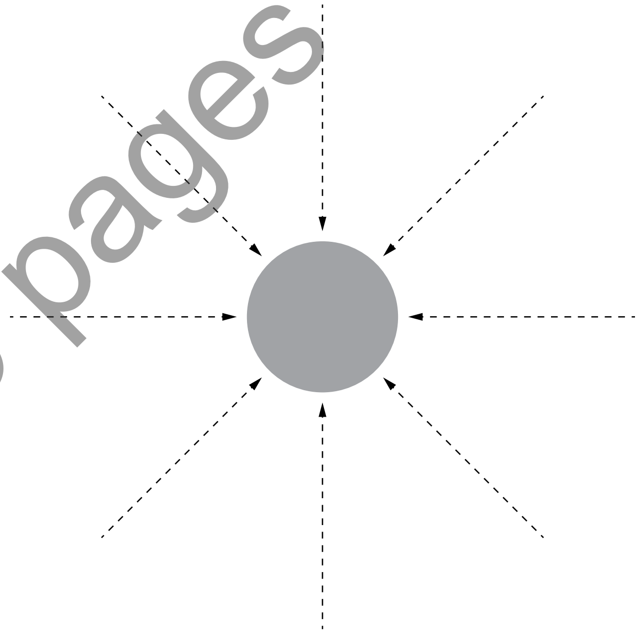

FIGURE 5.12 Gravitational field lines

The strength of a gravitational field can be calculated using the following formulae:

$$g = \frac{F_g}{m} \text{ or } g = \frac{GM}{r^2}$$

The acceleration due to gravity of an object near the Earth's surface can be calculated using the dimensions of the Earth:

$$g = \frac{Gm_{\text{Earth}}}{(r_{\text{Earth}})^2} = 9.80\ \text{N}\,\text{kg}^{-1}$$ towards the centre of the Earth.

This value for g varies from location to location and with altitude (but is consistent enough to be considered a constant for most Year 12 calculations for altitudes close to the Earth's surface). The gravitational field strength on the surface of any other planet depends on the mass and radius of the planet.

SATELLITE MOTION

A **satellite** is an object that is in a stable orbit around a larger central mass. Satellites can either be **natural** (e.g. the moon) or **artificial** (e.g. a communication satellite). Artificial satellites are very important for science, industry, communications and the military. The only force acting on a satellite is the gravitational attraction between it and the central body. Satellites are in continual free-fall. As satellites are moving at a velocity relative to the Earth, they are moving across the sky at the same rate that they are falling, so the combined effect is that they fall in a curved path. This effect is shown in Figure 5.13, which shows an astronaut orbiting the Earth.

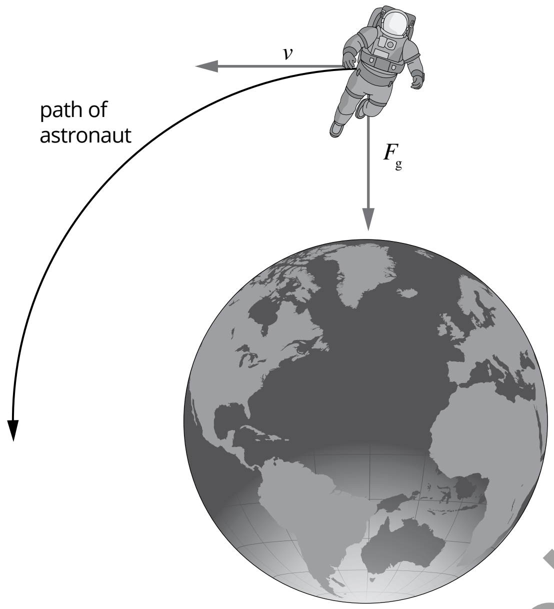

FIGURE 5.13 Astronauts are in free fall while orbiting the Earth.

Satellites move with a centripetal acceleration that is equal to the gravitational field strength at the location of their orbit. Artificial satellites are often equipped with tanks of propellant that are squirted in the appropriate direction when the orbit of the satellite needs to be adjusted. In a circular orbit, a satellite travels at a constant speed and stays the same distance from the Earth.

The speed of a satellite, v, in a circular orbit is given by:

$$v = \frac{2\pi r}{T}$$

This formula can then be used to determine the centripetal acceleration acting on this satellite. Using the scalar variables for these equations, the magnitude of the acceleration is then:

$$a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{T} = \frac{GM}{r^2} = g$$

These relationships can be manipulated to determine any feature of a satellite's motion: its speed, radius of orbit or period of orbit. The magnitude of the gravitational force acting on a satellite in a circular orbit is given by:

$$F_c = \frac{mv^2}{r} = \frac{4\pi^2 rm}{T^2} = \frac{GMm}{r^2} = mg$$

Artificial satellites usually move in circular orbits; however, it does depend on the energy and trajectory. Satellites could follow a spiral, hyperbolic, elliptical or circular orbit. Johannes Kepler, a German astronomer, published three laws regarding the motion of planets. He was the first to work out that planets do not travel in circular paths, but rather in elliptical paths. His three laws are as follows.

- The planets move in elliptical orbits with the Sun at one focus.
- The line connecting a planet to the Sun sweeps out equal areas in equal intervals of time (Figure 5.14).
- For every planet, the ratio of the cube of the average orbital radius, r, to the square of the period, T, of revolution is the same, i.e. $\frac{r^3}{T^2}$ = a constant, k.

For any central body of mass, M:

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

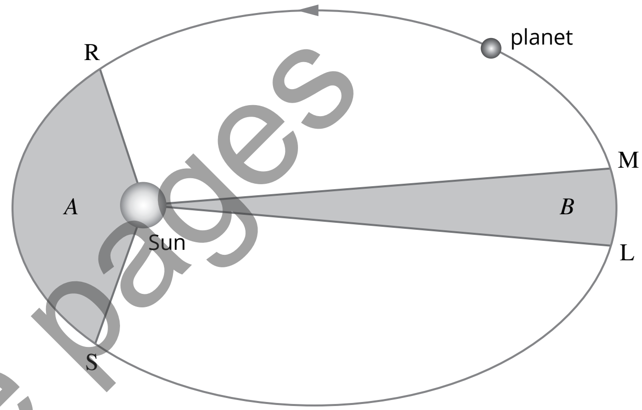

FIGURE 5.14 A line joining a planet to the Sun will sweep out equal areas in equal times. If the time taken for the planet to travel from R to S is the same as it takes to travel from M to L, then area A will equal area B.

If another satellite's orbital radius, r, is known this enables a satellite in the same system, with period T, to be determined.

GRAVITATIONAL POTENTIAL ENERGY

When considering gravitational potential energy with the motion of objects like rockets or satellites, a larger understanding is necessary. The gravitational potential energy formula, $\Delta U = mg\Delta h$, assumes that the Earth's gravitational field is constant. This is approximately true for objects that are within a few kilometres of the Earth's surface. Gravitational potential energy is important when combined with kinetic energy, $K = \frac{1}{2}mv^2$, and conservation of mechanical energy to calculate the speed of a falling object.

The strength of the Earth's gravitational field decreases as altitude increases. This means it is not sufficient to assume a constant value for the Earth's gravitational field, when considering objects like satellites or moons that orbit at high altitudes. Using Newton's universal law of gravitation and substituting this into the gravitational potential energy formula derives:

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

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Gravitational potential energy is measured against a reference level and a negative value means that it has moved below this level. By convention, the gravitational potential energy of a satellite is zero when it has escaped the gravitational field of the Earth. In most cases, the satellite will be close to Earth and in Earth's gravitational field, making the potential energy a negative value.

The total energy E in a non-constant gravitational field can be found by combining the law of conservation of energy, Newton's law of gravitation, centripetal force and Newton's second law. The formula is:

$$E = U + K = -\frac{GMm}{2r}$$

When an object like a rocket has enough kinetic energy to escape the Earth's gravitational field, it is said to have reached **escape velocity**.

Since an object that has escaped a gravitational field has a potential energy of $U = 0$, its energy will be entirely kinetic. Due to the conservation of mechanical energy, this kinetic energy is equal in magnitude to the object's initial gravitational potential energy when $K = 0$. This can be used to find the escape velocity—when $K = U$:

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

WORKSHEET 5.1

Knowledge review—straight-line motion

1 The motion of a ball rolling down a plank from rest is measured by marking its position each second. From $t = 3$ s to $t = 4$ s, the ball travels 56 cm. Calculate the magnitude of the acceleration of the ball.

2 From a platform 24.5 m above the ground, a stone is thrown straight up at 19.6 m s^{-1}.

a How long will it be in the air before hitting the ground?

b Calculate its velocity as it hits the ground.

3 An Alfa Romeo sports car travelling at 22 m s^{-1} west overtakes a bus travelling at 9 m s^{-1} in the same direction. Find:

a the velocity of the car relative to the bus

b the velocity of the bus relative to the car

c the direction the bus appears to move in the car driver's frame of reference.

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4 A 540 kg cable car is suspended from the middle of a light cable, with each half of the cable making an angle of 12.0° to the horizontal. Draw a force diagram of the situation and calculate the size of the tension in the cable.

5 Consider a 100 g teacup sitting on a kitchen bench.

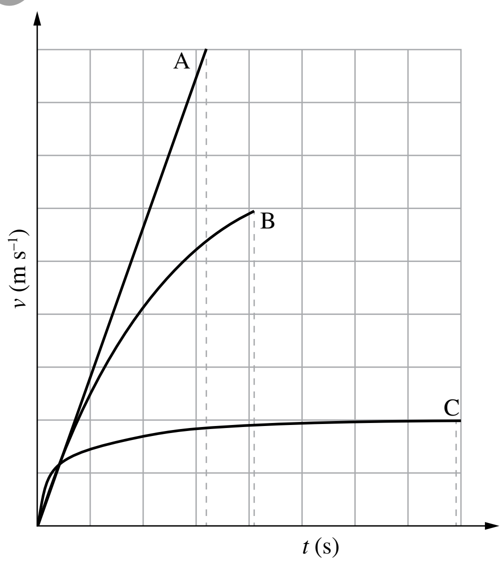
a What is its weight?

b What is the size of the force of the benchtop on the cup? In which direction does it act?

c Explain why these forces do *not* make an action–reaction pair. What are the action–reaction pairs here?

6 An 8.0 kg box rests on a plank which is inclined at an angle of 20° to the horizontal. The coefficient of friction between the plank and the box, μ, is 0.40. If the plank is gradually raised, find the angle at which the box will start to slip down the plank. (Hint: You will need to find the size of the normal force first.)

7 The velocity–time graphs for three objects, A, B and C, dropped from the same height are shown below.



a What physical quantity is represented by the gradient of graph A?

