

**Heinemann**  
**PHYSICS** **12**  
**4TH EDITION**

**VCE Units 3 & 4**

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## AREA OF STUDY 3: PRACTICAL INVESTIGATION

*Heinemann Physics 12 4th Edition ProductLink* provides extensive support material for Unit 4 Area of Study 3 Practical Investigation. This includes teacher notes and advice, logbook template and sample logbook, poster template and sample poster, rubrics, checklists and more.

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# How to use this book

## Heinemann Physics 12 4th Edition

Heinemann Physics 12 4th Edition has been written to the new VCE Physics Study Design 2017–2021. The book covers Units 3 and 4 in an easy-to-use resource. Explore how to use this book below.

### Extension

The extension boxes include material that goes beyond the core content of the Study Design and are intended for students who wish to expand their depth of understanding.

#### EXTENSION

##### Objects moving at an angle to the magnetic field

The force experienced by a charge moving in a magnetic field is a vector quantity. The original expression noted above applies only to that component of the velocity of the charge perpendicular to the magnetic field. To find the force acting on an object moving at an angle  $\theta$  to the magnetic field, use:

$$F = qvB \sin \theta$$

A charged particle travelling at a steady speed in a magnetic field experiences this force at an angle to its path and will be deflected. This is the theory behind CRT screens. As the direction of the charged particle changes, so does the angle of the force acting on it. In a very large magnetic field the charged particles will move in a circular path. Mass spectrometers and particle accelerators both work on this principle.

When high-energy particles in the solar wind from the Sun meet the Earth's magnetic field, they also experience this type of force. As the particles approach the Earth they encounter the magnetic field and are deflected in such a way that they spiral towards the poles, losing much of their energy and creating the auroras (the southern aurora, or aurora australis, and the northern aurora, or aurora borealis, as shown in Figure 2.4.4).

FIGURE 2.4.4 Charged particles from the Sun or deep space are trapped by the Earth's magnetic field, causing them to spiral towards the poles. As they do this, they lose energy and create the auroras.

#### Worked example 2.4.2

##### DIRECTION OF FORCE ON A NEGATIVELY CHARGED PARTICLE

A single, negatively charged particle with a charge of  $-1.6 \times 10^{-19}$  C is travelling horizontally out of a computer screen and perpendicular to a magnetic field,  $B$ , that runs horizontally from left to right across the screen. In what direction will the force experienced by the charge act?

**Thinking** (Fingers) (palm) (thumb)  
field  $\#$  force  $\#$  (+ (positive charge))



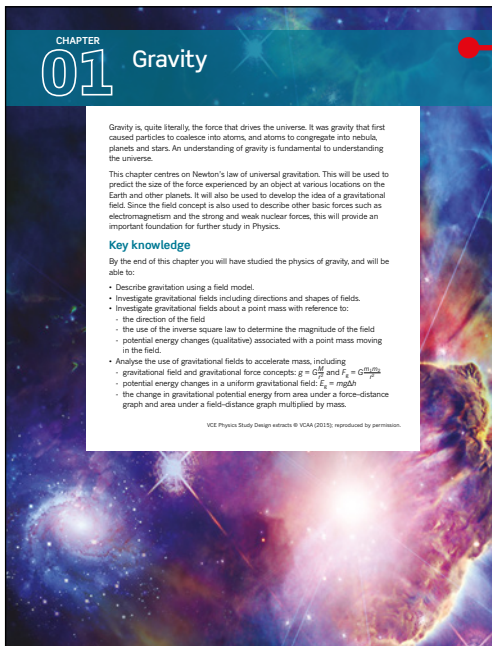
The right-hand rule is used to determine the direction of the force on a positively charged particle.

Align your hand so that your fingers are pointing in the direction of the magnetic field, i.e. left to right and horizontal. If the negatively charged particle is travelling out of the screen, a positively charged particle would be moving in the opposite direction. Align your thumb so it is pointing into the screen, in the direction that a positive charge would be moving. Your palm should be facing downwards. That is the direction of the force applied by the magnetic field on the negative charge out of the screen.

