NSW GOVERNMENT

NSW Education Standards Authority

Physics

Additional sample examination questions

Effective from	2019 HSC Examination
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Updated	Mod 5 – Question 14 Mod 7 – Question 13 (b)

Contents

Introduction

The first HSC examination for the new Physics Stage 6 syllabus will be held in 2019.

The syllabus and related assessment materials are available on the syllabus page of the NESA website.

The *Assessment and Reporting in Physics Stage 6* document provides the Physics HSC examination specifications. The *Physics – Sample examination materials* document indicates the layout and format of the HSC examination and provides examples of questions that may be found in HSC examinations, with annotations.

This document, *Physics – Additional sample examination questions*, provides additional examples of questions that may be found in HSC examinations for Physics. The document comprises new questions, as well as questions that have been published in the sample examination materials and some questions that have been drawn from previous HSC examinations.

The document has been developed to assist teachers to:

- create sample HSC examination papers
- prepare revision exercises
- model question design
- consolidate understanding of the syllabus.

The sample questions are arranged by module. Examples of both objective-response questions and short-answer questions for each of the modules, Advanced Mechanics, Electromagnetism, The Nature of Light and From the Universe to the Atom, are provided.

Each sample question has been mapped to show how the question relates to content, syllabus outcomes and bands. Questions may require candidates to integrate knowledge, understanding and skills from different content areas. Each question is mapped to the main content area(s) being assessed but may be relevant to one or more content areas. When a question has been mapped to multiple content areas, it has been placed under the topic deemed to be most relevant.

Answers for the objective-response questions and marking guidelines for the short-answer questions are also provided. The sample questions, sample answers and marking guidelines provide teachers and students with guidance as to the types of questions that may be included in the examination and how they may be marked. They are not meant to be prescriptive.

Note:

- In this set of sample questions, some stimulus material is used in more than one question. This illustrates how the same content area can be examined in different ways.
- The new Physics Stage 6 syllabus includes content areas that were also part of previous syllabuses. Where this occurs, teachers and students may still refer to past HSC examination papers for examples of other types of questions that are relevant.
- In this document, ‘Bands’ means the performance bands targeted by the question.

Question List

* denotes a multiple–choice question

Module 5 Advanced Mechanics

Question	Marks	Content	Syllabus Outcomes	Bands
Mod 5 – 1*	1	Mod 5 Projectile Motion	PH12–4, PH12–12	2–3
Mod 5 – 2*	1	Mod 5 Projectile Motion	PH12–2, PH12–12	3–4
Mod 5 – 3*	1	Mod 5 Projectile Motion	PH12–4, PH12–6, PH12–12	3–4
Mod 5 – 4*	1	Mod 5 Projectile Motion	PH12–5, PH12–6, PH12–12	3–4
Mod 5 – 5*	1	Mod 5 Circular Motion	PH12–6, PH12–12	2–3
Mod 5 – 6*	1	Mod 5 Circular Motion	PH12–2, PH12–12	3–4
Mod 5 – 7*	1	Mod 5 Circular Motion	PH12–6, PH12–12	3–4
Mod 5 – 8*	1	Mod 5 Circular Motion	PH12–6, PH12–12	4–5
Mod 5 – 9*	1	Mod 5 Motion in Gravitational Fields	PH12–6, PH12–12	4–5
Mod 5 – 10*	1	Mod 5 Motion in Gravitational Fields	PH12–4, PH12–6, PH12–12	4–5
Mod 5 – 11*	1	Mod 5 Motion in Gravitational Fields	PH12–4, PH12–6, PH12–12	5–6
Mod 5 – 12 (a)	3	Mod 5 Projectile Motion	PH12–4, PH12–6, PH12–12	3–6
Mod 5 – 12 (b)	4	Mod 5 Projectile Motion	PH12–4, PH12–6, PH12–12	3–6
Mod 5 – 13	3	Mod 5 Circular Motion	PH12–4, PH12–12	3–5
Mod 5 – 14 (a)	3	Mod 5 Circular Motion	PH12–5, PH12–12	3–5
Mod 5 – 14 (b)	4	Mod 5 Circular Motion	PH12–5, PH12–12	3–6
Mod 5 – 15	5	Mod 5 Circular Motion Mod 7 Electromagnetic Spectrum	PH12–4, PH12–6, PH12–7, PH12–12, PH12–14	2–6
Mod 5 – 16	3	Mod 5 Motion in Gravitational Fields	PH12–7, PH12–12	2–4
Mod 5 – 17	3	Mod 5 Motion in Gravitational Fields	PH12–7, PH12–12	2–5
Mod 5 – 18	5	Mod 5 Motion in Gravitational Fields	PH12–6, PH12–7, PH12–12	2–6
Mod 5 – 19	4	Mod 5 Motion in Gravitational Fields	PH12–12	2–6

Module 6 Electromagnetism

Question	Marks	Content	Syllabus Outcomes	Bands
Mod 6 – 1*	1	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–6, PH12–13	5–6
Mod 6 – 2*	1	Mod 6 The Motor Effect	PH12–2, PH12–13	2–3

Mod 6 – 3*	1	Mod 6 The Motor Effect	PH12–5, PH12–6, PH12–13	5–6
Mod 6 – 4*	1	Mod 6 Electromagnetic Induction	PH12–13	2–3
Mod 6 – 5*	1	Mod 6 Electromagnetic Induction	PH12–6, PH12–13	3–4
Mod 6 – 6*	1	Mod 6 Electromagnetic Induction	PH12–5, PH12–6, PH12–13	4–5
Mod 6 – 7*	1	Mod 6 Electromagnetic Induction	PH12–4, PH12–6, PH12–13	5–6
Mod 6 – 8*	1	Mod 6 Applications of the Motor Effect	PH12–6, PH12–13	3–4
Mod 6 – 9*	1	Mod 6 Applications of the Motor Effect	PH12–5, PH12–13	4–5
Mod 6 – 10*	1	Mod 6 Applications of the Motor Effect	PH12–4, PH12–13	5–6
Mod 6 – 11	5	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–5, PH12–13	2–6
Mod 6 – 12 (a)	2	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–6, PH12–13	3–5
Mod 6 – 12 (b)	2	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–6, PH12–13	3–4
Mod 6 – 13 (a)	3	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–13	2–4
Mod 6 – 13 (b)	3	Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–5, PH12–6, PH12–13	4–6
Mod 6 – 14	2	Mod 6 The Motor Effect	PH12–4, PH12–13	2–4
Mod 6 – 15	4	Mod 6 The Motor Effect Mod 6 Applications of the Motor Effect	PH12–7, PH12–13	2–5
Mod 6 – 16	3	Mod 6 Electromagnetic Induction	PH12–4, PH12–6, PH12–13	3–6
Mod 6 – 17	5	Mod 6 Applications of the Motor Effect	PH12–6, PH12–13	2–6