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b What do the areas underneath the graphs represent? How do they compare with each other?

c Explain what is happening to object C.

8 The foundations of large buildings are often built on supports called 'piles' which are driven down into the ground by a pile-driver. A 4.50×10^3 kg pile-driver mass falls through a height of 40.0 cm before colliding with the top of a pile. The mass drives the pile 30.0 cm into the ground when both the pile and the mass come to rest.

a Calculate the pile-driver's loss of potential energy.

b Calculate the average resistance force of the ground.

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WORKSHEET 5.2

Projectile motion—is it safe?

A group of students intends to fire a small missile with a velocity of $40.0\,\text{m}\,\text{s}^{-1}$ at an angle of $60.0°$ from the horizontal from a point on the oval. They intend to aim at the windowless wall of a building 45 m away from the launch site, so that there is no danger of the missile hitting anyone. The building is 36 m high.

1 Construct a diagram of the situation, showing all known variables.

2 Prove that the projectile will travel over the height of the building and hence that this situation is unsafe.

3 As this situation is unsafe, make two possible recommendations in order to make it safe. Show calculations to prove that your proposal is safe, and note any assumptions.

RATING MY LEARNING	My understanding improved	Not confident ⟷ Very confident ○ ○ ○ ○ ○	I answered questions without help	Not confident ⟷ Very confident ○ ○ ○ ○ ○	I corrected my errors without help	Not confident ⟷ Very confident ○ ○ ○ ○ ○

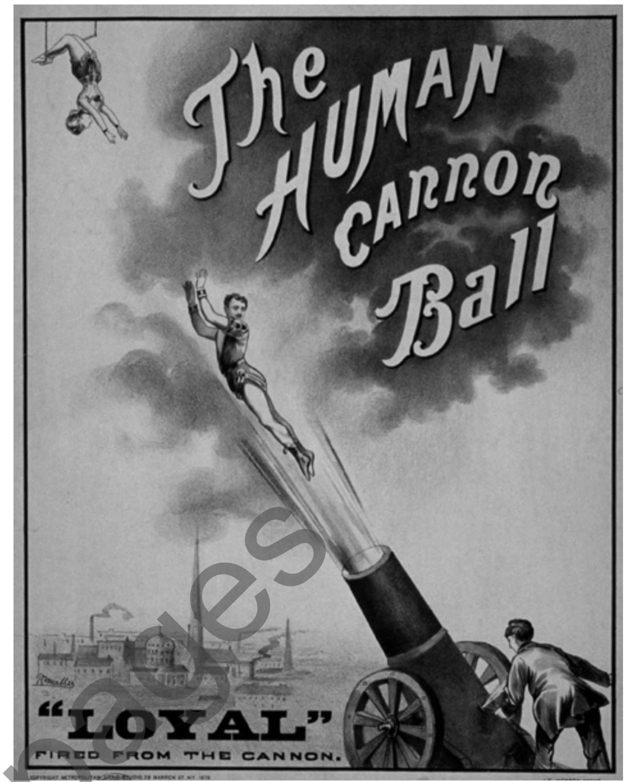
WORKSHEET 5.3

Projectile motion—human cannonball data analysis

Human 'cannonballs' used to be a common feature of circuses and fairs. Risk assessments and ever-increasing insurance premiums brought an end to them. More than 30 people have died over the years since the first cannonball, a 14-year-old girl, was launched at the Royal London Aquarium in 1877.

These days, some stunt performers still maintain the tradition. The human cannonball is fired from a specially designed cannon, and lands on a horizontal net or inflated bag. Amazingly, the official world record stands at 59.05 m.

The data below was collected from the launch of a human cannonball of mass 80 kg blasted towards the east from a cannon and landing in a safety net. The height of the net was equal to the launch height. The angle of launch was 45° and the initial speed was 28 m s^{-1}. In your calculations, ignore air resistance unless otherwise instructed and use $g = 9.80$ m s^{-2}.



Time after launch (s)	Speed (m s^{-1})
0	28.0
1.0	22.4
2.0	20.0
3.0	22.4
4.0	28.0

Air resistance (N)	Distance travelled (m)
0	0
400	50
600	100
700	150
780	200
830	250
850	300
870	350
890	400
900	450
900	500
900	550
900	600

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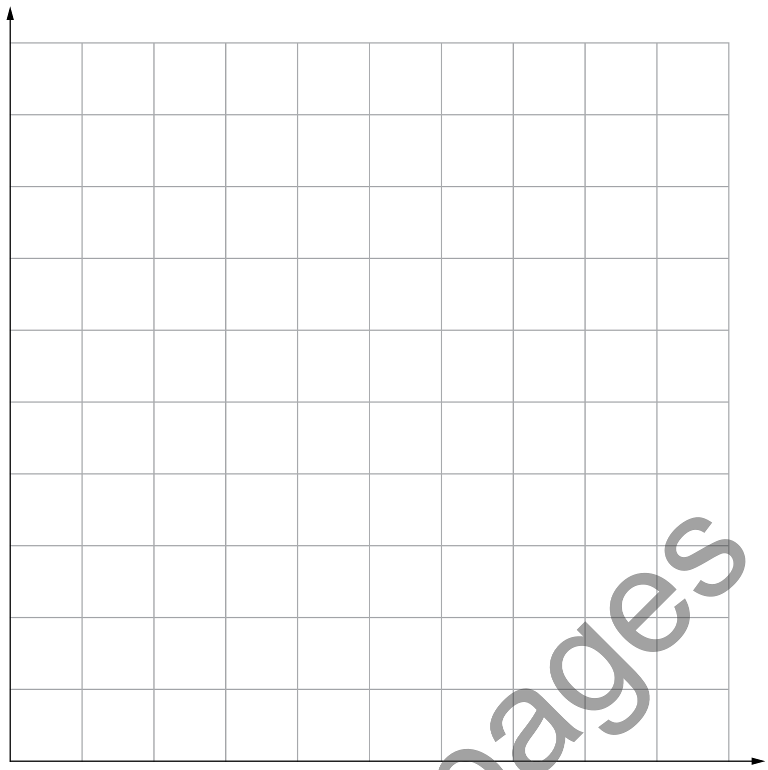
WORKSHEET 5.3

1 On the set of axes provided, produce a graph of vertical acceleration versus time for the human cannonball for the 4.0 s worth of motion. Use up as positive and ensure that your graph is appropriately labelled.



2 Using an energy approach, determine the:

a total mechanical energy of the human cannonball

b gain in gravitational potential energy of the human cannonball as they reach the maximum height

c change in height that the human cannonball achieved from launch.

3 Determine the height of the cannonball above the initial launch height after:

a 2.0 s

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b 3.5 s.

4 Calculate the speed of the human cannonball after:

a 2.0 s

b 3.5 s.

5 What is the velocity and acceleration of the human cannonball at the maximum height?

6 Discuss the forces that are acting on the human cannonball when passing through the highest point in the trajectory if air resistance is ignored. State the magnitude and direction of the net force acting at this point.

7 Discuss the forces that are acting on the human cannonball when passing through the highest point in the trajectory if air resistance is taken into account.

RATING MY LEARNING	My understanding improved	Not confident ◄——► Very confident ○ ○ ○ ○ ○	I answered questions without help	Not confident ◄——► Very confident ○ ○ ○ ○ ○	I corrected my errors without help	Not confident ◄——► Very confident ○ ○ ○ ○ ○

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WORKSHEET 5.4

Going around corners

In order for a body to travel in a circle or part of a circle, a centripetal force is required to be exerted on the object. This can be the pull of gravity for planets, the tension in a wire for a hammer thrower or the reaction force of a surface in contact with the object. In the case of a car going around a corner, the centripetal force must come from the sideways component of reaction from the road surface or the friction of the car tyres against the road surface.

The diagram below depicts a car travelling away from the viewer and turning to the left.

1 Draw and label the force vectors acting on the car at this instant.

2 Consider a car negotiating a suburban roundabout. The path taken has a radius of curvature of 8.0 m and the coefficient of friction between the tyre and the road is 0.72. What is the maximum speed the car can travel (in km h^{-1}) and still remain on the circular path?

3 The coefficient of friction between the tyre of a Formula One racing car and the asphalt track is typically 1.50. Calculate the minimum radius of curvature that can be taken by a Formula One car at 120 km h^{-1}.

4 Formula One cars are fitted with various aerofoils and body shaping, which can generate considerable downforce. Find how much downforce (as a fraction of the car's weight) would be needed to negotiate the same corner at a 30% greater speed.

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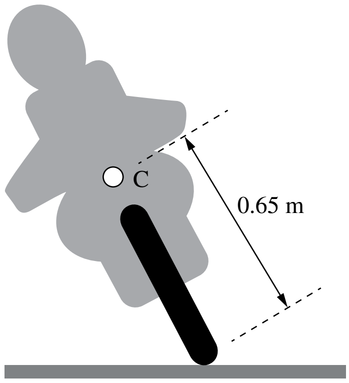
5 When a motorcycle goes around a corner, the rider needs to lean over into the corner. On the diagram of a cornering motorcycle below, draw and label the forces acting on the motorcycle and the rider. (Point C, 0.65 m from the contact point, is the centre of mass of the bike and rider.)



6 Assuming that the motorcycle's tyres can generate as much friction with the road as the car's tyres, find the angle of lean of the motorcycle from the vertical as it takes the corner.

Bicycles can travel faster around a bend by 'banking' the track as seen in a velodrome. The ideal situation on a banked curve is for the bike to be perpendicular to the track surface. The Dunc Gray Velodrome in Sydney was the venue for the track cycling in the 2000 Olympic Games. The maximum angle of bank in the end curves is 42°, while the straights are angled at 12.5°.

7 Anna Meares takes a path with a radius of curvature of 22 m where the track is banked at 42°. Find the greatest speed at which she can travel safely.

8 Find her angular velocity at that speed.

There are many further points to consider when investigating how vehicles can be helped to negotiate corners.

- When a car first enters a bend and when it leaves the bend, it is usually travelling faster than in the middle of the bend. This means the radius of curvature of the road needs to vary, and should be smallest at the apex of the corner.
- The radius of curvature of a velodrome track also changes as the banking angle varies from the straights to the ends.
- The greater the angle of bank, the harder a car is 'pushed' down onto the track. If pushed too far, the car body will touch the track and the tyres may lose adhesion.
- If a cyclist leans on a banked curve, they can generate more friction and take the curve even faster—provided they can pedal fast enough!