#### Worked example: Try Yourself 2.4.2

##### DIRECTION OF FORCE ON A NEGATIVELY CHARGED PARTICLE

A single, negatively charged particle with a charge of  $-1.6 \times 10^{-19}$  C is travelling horizontally from left to right across a computer screen and perpendicular to a magnetic field,  $B$ , that runs vertically down the screen. In what direction will the force experienced by the charge act?



### Chapter opener

Chapter opening pages links the Study Design to the chapter content. Key knowledge addressed in the chapter is clearly listed.

### Physics in Action

Physics in Action place physics in an applied situation or relevant context. These refer to the nature and practice of physics, applications of physics and the associated issues and the historical development of concepts and ideas.

#### PHYSICS IN ACTION

##### The current balance

A current balance can be used to determine the force on a conductor in a magnetic field, as shown in Figure 2.4.5.



#### THE FORCE ON A CURRENT-CARRYING CONDUCTOR

Since a conducting wire is essentially a stream of charged particles flowing in one direction, it is not hard to imagine that a conductor carrying a stream of charges within a magnetic field will also experience a force. This is the theory behind the operation of electric motors that will be explained in the chapter 'Applications of fields'.

The current in a conductor is dependent on the rate at which charges are moving through the conductor, that is:

$$I = \frac{Q}{t}$$

where  $I$  is the current (A)

$Q$  is the total charge (C)

$t$  is the time taken (s).

For a 1 m length of conductor, the velocity of the charges through the conductor is:

$$v = \frac{l}{t}$$

And hence

$$I = \frac{Q}{t} = Q \times \frac{1}{t} = Qv$$

As  $F = qvB$  for a single charge,  $q$ , moving perpendicular to a magnetic field, then:

$$F = IB$$

for a one metre conductor,

$$F = IB$$

and for a conductor of any length,  $l$ ,  $F = IlB$

$$F = nIlB$$

where  $F$  is the force on the conductor perpendicular to the magnetic field, newtons (N)

$n$  is the number of loops or conductors

$I$  is the current in the conductor in amperes (A)

$l$  is the length of the conductor in metres (m)

$B$  is the strength of the magnetic field in tesla (T)

Just as for a single charge moving in a magnetic field, the force on the conductor is at a maximum when the conductor is at right angles to the field. The force is zero when the conductor is parallel to the magnetic field. The right-hand rule is used to determine the direction of the force.

#### PHYSICSFILE

##### Gravitational repulsive forces

A leading theory is the explanation of the expansion of the universe is the concept of dark energy. While little is understood about dark energy at this time, it may be a source of a repulsive force of gravity originating from the interaction of matter and antimatter.

### Highlight **i**

The highlight boxes provide important information such as key definitions, formulae and summary points.

### PhysicsFile

PhysicsFiles include a range of interesting information and real world examples.

### Worked examples

Worked examples are set out in steps that show both thinking and working. This enhances student understanding by linking underlying logic to the relevant calculations.

Each **Worked example** is followed by a **Worked example: Try Yourself**. This mirror problem allows students to immediately test their understanding.

The fully worked solution to each **Worked example: Try Yourself** is available on *Heinemann Physics 12 4th edition ProductLink*.

## Chapter review

A set of higher order questions are provided at the end of each chapter to test students' ability to apply the knowledge gained from the chapter.

## Section summary

A summary is provided at the end of each section to assist students consolidate key points and concepts.

## Section review


A set of 'key questions' are provided at the end of each section to test students' understanding and ability to recall the key concepts of the section as well as highlight areas that they need to revise.

### 3.3 Review

#### SUMMARY

- Particle accelerators are machines that accelerate charged particles, such as electrons, protons or atomic nuclei, to speeds close to that of light. The device used to provide these particles is called an electron gun.
- The force,  $F$ , on a particle of charge  $q$  in an electric field of strength  $E$  is given by  $F = qE$ . This force causes work to be done on the charged particle. The work done on a charged particle in an electric field can cause a change in the kinetic energy of the particle. If the particle is accelerated from rest, the work done is equal to the final kinetic energy,  $W = qV = \frac{1}{2}mv^2$ .
- The magnitude of the force on a charged object within a magnetic field is given by  $F = qvB \sin \theta$ .
- The right-hand rule is used to determine the direction of the force on a positive charge moving in a magnetic field. The direction of the force on a negatively charged particle is in the opposite direction.
- The radius of the path of an electron travelling at right angles to a uniform magnetic field is given by  $r = \frac{mv}{qB}$ .