Module 7 The Nature of Light

Question	Marks	Content	Syllabus Outcomes	Bands
Mod 7 – 1*	1	Mod 7 Electromagnetic Spectrum	PH12–14	2–3
Mod 7 – 2*	1	Mod 7 Electromagnetic Spectrum	PH12–5, PH12–14	3–4
Mod 7 – 3*	1	Mod 7 Electromagnetic Spectrum	PH12–14	3–4
Mod 7 – 4*	1	Mod 7 Light: Wave Model	PH12–2, PH12–14	3–4
Mod 7 – 5*	1	Mod 7 Light: Wave Model	PH12–5, PH12–14	4–5
Mod 7 – 6*	1	Mod 7 Light: Quantum Model	PH12–5, PH12–6, PH12–14	4–5
Mod 7 – 7*	1	Mod 7 Light: Quantum Model	PH12–5, PH12–6, PH12–14	5–6
Mod 7 – 8*	1	Mod 7 Light and Special Relativity	PH12–6, PH12–14	2–3
Mod 7 – 9*	1	Mod 7 Light and Special Relativity	PH12–6, PH12–14	3–4
Mod 7 – 10*	1	Mod 7 Light and Special Relativity	PH12–5, PH12–14	5–6

Mod 7 – 11	3	Mod 7 Electromagnetic Spectrum	PH12–4, PH12–5, PH 12–14	3–5
Mod 7 – 12 (a)	3	Mod 7 Light: Wave Model	PH12–2, PH12–14	2–4
Mod 7 – 12 (b)	3	Mod 7 Light: Wave Model	PH12–2, PH12–14	2–4
Mod 7 – 13 (a)	2	Mod 7 Light: Wave Model	PH12–5, PH12–14	2–4
Mod 7 – 13 (b)	3	Mod 7 Light: Wave Model	PH12–4, PH12–6, PH12–14	3–5
Mod 7 – 14 (a)	3	Mod 7 Light: Wave Model	PH12–6, PH12–14	3–5
Mod 7 – 14 (b)	3	Mod 7 Light: Wave Model	PH12–4, PH12–6, PH12–14	4–6
Mod 7 – 15	6	Mod 7 Light: Wave Model	PH12–4, PH12–14	2–6
Mod 7 – 16	3	Mod 7 Light: Quantum Model	PH12–7, PH12–14	3–5
Mod 7 – 17	7	Mod 7 Light: Quantum Model	PH12–2, PH12–4, PH12–6, PH12–7, PH12–14	2–6

Module 8 From the Universe to the Atom

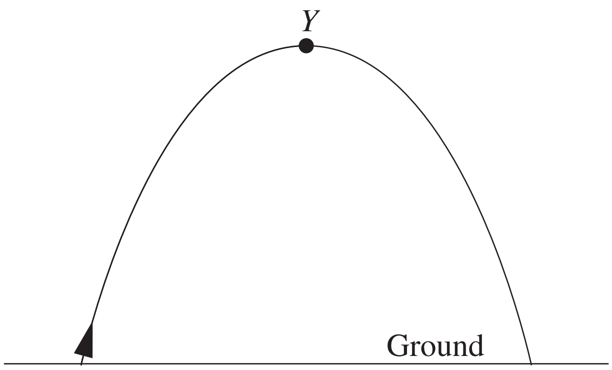
Question	Marks	Content	Syllabus Outcomes	Bands
Mod 8 – 1*	1	Mod 8 Origins of the Elements	PH12–5, PH12–15	2–3
Mod 8 – 2*	1	Mod 8 Origins of the Elements	PH12–6, PH12–15	4–5
Mod 8 – 3*	1	Mod 8 Structure of the Atom	PH12–15	2–3
Mod 8 – 4*	1	Mod 8 Structure of the Atom	PH12–1, PH12–2, PH12–15	2–3
Mod 8 – 5*	1	Mod 8 Structure of the Atom	PH12–5, PH12–15	3–4
Mod 8 – 6*	1	Mod 8 Quantum Mechanical Nature of the Atom	PH12–4, PH12–6, PH12–15	5–6
Mod 8 – 7*	1	Mod 8 Properties of the Nucleus	PH12–6, PH12–15	2–3
Mod 8 – 8*	1	Mod 8 Properties of the Nucleus	PH12–6, PH12–15	4–5
Mod 8 – 9*	1	Mod 8 Properties of the Nucleus	PH12–5, PH12–6, PH12–15	5–6
Mod 8 – 10*	1	Mod 8 Properties of the Nucleus	PH12–4, PH12–6, PH12–15	5–6
Mod 8 – 11*	1	Mod 8 Deep Inside the Atom	PH12–6, PH12–15	3–4
Mod 8 – 12	7	Mod 7 Light and Special Relativity Mod 8 Origins of the Elements Mod 8 Properties of the Nucleus	PH12–5, PH12–6, PH12–7, PH12–14, PH12–15	2–6
Mod 8 – 13	4	Mod 8 Origins of the Elements	PH12–7, PH12–15	2–5
Mod 8 – 14	4	Mod 8 Origins of the Elements	PH12–6, PH12–7, PH12–15	2–5
Mod 8 – 15	9	Mod 7 Light: Quantum Model Mod 8 Structure of the Atom	PH12–14, PH12–15	2–6
Mod 8 – 16	8	Mod 8 Structure of the Atom Mod 8 Quantum Mechanical Nature of the Atom	PH12–6, PH12–7, PH12–15	2–6

Mod 8 – 17	9	Mod 8 Deep Inside the Atom	PH12–5, PH12–6, PH12–7, PH12–15	2–6
Mod 8 – 18 (a)	4	Mod 8 Deep Inside the Atom	PH12–6, PH12–7, PH12–15	2–5
Mod 8 – 18 (b)	4	Mod 7 Light and Special Relativity	PH12–4, PH12–6, PH12–14	3–6

Module 5 Advanced Mechanics

Mod 5 – Question 1

An object is projected upwards from the ground, and follows a path as represented in the diagram.



Which of the following describes the projectile's horizontal and vertical acceleration at point *Y*?