RATING MY LEARNING	My understanding improved	Not confident ○ ○ ○ ○ ○ Very confident	I answered questions without help	Not confident ○ ○ ○ ○ ○ Very confident	I corrected my errors without help	Not confident ○ ○ ○ ○ ○ Very confident

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WORKSHEET 5.5

Circular motion and gravity

When a rocket takes off, it accelerates quickly to achieve enough speed to enter orbit. In a related situation, fighter pilots will undergo significant 'g-forces' while performing tight turns. To prepare themselves for this, the astronauts and pilots will need to experience high 'g-forces' during their training.

1 A brief period of acceleration can be achieved using a rocket sled equipped with a jet turbine or rocket motor. Consider a person strapped into such a sled where the total mass is 450 kg. The rocket motor exerts an upwards force of 36.0 kN for a 4.00 s burn. Calculate the acceleration produced and the distance travelled during the burn.

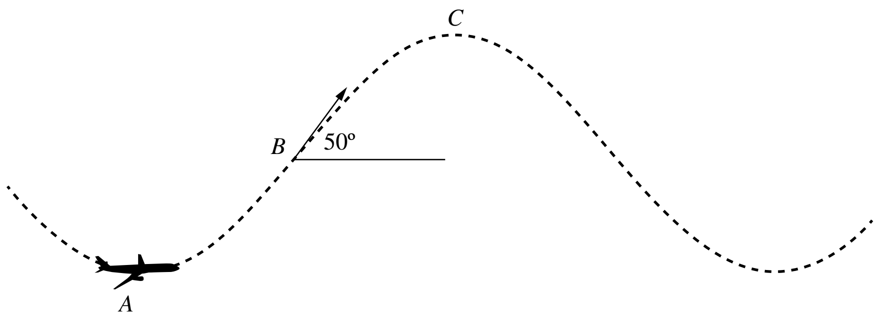
2 The acceleration can be measured in units of g, where $g = 9.80\ \text{m s}^{-2}$ at or near the Earth's surface. How many g's does the passenger experience?

Another way of producing high-g conditions is to use a centrifuge—a seat or capsule attached onto the end of a long arm which can be rotated at a variable rate in a horizontal plane.

3 A centrifuge with an 8.5 m arm is rotated at 24 rpm. How many g's are experienced by the test pilot in the cage at the end of the arm?

Anybody who is in orbit experiences 'apparent' weightlessness. Of course, they are not really weightless at all as they are still in the Earth's gravitational field—the very reason they are in orbit. However, they feel weightless because there are no contact forces from the sides of the spacecraft acting on them. As part of their training before they go to space, astronauts need to get experience of weightlessness. This is where the 'Vomit Comet' comes in.

There are several aeroplanes which qualify for this dubious title. Each plane follows a series of parabolic, free-fall segments during its flight. These free-fall sections are joined together by a series of dives and climbs during which higher than normal 'g-forces' are experienced by the passengers. A typical flight profile is as shown here.



4 Consider point A at the bottom of the dive phase where the aeroplane is travelling at $720\,\text{km}\,\text{h}^{-1}$. A 65.0 kg person lying on the floor of the cabin experiences 1.80*g*. Draw a diagram showing the forces acting on her.

5 Calculate the radius of curvature of the flight path at that point.

6 From that point the aeroplane begins to climb at an increasing angle until it reaches an elevation of 50° at point B. At this point it begins the parabolic trajectory phase by reducing engine power. Assuming the passenger still experiences 1.80*g* just before the engines are throttled back, draw a new diagram showing the forces acting on her then.

7 During this part of the flight, the engine power is reduced—but not to zero. If the aeroplane is entering free-fall, why does the plane still need the thrust of the engines?

8 Typically, the parabolic trajectory phase lasts 20 s: 10 s up and 10 s down. Calculate the velocity the plane will need at point B to achieve this duration of weightlessness.

9 Explain what would happen if the aeroplane were to fly a bit too fast at the top of the parabolic section of the flight at point C.

RATING MY LEARNING	My understanding improved	Not confident ○ ○ ○ ○ ○ Very confident	I answered questions without help	Not confident ○ ○ ○ ○ ○ Very confident	I corrected my errors without help	Not confident ○ ○ ○ ○ ○ Very confident

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WORKSHEET 5.6

Working with orbits

Getting a satellite into space is not a trivial exercise. The objective is to achieve enough speed and height to maintain orbit. Consider the task of putting a 100 kg satellite into a circular orbit.

1 Given the radius ($r_E = 6.37 \times 10^6$ m) and mass ($m_E = 5.97 \times 10^{24}$ kg) of the Earth, calculate the gravitational potential energy of the satellite before it is launched.

2 Find the total energy of the satellite once it has been placed in an orbit of altitude 100 km above the Earth's surface.

3 Explain why these quantities are negative.

4 The difference between the two quantities you have found is the amount of energy that needs to be imparted to the satellite by the launch vehicle. How much energy is this?

5 Of course, the satellite before launch is not really stationary—it is moving along with the Earth as it rotates. Assuming that the launch pad is on the equator, find the initial kinetic energy of the satellite.

6 This initial kinetic energy can be utilised by launching the satellite in the appropriate direction. What is that direction and why is the equator the best latitude for launch?

7 Describe this kinetic energy as a percentage of the amount of energy found in question 4.

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Now consider what is required to get such a satellite to Mars. To simplify things, first consider what energy is required to move the 100 kg satellite from Earth's orbit to the orbit of Mars.

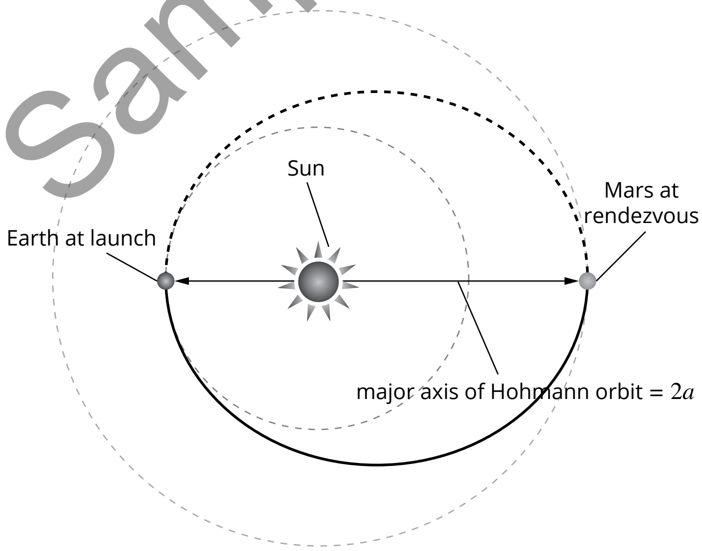
8 Find the difference between the total energy of the satellite when it is in Earth's orbit compared to when it is in Mars' orbit. (Use this data: mass of the Sun $M_{\odot} = 1.99 \times 10^{30}$ kg, radius of Earth's orbit = 1.50×10^{11} m, radius of Mars' orbit = 2.28×10^{11} m.)

This energy difference is only a part of the story. In addition, the satellite will need to be given enough energy to escape entirely from Earth's gravity. (This is also known as escaping Earth's gravity well.) When the satellite is in Mars' orbit, its gravitational potential energy in Earth's field can be taken to be zero as it is so far away.

9 What is the value of this escape energy? What percentage of the energy calculated in question 8 does this represent?

Now consider the trajectory required for this orbital transfer. Rather than trying to travel to Mars in a straight line, the path will be determined by the relative positions of Earth and Mars, both at the time of launch and at the planned rendezvous with Mars.

The orbit required for greatest efficiency is called the Hohmann transfer orbit. Where the orbits of Earth and Mars are approximately circular, the transfer orbit is elliptical, with the perihelion (the closest point to the Sun) equal to the Earth's orbital radius and the aphelion (the furthest point from the Sun) at the orbit of Mars.



Kepler's third law can be used to find out roughly how long the trip to Mars would take. The third law states that for all orbits around the Sun the quantity $\frac{R^3}{T^2}$ is a constant, where R is the radius of the orbit and T is the period. Most planets have a circular orbit and the application of the third law involves the orbital radius. But when the orbit is highly elliptical, the value of R needs to be replaced with the length of the semi-major axis, a. The third law then becomes $\frac{a^3}{T^2}$ = constant.

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10 Find the value of the semi-major axis of the Hohmann transfer orbit.

11 Compare the value of $\frac{a^3}{T^2}$ for the satellite in the Hohmann transfer orbit with the value of $\frac{a^3}{T^2}$ for the Earth, and find the duration of the Hohmann trip to Mars in units of days.

This exercise has presented some of the preliminary analyses required to plan a trip to Mars. There are many further questions that can be considered, including:

- Exactly when are both the Earth and Mars in the correct positions for a launch? (This is known as the launch window.)
- You have found the energy for the transfer orbit, but at what points does this energy need to be applied?
- How much does the orbital energy of the satellite in its 100 km orbit help?
- How will the gravity well of Mars affect calculations?
- Will a trip back to Earth be needed at some stage? (This has not yet been achieved.)

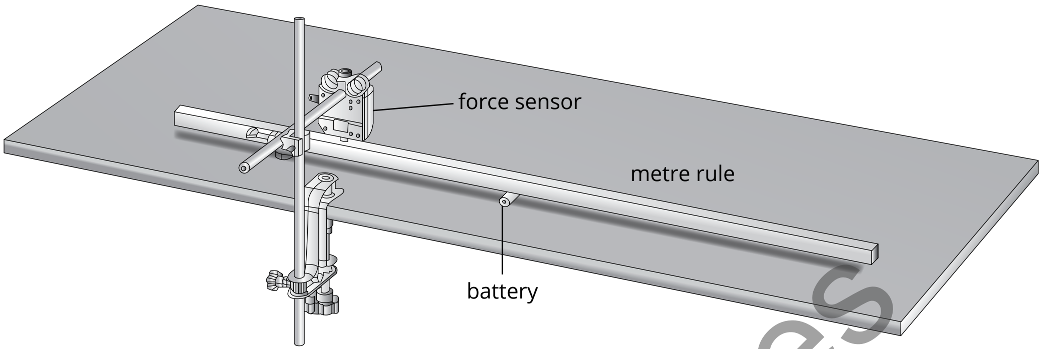
RATING MY LEARNING	My understanding improved	Not confident ◯ ◯ ◯ ◯ ◯ Very confident	I answered questions without help	Not confident ◯ ◯ ◯ ◯ ◯ Very confident	I corrected my errors without help	Not confident ◯ ◯ ◯ ◯ ◯ Very confident

WORKSHEET 5.7

Calculating torque

Torque is the rotational equivalent of force. Torque must be applied to an object to start an object rotating. For calculations involving torque, the entire weight of an object can be considered to act at a single point, the centre of gravity or centre of mass of the object. Torque is a vector quantity with direction parallel to the axis of rotation.
A torque is positive when it is applied in the anticlockwise direction and negative when it is applied in the clockwise direction.