#### KEY QUESTIONS

- How are particle accelerators able to provide the centripetal acceleration to change the direction of a charged particle using electromagnetic fields?
  - Charged particles are part of the electromagnetic spectrum.
  - Charged particles experience a force from the magnetic field that is proportional to the particle's velocity, constantly accelerating the charged particle.
  - The accelerator is curved around the magnetic field.
  - Charged particles will always accelerate when placed in a vacuum.
- An electron with a charge magnitude of  $1.6 \times 10^{19}$  C is moving eastwards into magnetic field of strength  $B = 1.5 \times 10^{-4}$  T acting into the screen, as shown below. If the magnitude of the initial velocity is  $1.0 \text{ m s}^{-1}$ , what is the magnitude and direction of the force it initially experiences as it enters the magnetic field?
 
- Electrons in a cathode ray tube (CRT) are accelerated through a potential difference of 25 kV. Calculate the speed at which they hit the screen of the CRT.
- An electron travelling at a speed of  $7.0 \times 10^6 \text{ m s}^{-1}$  passes through a magnetic field of strength  $8.6 \times 10^{-4}$  T. The electron moves at right angles to the field.
  - Calculate the force exerted on the electron by the magnetic field.
  - Given that this force directs the electron in a circular path, calculate the radius of its motion.
- An electron with speed  $7.6 \times 10^6 \text{ m s}^{-1}$  travels through a uniform magnetic field and follows a circular path of diameter  $9.2 \times 10^{-2}$  m. Calculate the magnetic field strength through which the electron travels.
- In an experiment similar to Thomson's for determining the charge to mass ratio  $\frac{e}{m}$  of cathode rays (electrons), electrons travel at right angles through a magnetic field of strength  $1.5 \times 10^{-4}$  T. Given that they travel in an arc of radius 6 cm and that  $\frac{e}{m} = 1.76 \times 10^{11} \text{ C kg}^{-1}$ , calculate the speed of the electron.
- A particle accelerator uses magnetic fields to accelerate electrons to very high speeds. Explain, using appropriate theory and relationships, how the accelerator achieves these high speeds.
- In an electron gun, an electron is accelerated by a potential difference of 28 kV. With what velocity does the electron exit the assembly?
  - An electron beam travelling through a cathode ray tube is subjected to simultaneous electric and magnetic fields. The electrons emerge with no deflection. Given that the potential difference across the parallel plates X and Y is 3.0 kV and that the applied magnetic field is of strength  $1.6 \times 10^{-4}$  T, calculate the distance between the plates.

102 AREA OF STUDY 1 | HOW DO THINGS MOVE WITHOUT CONTACT?

### Chapter review

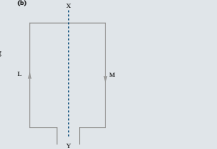
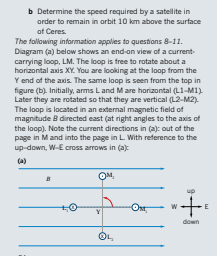
#### KEY TERMS

- apparent weight
- artificial satellites
- cathode ray tube
- centrifugal acceleration
- commutator
- direct current
- electromagnet
- electron gun
- fall full
- geostationary satellite
- natural satellite
- normal reaction force

- Calculate the apparent weight of a 45.0 kg child standing in a lift that is decelerating while travelling upwards at  $1.5 \text{ m s}^{-2}$ .
- Which description best describes the motion of astronauts when orbiting the Earth?
  - They float in a zero gravity environment.
  - They float in a reduced gravity environment.
  - They fall down very slowly due to the very small gravity.
  - They fall in a reduced gravity environment.