A. Both the horizontal and vertical acceleration are zero.

B. Both the horizontal and vertical acceleration are 9.8 m s^{-2}.

C. The horizontal acceleration is 9.8 m s^{-2} and the vertical acceleration is zero.

D. The horizontal acceleration is zero and the vertical acceleration is 9.8 m s^{-2}.

Content	Syllabus outcomes	Bands	Key
Mod 5 Projectile Motion	PH12–4, PH12–12	2–3	D

Mod 5 – Question 2

Some students were testing the hypothesis that launching a projectile at an angle of 45° will give the maximum horizontal range.

Which experimental setup will best test the hypothesis?

A.

Launch speed (m s^{-1})	*Launch angle* (degrees)
1	45
2	45
3	45
4	45
5	45

B.

Launch speed (m s^{-1})	*Launch angle* (degrees)
5	43
5	44
5	45
5	46
5	47

C.

Launch speed (m s^{-1})	*Launch angle* (degrees)
3	25
3	35
3	45
3	55
3	65

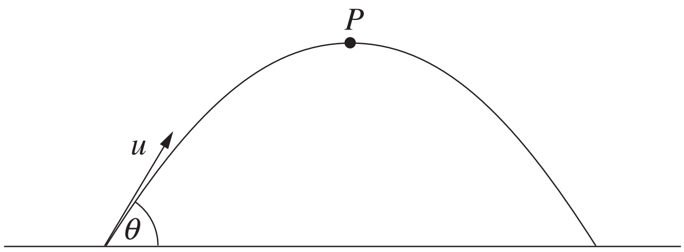
D.

Launch speed (m s^{-1})	*Launch angle* (degrees)
2	43
4	44
6	45
8	46
10	47

Content	**Syllabus outcomes**	**Bands**	**Key**
Mod 5 Projectile Motion	PH12–2, PH12–12	3–4	C

Mod 5 – Question 3

A ball is launched at speed u and angle θ from the horizontal as shown. P is the highest point reached by the ball.



Ignoring air resistance, what is the speed of the ball at point P?

A. Zero

B. u

C. $u \cos\theta$

D. $u \sin\theta$

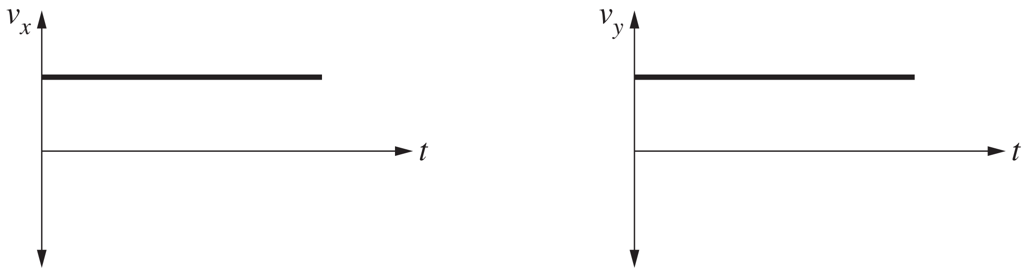
Content	Syllabus outcomes	Bands	Key
Mod 5 Projectile Motion	PH12–4, PH12–6, PH12–12	3–4	C

Mod 5 – Question 4

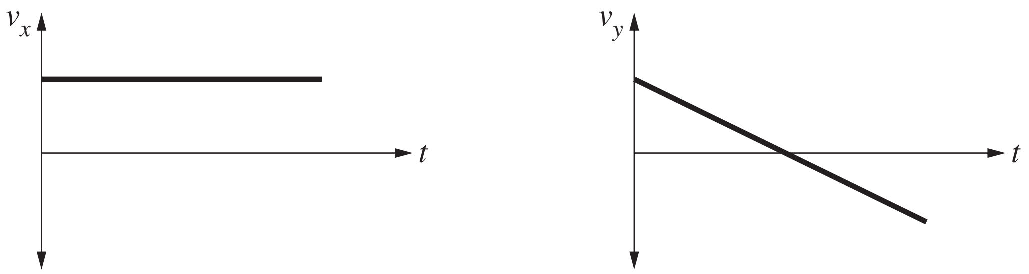
The horizontal and vertical components of the velocity of a projectile are respectively v_x and v_y.

Which pair of graphs best represents the velocity of the projectile?

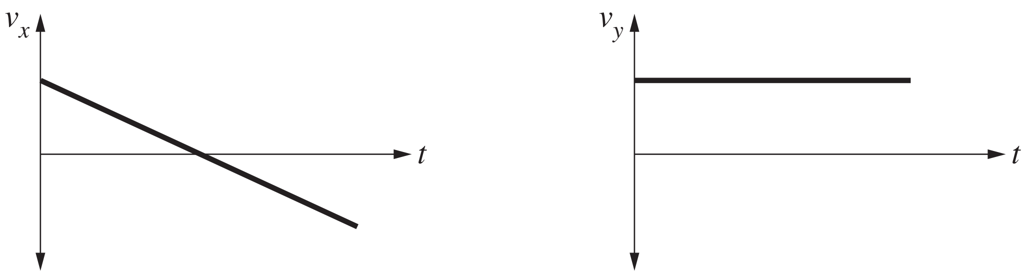
A.



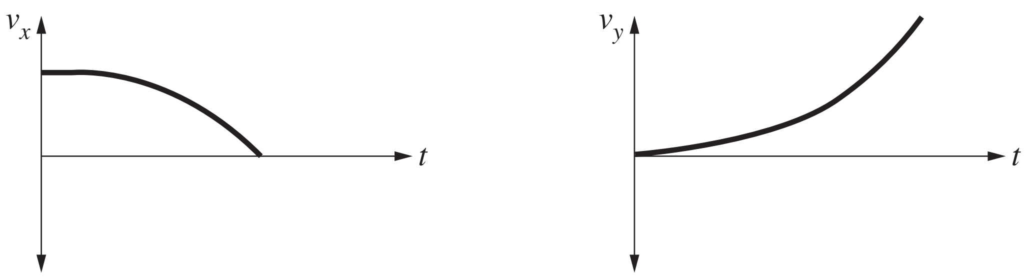
B.



C.



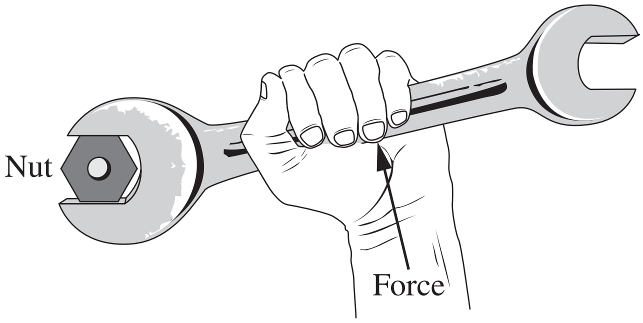
D.