In an experiment to investigate torque and the rotation of mechanical systems, the following system was set up.



The battery acts as the pivot point about which the metre rule will rotate. The force sensor measures the force at a fixed point when a mass is placed at varying distances along the rule on the opposite side of the pivot point.

The following data was collected in a series of trials when the horizontal distance from the force sensor to the pivot point was 0.350 m.

Trial	Horizontal distance of mass to pivot point (m)	Force measured by sensor (N)	Torque measured by sensor (N m)	Torque applied by mass (N m)
1	0.100	0.280		
2	0.200	0.560		
3	0.300	0.840		
4	0.400	1.12		
5	0.500	1.40		

1 Assuming the rule is in rotational equilibrium, complete the table to show the torque measured by the sensor and the torque applied by the mass. Treat the direction of the torque measured by the force sensor as anticlockwise (i.e. imagine you are looking at the apparatus from across the table).

2 Based on the test results, what is the size of the mass being applied?

3 Draw a force diagram of the setup above when the net torque acting on the object is zero. Indicate the direction and magnitude of the forces involved.

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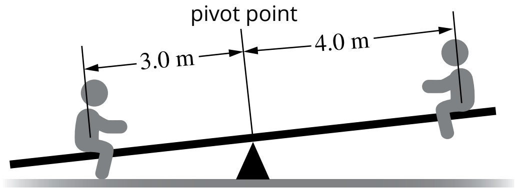
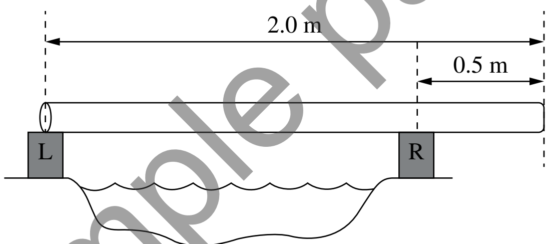
4 The equipment is rearranged so that the force sensor is now at an angle of 60° from the horizontal. What would be the force measured by the force sensor with the mass at a distance of 0.500 m from the pivot point? Assume that the force sensor is still applied at a distance of 0.350 m from the pivot point.

5 Two children are sitting on a seesaw. If the child on the left has a mass of 31.0 kg and sits 3.0 m from the pivot point, and the child on the right has a mass of 25.0 kg and sits 4.0 m from the pivot point, what is the net torque on the seesaw? If the seesaw is initially at rest, which way will it rotate? Assume that the pivot point is directly below the centre of mass of the seesaw. Show your working.



6 A log (m = 52 kg) has been placed on two supporting concrete blocks as shown. Assuming the log is in static equilibrium, find the normal force acting on each of the concrete blocks.



RATING MY LEARNING	My understanding improved	Not confident ○ ○ ○ ○ ○ Very confident	I answered questions without help	Not confident ○ ○ ○ ○ ○ Very confident	I corrected my errors without help	Not confident ○ ○ ○ ○ ○ Very confident

WORKSHEET 5.8

Literacy review—talking motion

Complete the statements by filling in the blanks from the list of randomly ordered words below. Some words may not be used and others may be used more than once.

gravity	free fall	speed	range	angle	circular	centripetal	parabolic
velocity	mass	projectile	radius	acceleration	constant	centrifugal	tension

1 When a ball falls vertically to the floor, it is in a ____________ state of motion. When a ____________ is launched horizontally, its horizontal velocity is ____________. The shape of the ball's flight is referred to as its trajectory and is ____________ in shape. The maximum ____________ of flight depends on the launch ____________ and the launch ____________. The force due to ____________ directly relates to the free fall acceleration of the ball.

2 The force that acts through a string is referred to as ____________. If an object is tied to a string such that its speed remains constant as it travels around a central point, it undergoes uniform ____________ motion. Even though the object's ____________ is constant, its ____________ is constantly changing. The tension in the string supplies the ____________ force.

3 An inwards, or centre-seeking, force is called the ____________ force. A constant force means a constant ____________, which makes sense if the object undergoing circular motion has a constantly changing ____________. If the centripetal force is kept constant then variables such as ____________ and ____________ are proportional to the time it takes to complete a revolution.

4 Centripetal and centrifugal forces are real and imaginary forces respectively that are used in discussions of circular motion. Find the derivation of each word and, from this, its definition.

____

____

5 Match each of the following terms with the description that best matches it.

Term	Definition
torque	
rotation	
lever arm	

a produced by a torque

b produces rotational motion

c distance from a turning point to the fulcrum

d direction of the applied force on a lever

RATING MY LEARNING	My understanding improved	Not confident ◄—► Very confident ○ ○ ○ ○ ○	I answered questions without help	Not confident ◄—► Very confident ○ ○ ○ ○ ○	I corrected my errors without help	Not confident ◄—► Very confident ○ ○ ○ ○ ○

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WORKSHEET 5.9

Thinking about my learning

On completion of Module 5: Advanced mechanics, you should be able to describe, explain and apply the relevant scientific ideas. You should also be able interpret, analyse and evaluate data.

1 The table lists the key knowledge covered in this module. Read each and reflect on how well you understand each concept. Rate your learning by shading the circle that corresponds to your level of understanding for each concept. It may be helpful to use colour; for example:

- green—very confident
- orange—in the middle
- red—starting to develop.

Concept focus	**Rate my learning**				
	Starting to develop ◄──► Very confident				
equations of motion	○	○	○	○	○
projectile motion	○	○	○	○	○
circular motion in a horizontal plane	○	○	○	○	○
circular motion in a vertical plane	○	○	○	○	○
motion on banked tracks	○	○	○	○	○
torque	○	○	○	○	○
Newton's law of universal gravitation	○	○	○	○	○
satellite motion and Kepler's laws	○	○	○	○	○
escape velocity	○	○	○	○	○
energy changes of an object in circular motion and for satellites	○	○	○	○	○

2 Consider points you have shaded from starting to develop to middle-level understanding. List specific ideas that you found challenging.

3 Write down two different strategies that you will apply to help further your understanding of these ideas.

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PRACTICAL ACTIVITY 5.1

Projectile motion—an introduction

Suggested duration: 40 minutes

INTRODUCTION

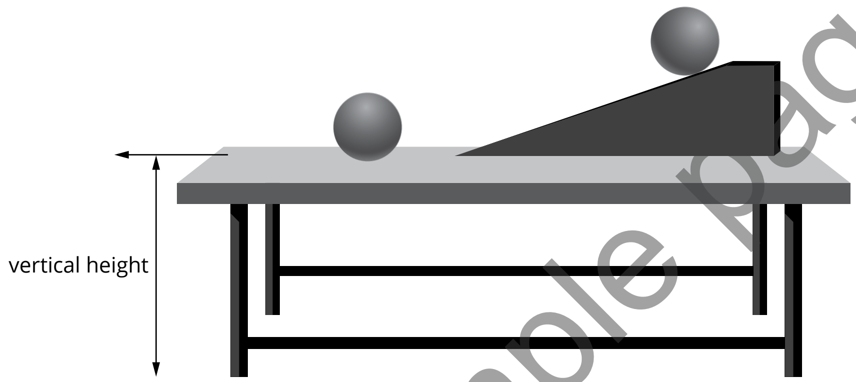
In this activity you will conduct a practical investigation to collect primary data to validate the relationship between time of flight, height and range.

PURPOSE

To confirm the dependence of the range of a projectile (the horizontal distance it travels) on its time of flight and launch velocity by predicting the landing point of a projectile and then testing the prediction.

PROCEDURE

Consider the situation in the figure below. A small ball rolls across a flat surface with a known speed, and then moves off the end of the table and falls to the floor. While it is in flight the only external forces acting on the ball are gravity and air resistance. Air resistance should be ignored in this investigation.



Part A: Determining the launch velocity

1 Mark a point on the ramp, where the ball can be consistently released from the same position. Measure the horizontal distance from the end of the ramp to the edge of the table. Record this in the Data and analysis section.

2 Release the ball and time how long it takes to travel the horizontal distance from the base of the ramp to the edge of the table. Do not let the ball fall to the floor while recording this time.

3 Repeat the test a number of times, recording each trial in Table 1 provided in the Data and analysis section.

4 Complete Table 1 by calculating the velocity across the tabletop for each trial and then finding the average velocity.

MATERIALS

- ramp or board
- small ball (each group may use one or more of different size and mass)
- stopwatch
- horizontal bench or table
- polystyrene cup

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Part B: Predicting and testing the range

1 Record the height the ball will fall from the table to the floor.

2 Calculate the time of flight and hence the distance the ball will travel in the horizontal direction (the range) while it is in the air. Show your working in the Data and analysis section.

3 Measure out the calculated landing distance on the floor and place a polystyrene cup at the predicted point. Attach the cup to the floor with some Blu Tack so it won't move when the ball hits it or lands in it.

4 Test your prediction by releasing the ball from the spot marked on the ramp as originally used in Part A.

DATA AND ANALYSIS

Part A: Determining the launch velocity

Distance across tabletop: s = ______________ m

TABLE 1 Data collected for Part A

Trial number	Time, t, taken to travel across tabletop (s)	Velocity across tabletop ($m\,s^{-1}$) $v = \frac{s}{t}$
1		
2		
3		
4		
5		
average		

1 Is the velocity being calculated the velocity of the ball at the edge of the table? If not, is it a reasonable approximation? Explain your answer.

2 What effect would increasing the horizontal distance have on the reliability of your measurements?

Part B: Predicting and testing the range

Height above the ground: _______ m

1 Calculate the time it takes for the ball to fall from the table to the floor.

2 Calculate the distance the ball will travel in the horizontal direction, i.e. the range.

CONCLUSION

1 State whether your prediction was successful, and describe any difficulties encountered in testing the prediction.

2 In this experiment, the assumption was made that there is negligible effect from air resistance. Would the effect of air resistance be more significant if the ball was released from a height of 30 cm up the ramp or 15 cm? Explain.

3 What is the major source of error in this experiment? What steps were taken to minimise it?

RATING MY LEARNING	My understanding improved	Not confident ○ ○ ○ ○ ○ Very confident	I answered questions without help	Not confident ○ ○ ○ ○ ○ Very confident	I corrected my errors without help	Not confident ○ ○ ○ ○ ○ Very confident

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PRACTICAL ACTIVITY 5.2

Projectile motion—the effect of launch angle on range

Suggested duration: 45 minutes

INTRODUCTION

In this activity students will use electronic means to:

- measure the initial velocity of a projectile
- measure the time of flight of a projectile
- interpret data to predict the angle that will give the longest range
- calculate the appropriate angle in order to hit a target at a given range.