- Select the statement below that correctly states how a satellite in a stable circular orbit 200 km above the Earth will move.
  - It will have an acceleration of  $9.8 \text{ m s}^{-2}$ .
  - It will have constant velocity.
  - It will have acceleration of less than  $9.8 \text{ m s}^{-2}$ .
- What can be said about an object if that object is orbiting the Earth in space and appears to be weightless?
  - It is in free fall.
  - It is in zero gravity.
  - It has no mass.
  - It is floating.

- A low-Earth-orbit satellite X has an orbital radius of  $r$  and period  $T$ . A high-Earth-orbit satellite Y has orbital radius of  $5r$ . In terms of  $T$ , what is the orbital period of Y?
  - $5T$
  - $25T$
  - $125T$
  - $625T$
- The planet Neptune has a mass of  $1.02 \times 10^{26}$  kg. One of its moons, Triton, has a mass of  $2.14 \times 10^{22}$  kg and an orbital radius equal to  $3.55 \times 10^8$  m.
  - Calculate the orbital acceleration of Triton.
  - Calculate the orbital speed of Triton.
  - Calculate the orbital period of Triton (in days).
- Ceres, the first asteroid to be discovered, was found by Giuseppe Piazzi in 1801. Ceres has a mass of  $7.0 \times 10^{22}$  kg and a radius of 385 km.
  - What is the gravitational field strength at the surface of Ceres?



CHAPTER 3 | APPLICATIONS OF FIELDS 103

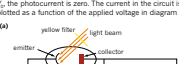
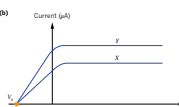
## Area of Study review

A comprehensive set of exam-style questions, including multiple choice and extended response are provided at the end of each Area of Study section. The questions are designed to assist students in to apply their knowledge and understanding across the entire Area of Study.

### UNIT 4 • Area of Study 2

#### REVIEW QUESTIONS

#### How are light and matter similar?

- The following information relates to questions 1–4. Light passing through a yellow filter is incident on the cathode in a photoelectric effect experiment as shown in diagram (a). The reverse current in the circuit can be altered using a variable voltage. At the stopping voltage,  $V_s$ , the photocurrent is zero. The current in the circuit is plotted as a function of the applied voltage in diagram (b).
- 
- 
- Which of the following descriptions of the graphs X and Y in diagram (b) are correct?
    - Both graphs are produced by yellow light of different intensities.
    - Graph X is produced by yellow light while graph Y is produced by blue light.
    - Each graph is produced by light of a different colour and different intensity.
  - The emitter of the photocell is coated with nickel. The filter is removed and a 200 nm light is directed onto the cathode. The minimum value of  $V_s$  that will result in zero current in the circuit is 1.21 V. What is the work function of nickel?
    - Describe three experimental results associated with the photoelectric effect that cannot be explained by the wave model of light.

- The following information relates to questions 5–6. In a double-slit interference experiment, an electron beam travels through two narrow slits, 20 nm apart, in a piece of copper foil. The resulting pattern is detected photographically at a distance of 2.0 m. The speed of the electrons is 0.1% of the speed of light.
- Calculate the de Broglie wavelength of the electrons used in the experiment.
  - What do you expect to see on the photographic plate?
    - Given that electrons are particles, how do you interpret the behaviour of the electrons in this experiment?
    - If the experiment were to be repeated using neutrons, at what speed would a neutron need to travel to have the same de Broglie wavelength as the electrons in Question 5f?

- The following information relates to questions 7–12. The energy levels for atomic mercury are as follows.
- 

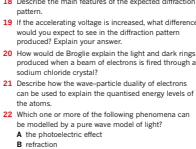
- Determine the frequency and wavelength of the light emitted when the atom makes the following transitions:
  - $n = 4$  to  $n = 1$
  - $n = 2$  to  $n = 1$
  - $n = 4$  to  $n = 3$

372 AREAS OF STUDY 1 & 2 | WAVES AND LIGHT BEHAVIOUR OF LIGHT AND MATTER

- The following information relates to questions 13–15. An electron is accelerated across a potential difference of 65 V.
- What kinetic energy will the electron gain?
  - What speed will the electron reach?
  - What is the de Broglie wavelength of the electron?
  - How did Niels Bohr explain the observation that for the hydrogen atom, when the frequency of incident light was below a certain value, the light would simply be absorbed through a sample of hydrogen gas without any absorption occurring?