Content	Syllabus outcomes	Bands	Key
Mod 5 Projectile Motion	PH12–5, PH12–6, PH12–12	3–4	B

Mod 5 – Question 5

A torque is applied to a nut, using a wrench.



Which change will increase the magnitude of applied torque?

A. Increasing the angle between the applied force and the wrench

B. Decreasing the angle between the applied force and the wrench

C. Increasing the distance between the nut and the point of application of the force

D. Decreasing the distance between the nut and the point of application of the force

Content	Syllabus outcomes	Bands	Key
Mod 5 Circular Motion	PH12–6, PH12–12	2–3	C

Mod 5 – Question 6

A student wants to evaluate the relationship between centripetal force and speed. The student connects a tennis ball to a rope, and swings it in a circle horizontally.

Which of the following needs to be kept constant to ensure a valid experiment?

A. The mass of the ball only

B. The length of the rope only

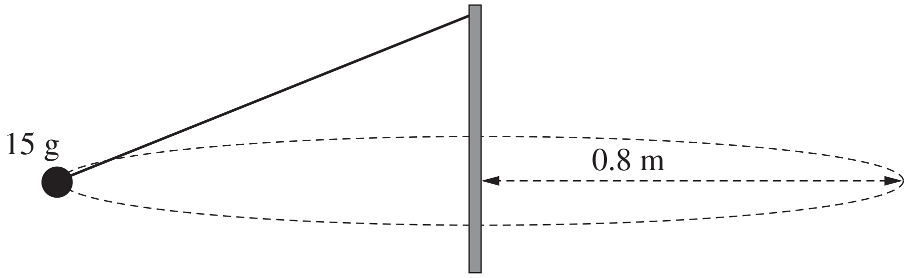
C. The angular velocity of the ball

D. The mass of the ball and the length of the rope

Content	Syllabus outcomes	Bands	Key
Mod 5 Circular Motion	PH12–2, PH12–12	3–4	D

Mod 5 – Question 7

A 15-gram metal ball bearing on a string is swung around a pole in a circle of radius 0.8 m. The plane of the circular path is horizontal. The angular velocity of the motion is 4π rad s^{-1}.



What is the magnitude of the centripetal force required to maintain the motion of the ball?

A. 0.7 N

B. 1.9 N

C. 2.4 N

D. 3.0 N

Content	Syllabus outcomes	Bands	Key
Mod 5 Circular Motion	PH12–6, PH12–12	3–4	B

Mod 5 – Question 8

A satellite is orbiting a planet at a fixed altitude.

Which row of the table correctly identifies the magnitude of the work done by the forces on the satellite and the reason for this being the case?

	Magnitude of work done	*Reason*
A.	Zero	The net force on the satellite is zero.
B.	Zero	Gravity acts at 90 degrees to the direction of motion of the satellite.
C.	Greater than zero	The work done equals the kinetic energy of the satellite.
D.	Greater than zero	The work done equals the gravitational force multiplied by the length of the orbital path of the satellite.

Content	Syllabus outcomes	Bands	Key
Mod 5 Circular Motion	PH12–6, PH12–12	4–5	B

Mod 5 – Question 9

Planet X has a mass twice that of Earth. The acceleration due to gravity on the surface of this planet is half that on the surface of Earth.

If Earth has a radius of 1, what is the radius of Planet X?

A. 1

B. 2

C. 4

D. 8

Content	Syllabus outcomes	Bands	Key
Mod 5 Motion in Gravitational Fields	PH12–6, PH12–12	4–5	B

Mod 5 – Question 10

The table shows data about the solar system.

Planet	*Average distance from the Sun* (AU)	*Period* (days)
Mercury	0.389	87.77
Earth	1	365

What would be the period of another planet if it orbited the Sun at an average distance of 3.5 AU?

A. 8.4×10^2 days

B. 2.4×10^3 days

C. 1.1×10^4 days

D. 4.0×10^6 days

Content	Syllabus outcomes	Bands	Key
Mod 5 Motion in Gravitational Fields	PH12–4, PH12–6, PH12–12	4–5	B

Mod 5 – Question 11

Two identical masses are placed at points P and Q. The escape velocity and circular orbital velocity of the mass at point P are $v_{P_{esc}}$ and $v_{P_{orb}}$. The escape velocity and circular orbital velocity of the mass at point Q are $v_{Q_{esc}}$ and $v_{Q_{orb}}$. The diagram is drawn to scale and X denotes the centre of Earth.

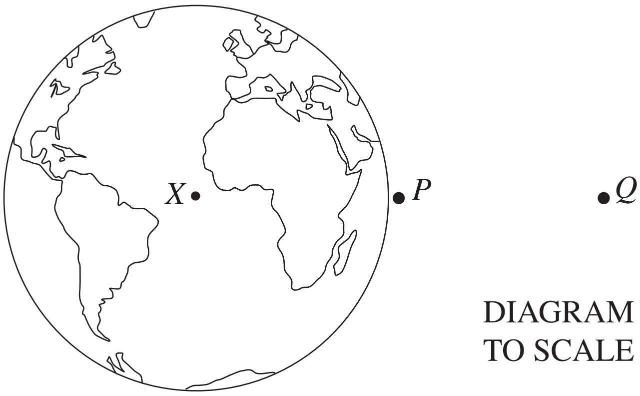


DIAGRAM TO SCALE

The velocity for a body in circular orbit is given by $v_{orb} = \sqrt{\frac{GM}{r}}$.

What is the value of $\frac{v_{Q_{esc}}}{v_{P_{orb}}}$?

A. 0.5

B. 1

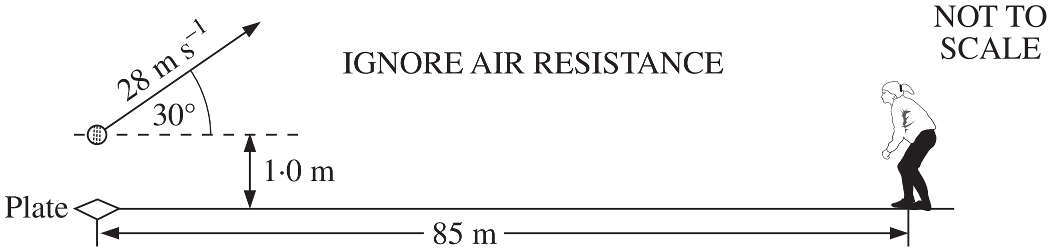
C. $\sqrt{2}$

D. 2

Content	Syllabus outcomes	Bands	Key
Mod 5 Motion in Gravitational Fields	PH12–4, PH12–6, PH12–12	5–6	B

Mod 5 – Question 12 (7 marks)

A baseball is hit with a velocity of 28 m s^{-1} at an angle of 30° to the horizontal at an initial height of 1.0 m above the plate. Ignore air resistance in your calculations.