PURPOSE

To investigate the relationship between the launch angle of a projectile, its motion and the range of the projectile.

Safety warning: Always wear safety glasses when using any kind of projectile launcher. Never look down the barrel of a mechanical projectile launcher.

MATERIALS

- data-collection system
- projectile launcher (commercial or improvised e.g. poly tube)
- projectile
- photogate/s and (optional) time-of-flight pad or stopwatch
- angle indicator
- tabletop or bench
- table clamp or burette stand and clamps
- A4 paper
- tape measure
- sticky tape
- carbon paper (optional)

PROCEDURE

1 Start a new experiment on your data collection system. Connect the photogates to your system following the manufacturer's instructions.

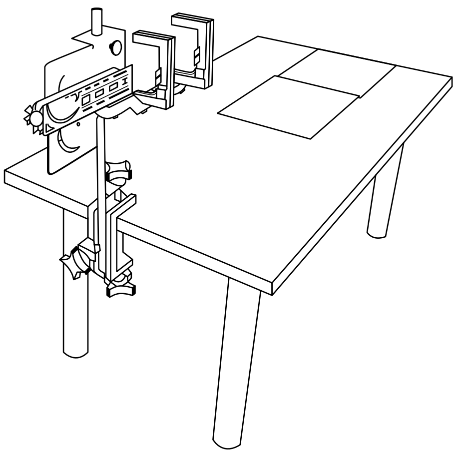
2 Select 'velocity between gates' if prompted by your data collection system.

Ensure the 'space between gates' parameter on your data collection system is set to the measured space between your photogates.

3 Put your data collection system into manual sampling mode with manually entered data. Name the manually entered numerical data 'angle' measured in degrees.

4 Add a column to the table to display the distance in metres.

5 Attach the projectile launcher to a table so that the projectiles travel across the longest part of the table. One suitable arrangement of the launcher is shown below. Use the equipment available to you to arrange the launcher to 'fire' down the length of the table and through the photogates. Be careful to avoid firing the projectile at classmates!



6 Place sheets of paper end-to-end in a line across the length of the table in front of the projectile launcher, and secure them in place with tape.

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7 Measure the height from the point where the ball is released to the tabletop, and record this value in the Data and analysis section.

8 Mount the photogates to the launcher. Be sure to mount the first named photogate in your data analysis software closest to the launcher.

Part A: Distance versus angle

1 Set the launcher in the horizontal position with a launch angle of 0°.

2 Load a projectile into the launcher, and ensure that the launcher is set to its maximum compression or distance setting.

3 Launch the projectile, and note the point of impact on the paper.

4 Lay a sheet of carbon paper on top of the white paper over the point of impact, carbon side down, so that when a ball lands on it there will be a mark on the paper. Place a sheet of paper over the carbon paper to prevent damage to the carbon paper by the projectile.

If carbon paper is not available, look for a small indentation on the paper where the ball hits. Highlight the point with a pencil or marker when the projectile lands. Before continuing, answer question 1 in the Data and analysis section.

5 Start recording with the data collection system and launch the projectile.

Record the sampled 'velocity between gates' data point, and enter the corresponding angle value in Table 1 in the Data and analysis section.

6 Move the carbon paper, and measure the distance to the mark. Write the angle next to the mark on the paper.

7 Use the angle indicator on the launcher to position the launcher at the next angle, 10°.

8 Repeat the data collection steps, increasing the angle of inclination by 10° each time until you have recorded a data point every 10° from 0° to 80°.

9 Measure and enter the horizontal distance for each angle value into Table 1. Draw a graph of distance versus angle and a graph of velocity versus angle in the spaces provided.

Part B: Time of flight

1 If a time-of-flight pad is available, remove one photogate and attach the time-of-flight pad. Alternatively, a hand-held stopwatch or other timing mechanism can be used. Position the time-of-flight pad over the landing point recorded for an angle of 0^o and reset the launcher to an angle of 0°. Before continuing, answer question 2 in the Data and analysis section.

2 Start a new data-collection session. Launch the ball from the launcher and, using the time-of-flight pad or a stopwatch, record the time the ball is in flight in Table 1.

3 Use the angle indicator on the launcher to position the launcher at the next angle, and repeat the data collection steps until you have recorded a data point every 10° from 0° to 80°. Record the time of flight for each angle in Table 1 of the Data and analysis section. Draw a graph of time of flight versus angle in the space provided.

DATA AND ANALYSIS

Ball release height: ________ m

1 What launch angle do you predict will yield the greatest range (horizontal distance)?

2 Which angle do you think will give the greatest time of flight? Explain the reasons behind your prediction.

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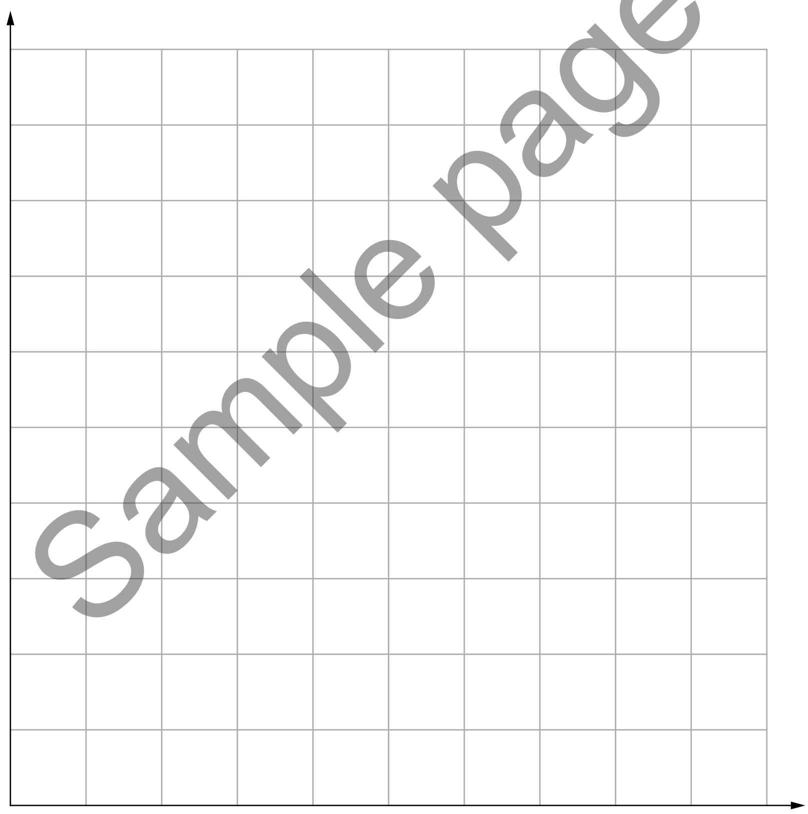
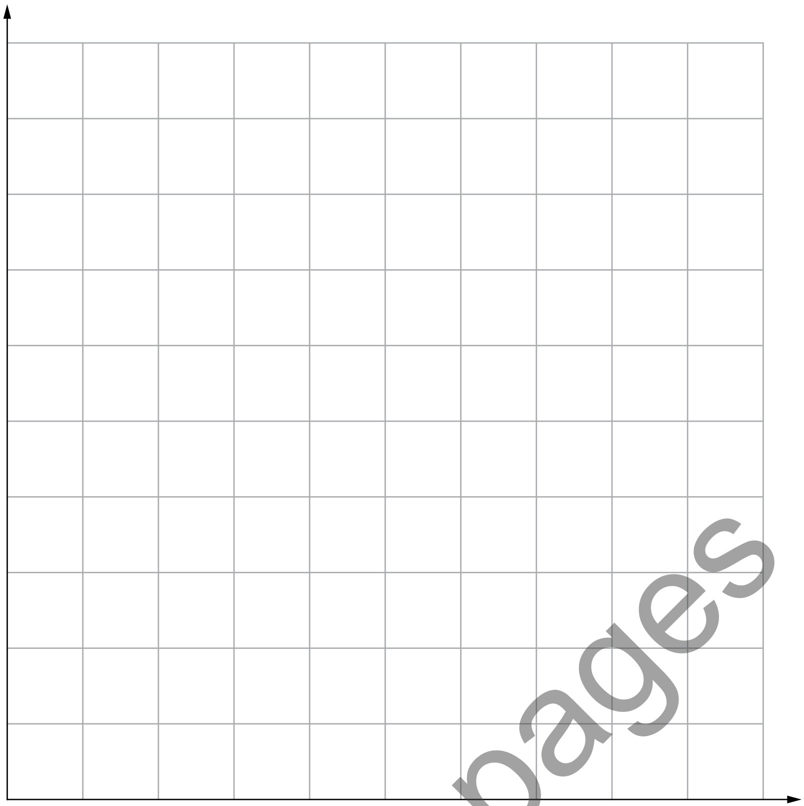
TABLE 1 Collected data for your projectile

Angle (°)	Velocity (m s^{-1})	Distance (m)	Time of flight (s)
0			
10			
20			
30			
40			
50			
60			
70			
80			

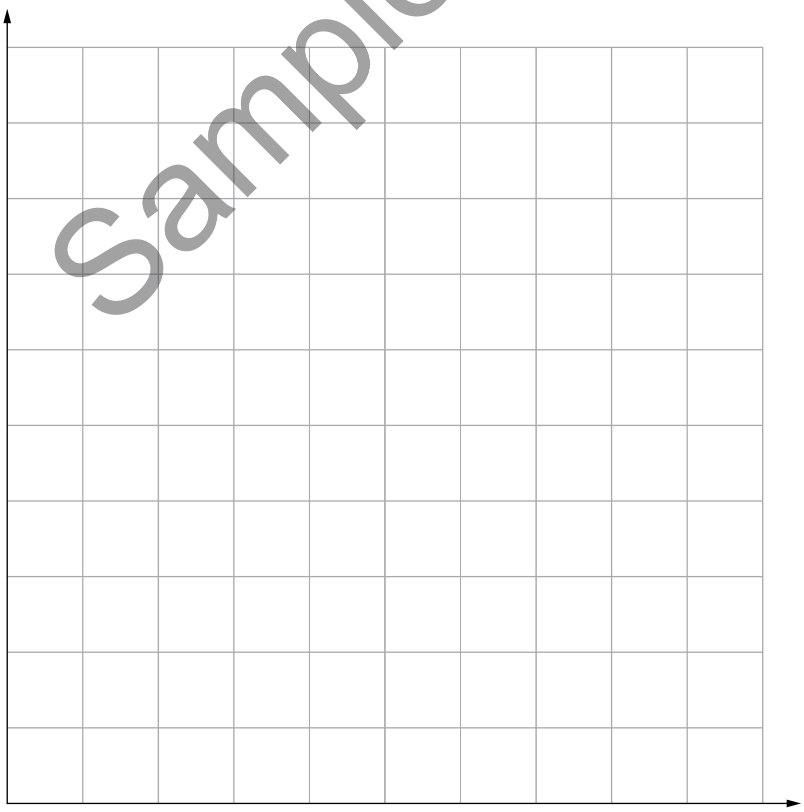
Distance versus angle



Initial velocity versus angle



Time of flight versus angle



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3 Calculate the initial horizontal and vertical components of velocity for each angle, and fill in the columns in Table 2.