- The following information relates to questions 17–19. Physicists can investigate the spacing of atoms in a powdered crystal sample using electron diffraction. This involves accelerating electrons to known speeds using an accelerating voltage. In a particular experiment, electrons of mass  $9.11 \times 10^{-31}$  kg are accelerated to a speed of  $1.75 \times 10^7 \text{ m s}^{-1}$ . The electrons pass through a powdered crystal sample, and the diffraction pattern is observed on a fluorescent screen.
- Calculate the de Broglie wavelength (in nm) of the accelerated electrons.
  - Describe the main features of the expected diffraction pattern.
  - If the accelerating voltage is increased, what difference would you expect to see in the diffraction pattern produced? Explain your answer.
  - How would de Broglie explain the light and dark rings produced when a beam of electrons is fired through a sodium chloride crystal?

- 20 Describe how the wave-particle duality of electrons can be used to explain the quantised energy levels of the atoms.
- 21 Which one or more of the following phenomena can be modelled by a pure wave model of light?
  - the photoelectric effect
  - reflection
  - the double-slit interference of light
- 22 Define the electron-volt.
- 23 Why are all of the frequencies of light above the ionisation energy value for hydrogen continuously absorbed?
- 24 How do our wave and particle models of light parallel the ideas related to electrons and matter waves?

- 25 For an electron and a proton to have the same wavelength:
  - the electron must have the same energy as the proton.
  - the electron must have the same speed as the proton.
  - the electron must have the same momentum as the proton.
  - it is impossible for an electron and a proton to have the same wavelength.
- The following information relates to questions 27 and 28. When conducting a photoelectric effect experiment, a student correctly observes that the energy of emitted electrons depended only on the frequency of the incident light and was independent of the intensity.
- 27 Explain why the wave model cannot account for this observation.
- The following information relates to questions 29–33. Consider the energy level diagram for the hydrogen atom shown below. A photon of energy 14.0 eV collided with a hydrogen atom in the ground state.
- 
- Calculate the energy of the ejected electron in photoelectrons and in joules.
  - What is the momentum of the ejected electron?
  - Determine the wavelength of the ejected electron.
  - A hydrogen atom in the ground state collides with a 10.0 eV photon. Describe the result of such a collision.

REVIEW QUESTIONS 373

## Answers

Numerical answers and key short response answers are included at the back of the book. Comprehensive answers and fully worked solutions for all section review questions, each Worked example: Try Yourself, chapter review questions and Area of Study review questions are provided via *Heinemann Physics 12 4th edition ProductLink*.

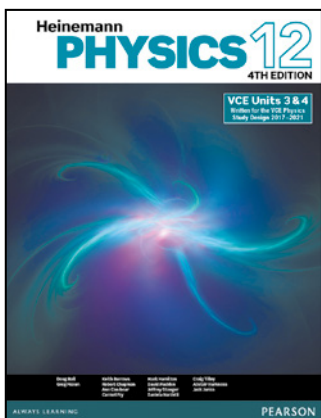
## Glossary

Key terms are shown in bold and listed at the end of each chapter. A comprehensive glossary at the end of the book provides comprehensive definitions for all key terms.

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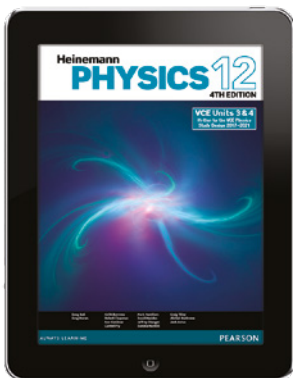
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## 4th Edition



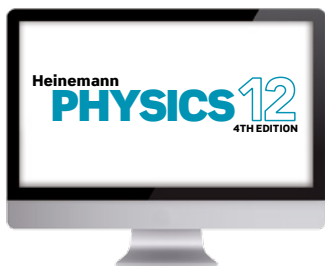
### Student Book

*Heinemann Physics 12 4th Edition* has been written to fully align with the *2017–2021 VCE Physics Study Design*.



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