(a) How long does it take the ball to return to the initial height above the ground? **3**

(b) The ball is hit directly towards a stationary outfielder who is 85 m from the plate. At the instant the ball is hit, the outfielder begins to run towards the plate with constant acceleration. **4**

What is the magnitude of her acceleration if she catches the ball when it is 0.50 m above the ground?

Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 5 Projectile Motion	PH12–4, PH12–6 PH12–12	3–6

Marking guidelines (a):

Criteria	Marks
• Correctly calculates the time of flight	3
• Shows some relevant calculation steps	2
• Provides some relevant information	1

Sample answer:

Initial vertical velocity (u) $= 28 \times \sin 30°$

$= 14$

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

$$0 = 14t + \frac{1}{2} \times (-9.8) \times t^2$$

$$0 = 14t - 4.9 \times t^2$$

$$0 = t(14 - 4.9t)$$

$$t = 0 \text{ or } 2.86$$

$$t = 2.9 \text{ s}$$

Question 12 continues on page 17

Question 12 (continued)

Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 5 Projectile Motion	PH12–4, PH12–6 PH12–12	3–6

Marking guidelines (b):

Criteria	Marks
• Correctly calculates the magnitude of the acceleration	4
• Provides the main steps of the calculation	3
• Shows some relevant calculations	2
• Provides some relevant information	1

Sample answer:

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

$v^2 = 14^2 + 2(-9.8)(-0.50)$

$v = 14.3457$

$v = u + at$

$t = \dfrac{-14.3457 - 14}{-9.8}$

$t = 2.8924$ s

Range $= u_x t$

Range $= 28 \cos 30° \times 2.8924$

Range $= 70.1370$ m

Distance fielder travels $= 85 - 70.1370$

$= 14.863$ m

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

$14.863 = 0 + \dfrac{1}{2} \times a \times 2.8924^2$

$a = 3.6 \text{ m s}^{-2}$

End of Question 12

Mod 5 – Question 13 (3 marks)

A horizontal disc is rotating clockwise on a table when viewed from above. Two small blocks are attached to the disc at different radii from the centre. **3**

Draw a diagram of this scenario, using vector arrows to show the relative linear velocities and centripetal forces for each block as the disc rotates.

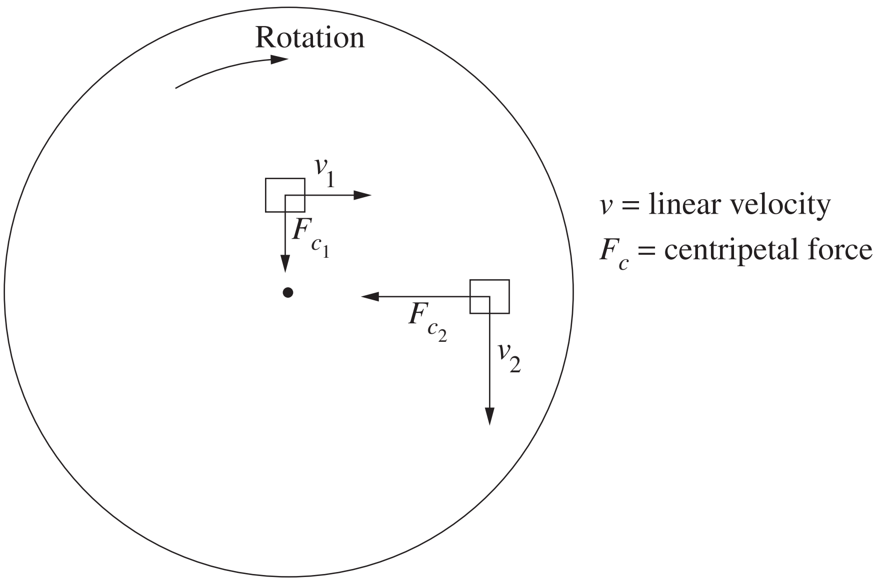
Mapping grid:

Content	Syllabus outcomes	Bands
Mod 5 Circular Motion	PH12–4, PH12–12	3–5

Marking guidelines:

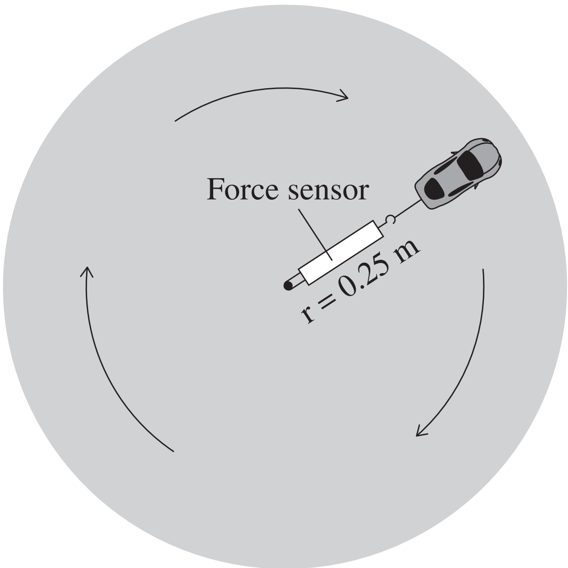
Criteria	Marks
• Correctly draws vector arrows to show the directions and relative magnitudes of the linear velocities and centripetal forces	3
• Correctly draws vector arrows to show the direction of the linear velocities and/or centripetal forces	2
• Provides some relevant information	1

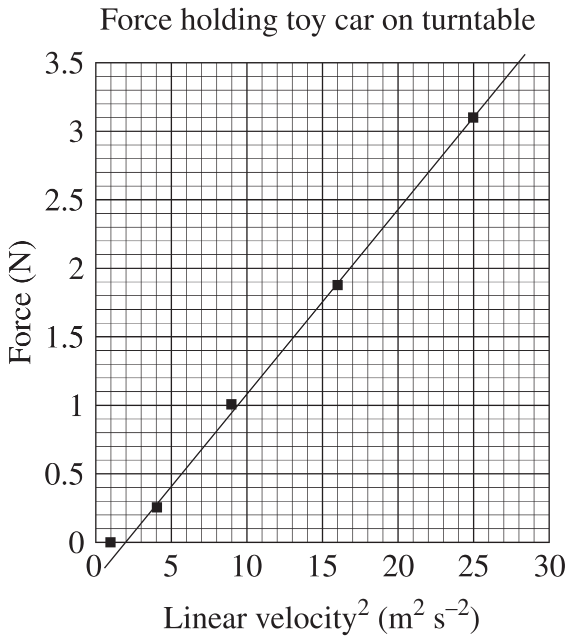
Sample answer:



Mod 5 – Question 14 (7 marks)

A toy car was placed facing outwards on a rotating turntable. The car was held in place by a force sensor connected to the centre of the turntable. The centre of mass of the car was 0.25 metres from the centre of the turntable. The reading from the force sensor was recorded at varying speeds of rotation. A stopwatch was used to time the rotation of the turntable. The linear velocity was calculated from the period of rotation. The graph shows the force on the car versus the square of the linear velocity of the car.