4 Use the horizontal distance and time of flight to calculate the average horizontal velocity for each angle, and fill in the corresponding column in Table 2. Why is this referred to as the *average* horizontal velocity?

5 Use the initial vertical velocity and the height of the launcher for each launch angle to calculate the theoretical time of flight of an object shot straight up. Record the results in Table 2.

TABLE 2 Projectile data calculations

Angle (°)	Initial horizontal velocity ($m\,s^{-1}$)	Initial vertical velocity ($m\,s^{-1}$)	Average horizontal velocity ($m\,s^{-1}$)	Theoretical time of flight (s)
0				
10				
20				
30				
40				
50				
60				
70				
80				

CONCLUSION

1 How did the measured horizontal velocities compare to the average horizontal velocities?

2 For any projectile launched horizontally, what can you state about the horizontal velocity?

3 Which launch angle will yield the maximum range (horizontal distance)?

4 Are there launch angles that yield the same range? What are they and why is that the case?

RATING MY LEARNING	My understanding improved	Not confident ◄—► Very confident ○ ○ ○ ○ ○	I answered questions without help	Not confident ◄—► Very confident ○ ○ ○ ○ ○	I corrected my errors without help	Not confident ◄—► Very confident ○ ○ ○ ○ ○

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PRACTICAL ACTIVITY 5.3

Circular motion—centripetal force in a horizontal plane

Suggested duration: 50 minutes

INTRODUCTION

The centripetal force, F_c, of an object of mass m moving at a constant velocity v and radius r is given by:

$$F_c = \frac{mv^2}{r} = 4\pi^2 rmf^2$$

where f is the frequency of its motion. The angular velocity, ω, of an object in a horizontal circular path is given by:

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

where θ is the angle subtended by the object in time t.

In this activity the centripetal force experienced by an object traveling in a horizontal plane will be investigated. A simple version of this experiment involves a mass being moved in a horizontal circular path. The addition of a force sensor to monitor the applied force rather than the use of a mass, or the use of a fully automated solution from one of the physics equipment manufacturers, can add a further degree of sophistication.

MATERIALS

- thin plastic tube about 15 cm long, with no sharp edges (the barrel of a ballpoint pen will do)
- 1.5 m of fishing line
- paperclip
- small soft mass (rubber stopper, cork or similar)
- mass carrier and slotted masses (50 g each)
- stopwatch
- metre rule

PURPOSE

To investigate the relationship between the centripetal force acting on an object moving in a circle of constant radius and the frequency of revolution.

Substitute a force sensor for the mass carrier and slotted masses for real-time graphing of the centripetal force.

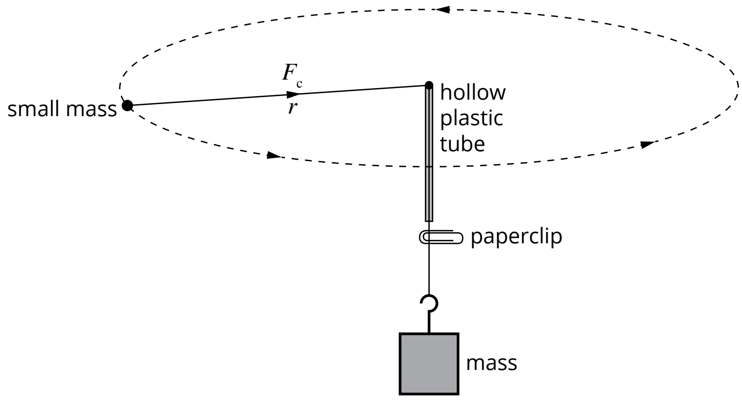
Warning: Students must wear safety glasses.

PROCEDURE

1 Securely tie one end of the fishing line to the small, soft mass. (Since this is going to be twirled around your head, make sure the mass isn't too hard!)

2 Pass the fishing line down through the thin plastic tube and attach a 50 g slotted mass carrier to the end as shown in the diagram. Add three 50 g masses to the mass carrier to make a total mass of 200 g. If using slotted masses, secure them to the fishing line with sticky tape. Alternatively, connect the hook of a force sensor to the end of the fishing line instead of the mass carrier.

3 Attach a paperclip to the line to act as a marker for a measured radius of around 1 m. Measure and record the exact radius in the Data and analysis section.



4 Twirl the stopper in a horizontal circular path at a speed that pulls the paperclip up to, but not touching, the bottom of the tube. Get a partner to keep an eye on the position of the clip to ensure that the speed of rotation stays quite constant. Practise doing this for a while before trying any measurements.

5 Maintain the speed of revolution and measure the time taken for 20 revolutions of the small mass. Record this time in Table 1 of the Data and analysis section.

6 Add an extra 100 g to the mass carrier and repeat steps 2 and 3. Keep adding an extra 100 g mass to the mass carrier, until the mass carrier is full.

DATA AND ANALYSIS

Measured radius of revolution: __________ m

1 What force is the mass carrier providing in this experiment?

2 If using a force sensor, additional masses won't be added. What would you do instead to increase the applied force?

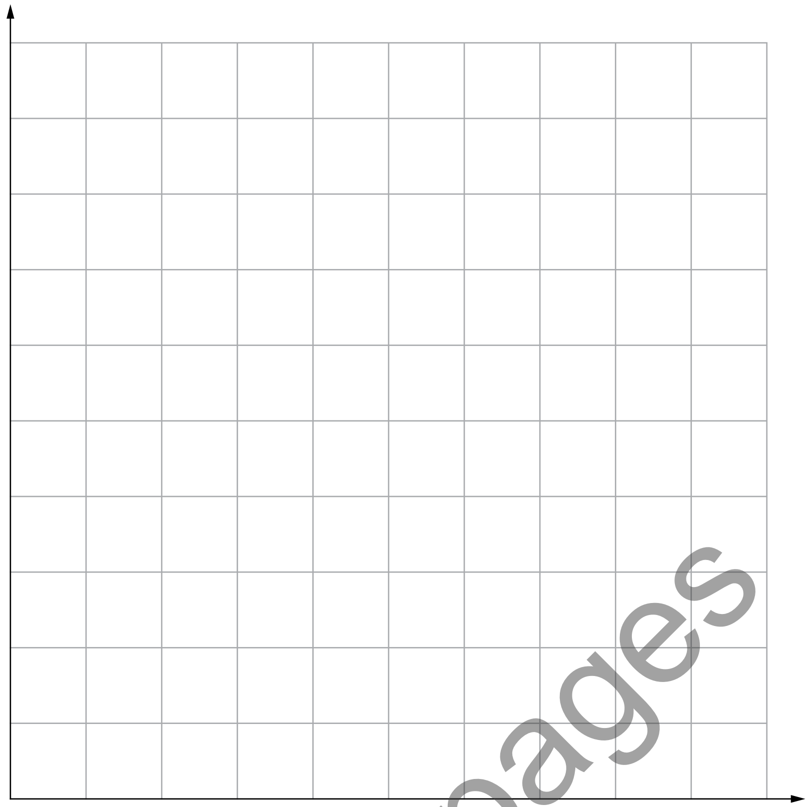
The force of gravity on the suspended mass is providing the centripetal force. Calculate the weight of the force acting on each mass using $g = 9.80\,\mathrm{m\,s^{-2}}$. Alternatively, if using a force sensor, record the average recorded force for each test as the centripetal force. Complete Table 1 with the calculated results.

TABLE 1 Results

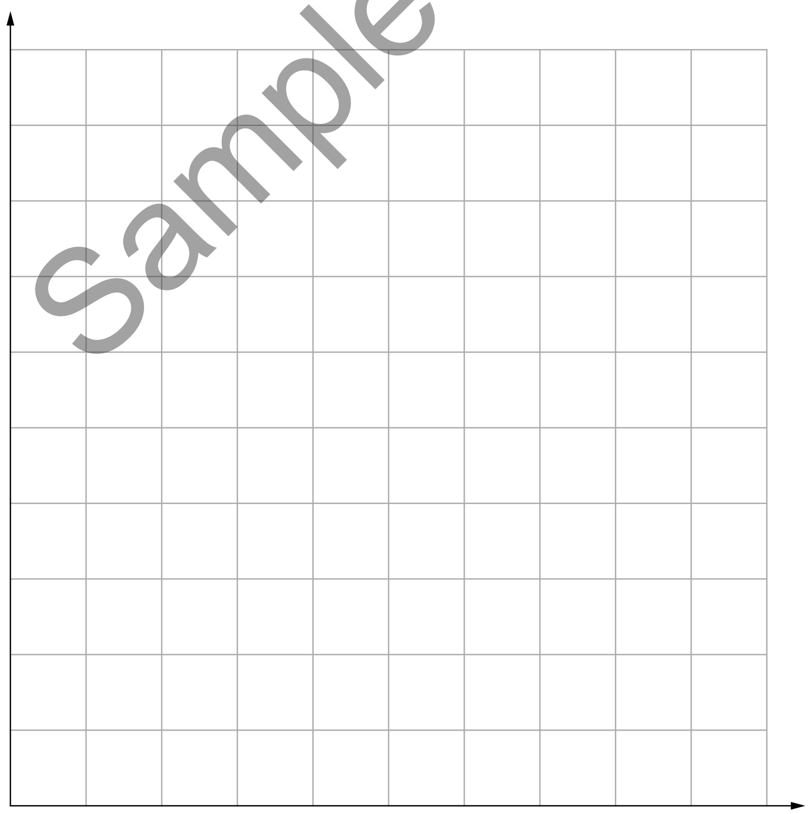
Mass (kg)	**F_c (N)**	**Time for 20 revolutions (s)**	**Period T for one revolution (s)**	**$f = \frac{1}{T}$ (Hz)**	**Angular velocity ω (° s^{-1})**

Plot a graph of frequency, f, versus centripetal force, F_c, and of frequency squared, f^2, versus centripetal force on the axes below.

Frequency versus centripetal force



Frequency squared versus centripetal force



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3 What does the shape of the frequency squared versus centripetal force graph suggest?