(a) Use the graph to determine the mass of the car. **3**

(b) Identify possible errors in the data and outline how to reduce their effects on the estimation of the mass of the car. **4**

Question 14 continues on page 20

Question 14 (continued)

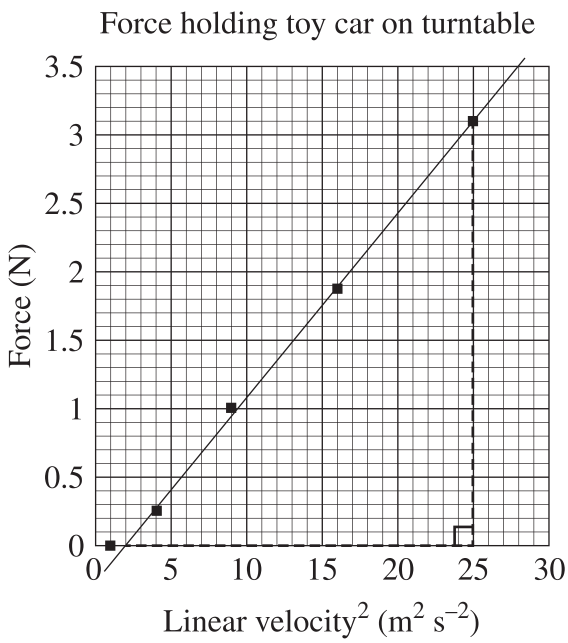
Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 5 Circular Motion	PH12–5, PH12–12	3–5

Marking guidelines (a):

Criteria	Marks
• Correctly uses the gradient of the graph to determine the mass of the car	3
• Provides some correct steps in calculating the mass of the car	2
• Provides a correct step in calculating the mass of the car	1

Sample answer (a):



From graph, gradient $= \dfrac{3.1 - 0}{25 - 2} = 0.135$

$F = \dfrac{mv^2}{r}$

gradient $= \dfrac{F}{v^2} = \dfrac{m}{r}$

$0.135 = \dfrac{m}{0.25}$

$m = 0.25 \times 0.135 = 0.034$ kg

Question 14 continues on page 21

Question 14 (continued)

Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 5 Circular Motion	PH12–5, PH12–12	3–6

Marking guidelines (b):

Criteria	Marks
• Identifies possible errors in the data • Outlines how to reduce their effects	4
• Identifies possible errors in the data • Outlines how to reduce the effect of one source of error in the data	3
• Identifies possible errors in the data OR • Outlines how to reduce the effect of one source of error in the data	2
• Provides some relevant information	1

Sample answer:

The sensor will produce a systematic error if it has not been zeroed or calibrated correctly. The sensor error can be minimised by zeroing it and checking it against a known force such as the force of gravity on a 1-kg mass.

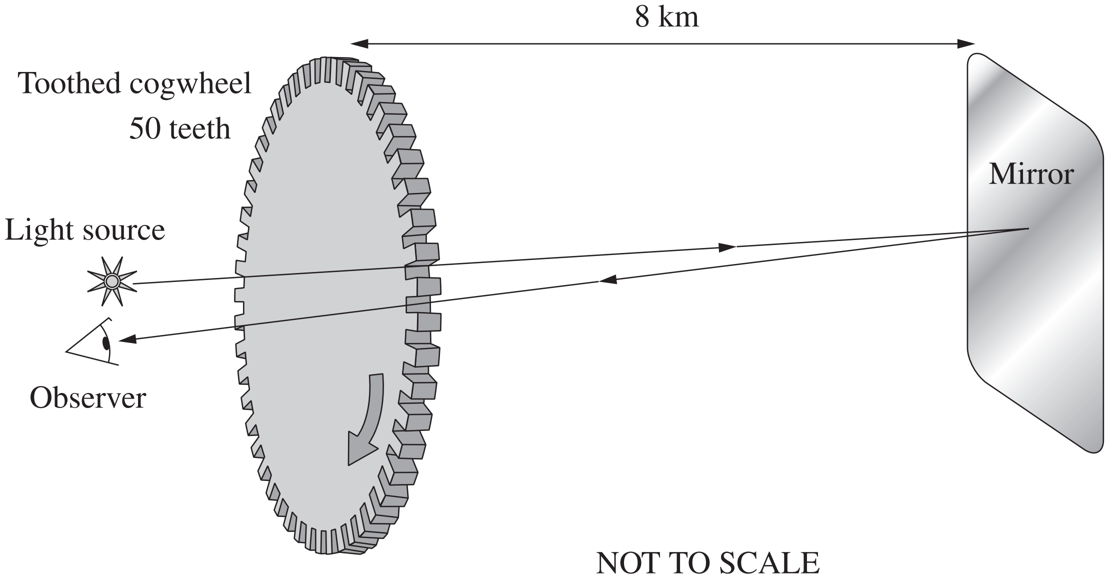
If a manual stopwatch were used to time the rotations, allowing the linear velocity to be calculated using $v = r\omega$, then random errors would arise due to judgement or reaction times. The timing/random error can be minimised by measuring the time for several rotations at a constant ω and then dividing the time by the number of rotations.

End of Question 14

Mod 5 – Question 15 (5 marks)

In the 1840s, French physicist, Hippolyte Fizeau performed an experiment to measure the speed of light. He shone an intense light source at a mirror 8 km away and broke up the light beam with a rotating cogwheel. He adjusted the speed of rotation of the wheel until the reflected light beam could no longer be seen returning through the gaps in the cogwheel. **5**

The diagram shows a similar experiment. The cogwheel has 50 teeth and 50 gaps of the same width.



Explain why specific speeds of rotation of the cogwheel will completely block the returning light. Support your answer with calculations.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 5 Circular Motion Mod 7 Electromagnetic Spectrum	PH12–4, PH12–6, PH12–7, PH12–12, PH12–14	2–6

Question 15 continues on page 23

Question 15 (continued)

Marking guidelines:

Criteria	Marks
• Explains why specific speeds will completely block the light • Supports answer with calculations	5
• Explains why a specific speed will block the light with relevant calculations	4
• Provides some relevant calculations AND/OR • Outlines how movements of the wheel can cause a tooth to completely block the light	2–3
• Provides some relevant information	1

Sample answer:

Light travels at 3.00×10^8 m s^{-1}, so for an 8 km journey to the mirror and 8 km back, the time taken will be:

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

$$\frac{2 \times 8000}{3.00 \times 10^8} = 5.33 \times 10^{-5} \text{ seconds.}$$

If the wheel is stationary, the light travelling through a gap will return completely through the gap, but if the wheel is rotating, a cog (tooth) will begin to block the returning light. If a tooth moves exactly the width of a gap in the time it takes the light to return, it will completely block the light.

It takes 5.33×10^{-5} seconds for the light to travel to the mirror and back. To completely block the light, the tooth will have moved into the path of a gap in this time. Since there are 50 teeth and 50 gaps, the wheel will have rotated 1/100th of a rotation in this time. This is equal to $2\pi/100$ radians.

The rotational speed of the wheel is given by $\omega = \triangle\theta / t$.

$$\omega = \frac{\frac{2\pi}{100}}{5.33 \times 10^{-5}} = 1180 \text{ rad s}^{-1}$$

Spinning the cogwheel at 3, 5 and 7 times this rate (or any odd multiple) would also completely block the returning light, as the light will be blocked by subsequent teeth.

End of Question 15

Mod 5 – Question 16 (3 marks)

Long-period comets, such as Comet Kohoutek, are believed to come from the Oort cloud that lies far beyond the outermost planets. In our solar system, Kohoutek travels in an elliptical orbit around the Sun and spends most of its time beyond the outermost planets. **3**

Explain how the motion of Comet Kohoutek in its orbit supports Kepler's second law. Include a diagram in your answer.

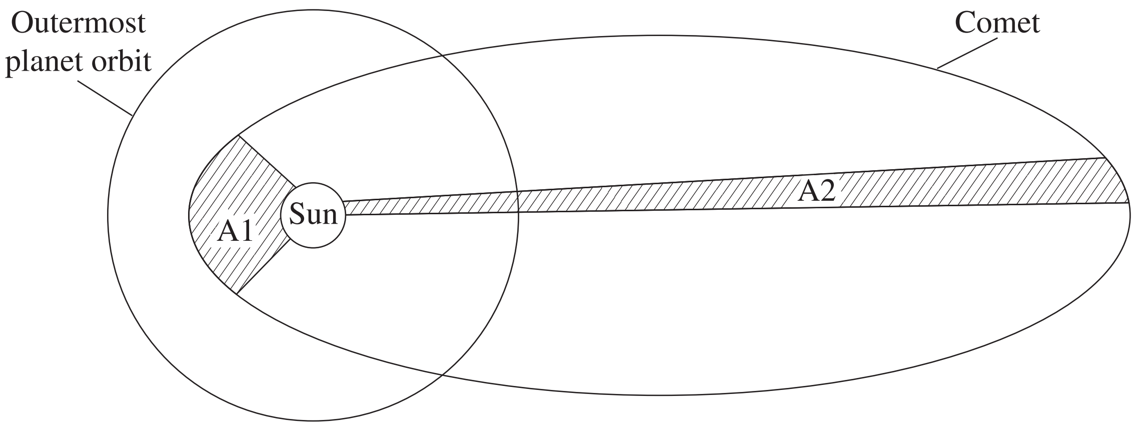
Mapping grid:

Content	Syllabus outcomes	Bands
Mod 5 Motion in Gravitational Fields	PH12–7, PH12–12	2–4

Marking guidelines:

Criteria	Marks
• Explains how the comet's motion supports Kepler's second law • Includes a relevant diagram	3
• Explains Kepler's second law and/or the comet's motion	2
• Provides some relevant information	1

Sample answer:



Kepler's second law states that a line between the Sun and the comet sweeps an equal area in equal time, therefore its orbit travels a greater distance when it is closer to the Sun. As seen in the diagram, if A1 and A2 are equal areas, when the comet is closer to the Sun it needs to travel a greater distance in its orbit compared to when it's further away to sweep the same area in the same time. Kepler's second law is supported by Kohoutek's orbit.
It obeys the law and that is why most of its time is spent beyond the outermost planets, because it does not need to travel as fast to sweep the same amount of area compared to when it is closer to the Sun.

Mod 5 – Question 17 (3 marks)

A rocket carrying a satellite is launched from Earth. Once the rocket engine is switched off the satellite continues in an elliptical orbit.

Explain the satellite's changes in energy during this journey.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 5 Motion in Gravitational Fields	PH12–7, PH12–12	2–5

Marking guidelines:

Criteria	Marks
• Explains energy changes in terms of kinetic, potential and total energy for the launch and the elliptical orbit	3
• Outlines some energy changes OR • Explains an energy change	2
• Provides some relevant information	1

Sample answer:

During launch, both the potential and kinetic energy of the satellite are increasing, thereby increasing the total energy. This energy comes from the fuel of the rocket. Once the rocket engine is switched off, the total energy is fixed. As it is in an elliptical orbit, the satellite will convert kinetic energy into potential energy as it gains altitude. After the satellite has reached its maximum distance from Earth, its potential energy will begin to convert back into kinetic energy, with the total energy being constant.

Mod 5 – Question 18 (5 marks)

A bullet is fired vertically from the surface of Mars, at the escape velocity of Mars. Another bullet is fired vertically from the surface of Earth, at the escape velocity of Earth. **5**

Neglecting air resistance, compare the energy transformations of the two bullets.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 5 Motion in Gravitational Fields	PH12–6, PH12–7, PH12–12	2–6

Marking guidelines:

Criteria	Marks
• Demonstrates a comprehensive understanding of the energy transformations of both bullets • Shows the similarities and/or differences in the energy transformations of the bullets	5
• Outlines the energy transformations of both bullets • Indicates a similarity/difference in the energy transformations	4
• Outlines the energy transformations of both bullets	3
• Outlines an energy transformation as a bullet travels OR • Outlines a difference between the energy transformations of the bullets	2
• Provides some relevant information	1

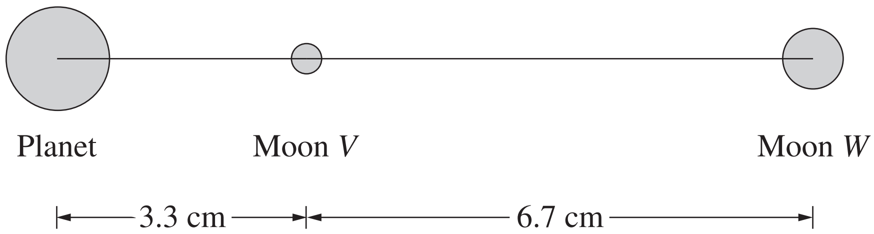
Sample answer:

The Martian bullet's total energy (due to conservation of energy) will remain unchanged, but as it travels away from the surface, its kinetic energy (K) will transform into gravitational potential energy (U) ie $K + U =$ bullet's energy. When it escapes, at 'infinity', the K will be zero since the object will have expended all of its initial kinetic energy escaping from Mars's gravitational force. The U of the bullet will be described by the equation $U = -\frac{GMm}{r}$, $U = 0$.