4 What value should the gradient of this graph approximate?

CONCLUSION

1 Based on your results, what is the relationship between the centripetal force and the frequency of rotation? Do your results confirm what was expected from theory? Comment on any differences.

2 The radius of revolution will not actually be quite what was measured, nor will the tension in the string be exactly equal to the centripetal force. Why is this so?

3 What effect does this have on your results?

RATING MY LEARNING	My understanding improved	Not confident ⟷ Very confident ○ ○ ○ ○ ○	I answered questions without help	Not confident ⟷ Very confident ○ ○ ○ ○ ○	I corrected my errors without help	Not confident ⟷ Very confident ○ ○ ○ ○ ○

PRACTICAL ACTIVITY 5.4

Circular motion—centripetal force in a vertical plane

Suggested duration: 50 minutes

INTRODUCTION

In this activity, the centripetal force experienced by an object traveling in a vertical plane will be investigated.

PURPOSE

To investigate the non-uniform nature of the forces acting in vertical circular motion.

PROCEDURE

1 Tie the string to the mass and measure the length of the string to the centre of the mass. Mark the string in 20 cm segments.

2 To reduce the friction between the string and your fingers, fasten the alligator clip at one of the 20 cm marks. This will give a better defined radius of the mass and reduces friction, allowing a more constant speed of rotation and greatly improving accuracy.

3 Rotate the mass in a vertical circle. With practice, you can feel the change in tension in the string at the top of the circle compared with that at the bottom. Keep the rotation as even as possible.

4 Time the period of rotation for 20 revolutions and then find the average period. Repeat five times for each particular radius. You may need to use some additional paper if results are recorded for more than four radii.

5 Record your results in Table 1 of the Data and analysis section.

MATERIALS

- string
- small mass
- alligator clip
- stopwatch
- metre rule

As an option for more accurate timing, phones and tablets can be used to video the motion for video analysis. Use a bright coloured mass against a plain background to allow for auto tracking through video analysis tools.

DATA AND ANALYSIS

TABLE 1 Radius and period

Radius, r (m)	Time for 20 revolutions (s)	Period T for one revolution (s)	T_{av} (s)

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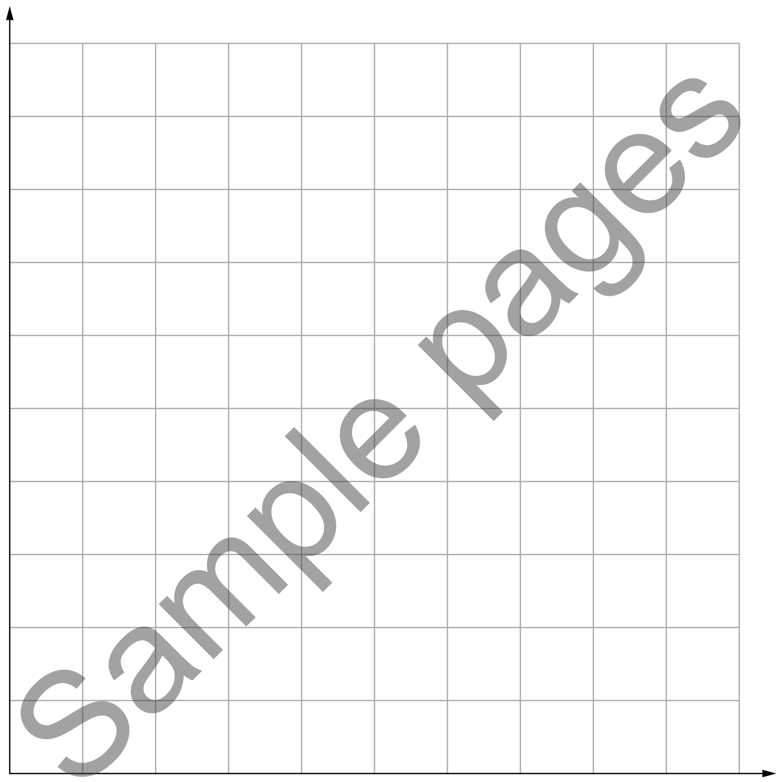
PRACTICAL ACTIVITY 5.4

Plot a graph of period versus radius on the axes provided.

Period versus radius



Why is a graph of period versus radius being plotted?

CONCLUSION

Based on your graph, comment on the relationship between period and radius. Do your results confirm what was expected from theory? Comment on any discrepancies.

RATING MY LEARNING	My understanding improved	Not confident ○ ○ ○ ○ ○ Very confident	I answered questions without help	Not confident ○ ○ ○ ○ ○ Very confident	I corrected my errors without help	Not confident ○ ○ ○ ○ ○ Very confident

DEPTH STUDY 5.1

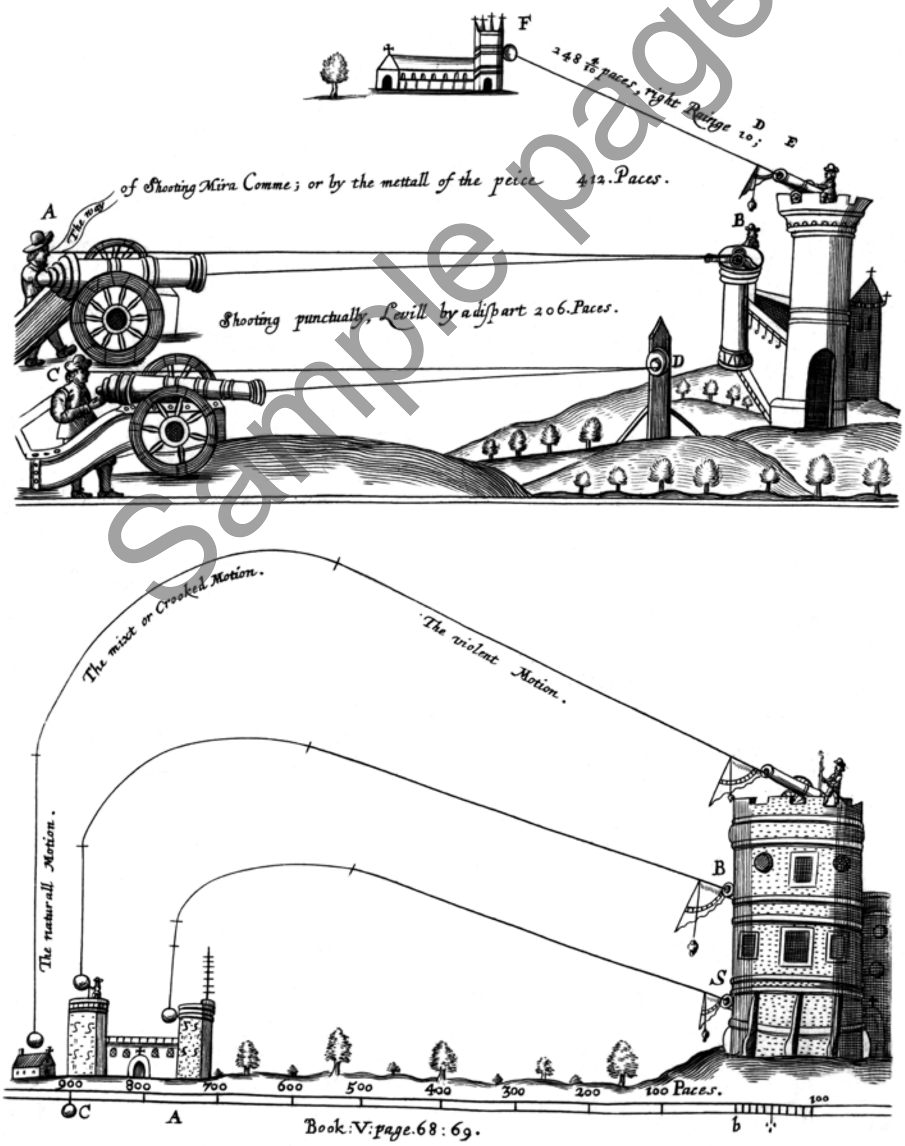
Projectile motion—what happens when the wind blows?

Suggested duration: 3.75 hours

INTRODUCTION

Your initial studies of projectile motion mention air resistance as the other force, apart from gravity, acting on a projectile in flight, but for the purposes of the definition of projectile motion consider only the effect of gravity. In normal practice, of course, air resistance (including its variation with the projectile's velocity) and projectile spin play a big part in determining the final path of the projectile. Sports players can take advantage of spin to adjust the forces experienced by a ball in flight and to alter the flight of the ball. However, air resistance and the blowing of the wind can also have an unwanted effect that needs to be considered in setting the initial launch angle and speed.

This depth study requires you to question the role of the forces due to air resistance, spin and the wind on the flight path of a projectile. You will develop an inquiry question that requires research or experimentation to develop an informed hypothesis; plan an experimental investigation; and analyse primary- and secondary-sourced data and information from appropriate sources, using problem-solving techniques to determine the validity of the data and sources. You will evaluate the data to form conclusions by considering the quality of the data. You will process the data and information in order to communicate your findings in a poster format of approximately 500 words that includes your initial research or planning, experimentation, problem-solving and development of knowledge and understanding of the topic.



The potential path of a projectile has occupied the minds of scientists, mathematicians and others over many centuries. This illustration of the projected paths of cannonballs fired at different angles and heights was first published in *Mariners Magazine* in 1669.

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Your presentation will use appropriate scientific notation and nomenclature, graphs, force diagrams and appropriate calculations, and will appropriately apply scientific language that is suitable for the audience and context.

TOPIC REQUIREMENTS AND CONSTRAINTS

Your research must be conducted individually.

The topic chosen must relate to the motion of a projectile.

The topic must allow the development and answer of one clear inquiry question related to the effect of spin, wind, air resistance due to the shape of the object, or combinations of these, on the flight of the projectile, developing appropriate graphs of the flight path and associated vector diagrams.

PURPOSE

Research and experimentally investigate an application of projectile motion such as a particular ball sport, athletics event or 'human cannonball' phenomenon, to develop an appropriate hypothesis that explains the effect of wind, spin and other factors affecting air resistance on the projectile. Report on your knowledge and understanding of the topic based on an analysis of primary and secondary data.

QUESTIONING AND PREDICTING

1 What is a 'projectile' within the area of study of projectile motion?

2 Phrase your topic as a question. For example, 'How does backspin and top spin affect the path of a tennis ball in flight?' You may want to consult a few resources first. Choose a topic that is readily accessible and can be researched with the equipment that is available.

3 List three or four possible questions that would help answer your main question. For example, 'What force does backspin apply to a tennis ball?' or 'What force does top spin apply to a tennis ball?'

4 Do some preliminary research to help answer your initial questions. You may want to rephrase your questions to make them as clear and specific as possible. List your references and rephrased questions in the space provided.

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5 Look back at your initial topic question. Construct a hypothesis that can be applied to answer your question. This becomes your working hypothesis and should summarise the answer to your main question. It may change after some further research.

PLANNING YOUR INVESTIGATION

6 Make note of any equations that are relevant to your investigation.

7 Describe your experimental method, justifying the reliability of the data you will collect. Start by creating a mathematical model of your projectile's flight, potentially using a spreadsheet program, and then follow this with a practical application of your model. Consider the use of video analysis to analyse the experimental flight. Keep the videos short and ensure that you are videoing from a position perpendicular to the motion so there is as little change in perspective as possible.

Comment on what steps you have taken to ensure the validity of the data as it applies to your hypothesis.

8 Working in small groups, evaluate other students' topics. What are the strengths of their experimental investigations or research? How could you improve your own investigation or research question?

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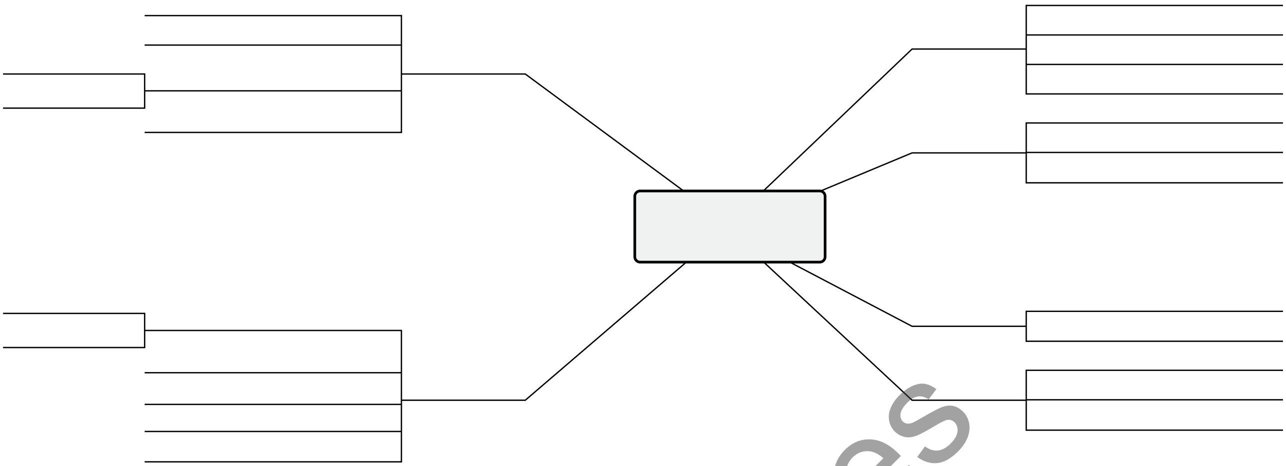
CONDUCTING THE INVESTIGATION

9 Refine your mathematical model by synthesising your research from secondary sources.

Carry out the remainder of your investigation, summarising key points as you proceed so that your topic has a clear focus and development. Use the tree diagram below to link your development back to your original hypothesis.



ANALYSING DATA AND INFORMATION

10 Were you successful in answering your original hypothesis? Did you need to rephrase it?

11 Does your experimental data support your conclusions? How reliable is your primary and secondary data? You may be able to calculate a reasonable measure of the likely error in your results.

PROBLEM SOLVING

12 To what extent do your findings confirm or contradict other sources?

13 How well did your mathematical model fit your experimental results? You may want to calculate a percentage difference between the experimental and theoretical results.

14 Comment on any assumptions made within your model and whether you accounted for them within your experiment.

COMMUNICATING

Communicate your findings in the form of a scientific poster. It should include explanations of the topic development and/or experimental methodology, and assumptions you have made, relevant calculations, data, graphs and clear vector diagrams illustrating the effect of the additional outside force/s on the flight of the projectile. A suitable template for your poster is below.

Title (*inquiry question, ending in a '?'*)

Student name

School name

Year 12 Physics

Introduction

Cut and paste from Microsoft® Word® document/logbook

- *Include purpose and hypothesis.*
- *Summarise background physics concepts, including in-text citations to appropriate references.*
- *Font should be easy to read from 1 m away (suggest minimum 16 point in Calibri, Arial or Tahoma).*
- *Use contrasting colours (e.g. black or blue colour on white background).*

Cut and paste images (e.g. from logbook)

Where possible include a labelled diagram of experimental set-up/results

Each figure should be numbered with an appropriate label (and reference where applicable)

Analysis

Cut and paste from Word document/logbook

- *Discuss, analyse and evaluate data obtained (directly refer to data in tables).*
- *Link results to key physics concepts (include in-text citations as appropriate).*
- *Identify outliers.*
- *Include limitations and recommendations for further research.*

Data

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- *Include summary of results obtained.*
- *Avoid including all raw and processed experimental data—use extract of raw and processed experimental data.*
- *Where possible, present data graphically (e.g. in pie/bar/line graphs).*
- *Number each table/graph and give it an appropriate title.*
- *Ensure axes are labelled, including units if applicable.*

Procedure

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- *Include summary of method used:*
  - *e.g. flow chart*
  - *consider using embedded graphics in media presentation programs such as Microsoft® PowerPoint®.*
- *Identify and manage relevant risks and follow relevant safety guidelines.*

Conclusion

Cut and paste from Word document/logbook

- *Summarise research findings according to aim and hypothesis.*
- *Include recommendations for future research.*

References

Include alphabetical listing (by author last name/institution) of all sourced material; ensure in-text citations included where appropriate in poster

Use consistent referencing style (e.g. APA)

Acknowledgements

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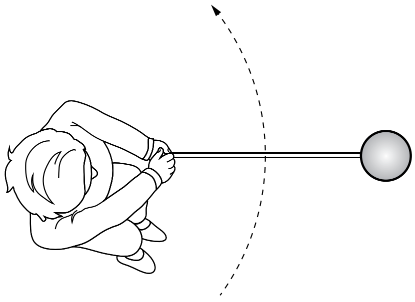
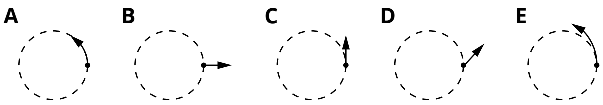
MODULE 5 • REVIEW QUESTIONS

Multiple choice

1 The figure shows a view from above a hammer thrower at the instant of release. The arrow shows the direction of rotation of the athlete and hammer.



Which one of the diagrams A to E below best shows the path of the ball after release?



2 Which one or more of the following are correct? From a location on the Earth's equator, the apparent position of a geostationary satellite:

A reappears directly overhead every 24 hours.

B moves between two positions north and south of the location.

C remains directly overhead.

D remains directly overhead but only during the day.

3 Which one or more of the following are correct? The quantity $\frac{r^3}{T^2}$ is the same for all the:

A planets in the solar system.

B planets and moons in the solar system.

C planets and asteroids in the solar system.

D planets excluding Pluto.

4 In the absence of air resistance, the maximum range of a projectile occurs when the angle of elevation is:

A 30°

B 45°

C 60°

D 90°

5 Simple manipulation of Newton's equation $F = -\frac{GMm}{r^2}$ gives an expression for g with a value of $9.80\,\text{m s}^{-2}$. Which one of the descriptions below does not describe the term g?

A g is the gravitational field at the surface of the Earth.

B g is the force that a mass m feels at the surface of the Earth.

C g is the force experienced by a mass of 1 kg at the surface of the Earth.

D g is the acceleration of a free body at the surface of the Earth.

6 The planet Mercury has a mass about $\frac{1}{20}$ of the Earth's mass and a radius of about $\frac{2}{5}$ Earth's radius. What is the approximate gravitational field on Mercury's surface?

A $0.40g$

B $0.05g$

C $0.13g$

D $0.31g$

Short answer

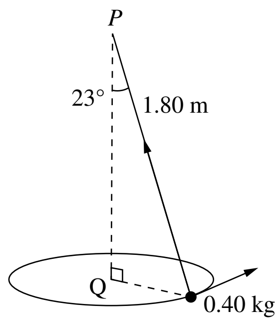
7 A golfer hits a golf ball at $33.0\,\text{m s}^{-1}$ at an angle of 26.0° to the horizontal and it lands on the green, 5.00 m below her position. She was trying to stop the ball close to the flag, which is 107 m away.

a Calculate the time that the ball is in the air before hitting the green and then find how far horizontally from the golfer the ball first strikes the green.

b What is the velocity of the ball as it lands?

c Why would a higher shot be preferred if the golfer wanted to stop the ball as near to the hole as possible?

8 A 0.40 kg object is whirled in a horizontal circle (as a conical pendulum) on the end of a string 1.80 m long. The string makes an angle of 23° to the vertical.



a What is the net vertical force acting on the object?

b What is the radius of the object's path?

c Calculate the tension in the string.

d How fast is the object travelling?

9 A catapult is set up to throw a rock over a 16.0 m high castle wall 65 m away. The initial velocity and angle of elevation are 48 m s^{-1} and 32° respectively. The catapult and the base of the wall are on the same horizontal level.

a How long will it take for the rock to pass over the wall?

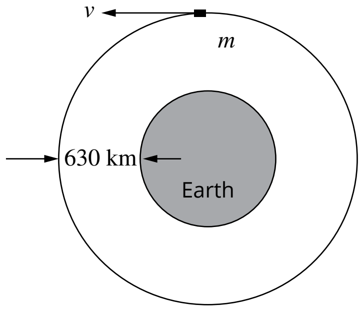
b By what distance will the rock clear the wall?

10 A small space probe is placed in a very low orbit around the Moon (effectively at an altitude of 0 m).

a Use the equations of gravity and circular motion to show that the Moon's average density can be expressed as $\frac{3\pi}{GT^2}$.

b If the orbital period of the probe is observed to be 109 minutes, calculate the Moon's average density.

11 A rocket-powered spacecraft of mass 125 kg (including fuel) is in Earth's orbit at an altitude of 6.30×10^2 km.



a Show that the speed v of the satellite is given by $v^2 = \frac{GM_e}{r}$.

b Calculate the speed and kinetic energy of the satellite.

The controllers at NASA want to alter the orbit to a higher path at 730 km above the Earth's surface. They do this by firing the satellite's thruster engine for a short time, in the direction of the satellite's velocity.

c What will be the satellite's kinetic energy in the new orbit?

d Explain how an initial increase in the satellite's speed ends in reducing its kinetic energy.

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