The process will be similar for a bullet fired from the surface of Earth at the escape velocity. A key difference is that the actual velocity will be different in accordance with $v_{esc} = \sqrt{\frac{2GM}{r}}$ so the actual values of kinetic energy and $U = -\frac{GMm}{r}$ (gravitational potential energy) will be different.

Mod 5 – Question 19 (4 marks)

A student used the following scale diagram to investigate orbital properties. The diagram shows a planet and two of its moons, *V* and *W*. The distances between each of the moons and the planet are to scale while the sizes of the objects are not. **4**



Complete the table to compare the orbital properties of Moon *V* and Moon *W*. Show relevant calculations in the space below the table.

	Orbital radius (*W* relative to *V*)	*Orbital period* (*W* relative to *V*)	*Orbital velocity* (*W* relative to *V*)
Quantitative comparison			
Qualitative comparison			

Mapping grid:

Content	**Syllabus outcomes**	**Bands**
Mod 5 Motion in Gravitational Fields	PH12–12	2–6

Question 19 continues on page 28

Question 19 (continued)

Marking guidelines:

Criteria	Marks
• Correctly completes the table • Provides relevant and correct working	4
• Correctly completes most of the table • Applies correct approach to calculate at least two of the ratios	3
• Provides some details of the table • Applies correct approach to calculate at least one of the ratios	2
• Provides some relevant information	1

Sample answer:

	Orbital radius (W relative to V)	*Orbital period (W relative to V)*	*Orbital velocity (W relative to V)*
Quantitative comparison	3.0	5.2	0.58
Qualitative comparison	Larger	Larger	Slower

Radius

$$\frac{r_W}{r_V} = \frac{10.0}{3.3} = 3.0$$

Period

$$\frac{r_W{}^3}{T_W{}^2} = \frac{GM}{4\pi^2} = \frac{r_V{}^3}{T_V{}^2}$$

$$\left(\frac{r_W}{r_V}\right)^3 = \left(\frac{T_W}{T_V}\right)^2$$

$$3.0^3 = \left(\frac{T_W}{T_V}\right)^2$$

$$\frac{T_W}{T_V} = \sqrt{3.0^3} = 5.2$$

Orbital velocity

$$v_W = \frac{2\pi r_W}{T_W}$$

$$= \frac{2\pi(3.0 r_V)}{5.2 T_V}$$ ... see radius calculation ... see period calculation

$$= \frac{2\pi \times 3.0}{5.2} \frac{r_V}{T_V}$$

$$= \frac{3.0}{5.2} \times \frac{2\pi r_V}{T_V}$$

$$= \frac{3.0}{5.2} \times v_V$$

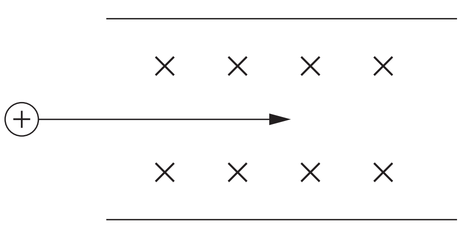
$$v_W = 0.58\ v_V$$

End of Question 19

Module 6 Electromagnetism

Mod 6 – Question 1

A positively-charged ion travelling at 250 m s^{-1} is fired between two parallel charged plates, *M* and *N*. There is also a magnetic field present in the region between the two plates. The direction of the magnetic field is into the page as shown. The ion is travelling perpendicular to both the electric and the magnetic fields.



The electric field between the plates has a magnitude of 200 V m^{-1}. The magnetic field is adjusted so that the ion passes through undeflected.

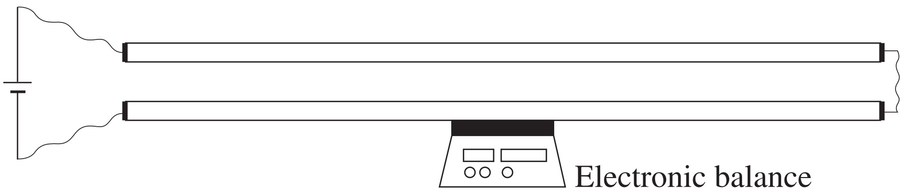
What is the magnitude of the adjusted magnetic field, and the polarity of the *M* terminal relative to the *N* terminal?

	Magnitude of magnetic field (teslas)	*Polarity of M relative to N*
A.	0.8	positive
B.	0.8	negative
C.	1.25	positive
D.	1.25	negative

Content	**Syllabus outcomes**	**Bands**	**Key**
Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–6, PH12–13	5–6	A

Mod 6 – Question 2

A student performed an experiment using two identical, current-carrying metal rods connected to a power supply. Rod *A* was placed at different distances from Rod *B*, and the measurements on the electronic balance were recorded.



What is the dependent variable in this experiment?

A. The current in Rod *A*

B. The length of the rods

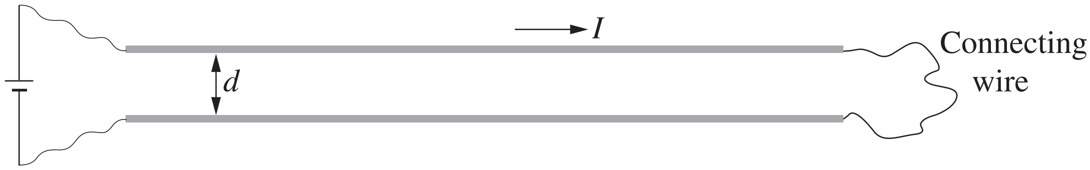
C. The mass recorded on the balance

D. The distance between the two rods

Content	Syllabus outcomes	Bands	Key
Mod 6 The Motor Effect	PH12–2, PH12–13	2–3	C

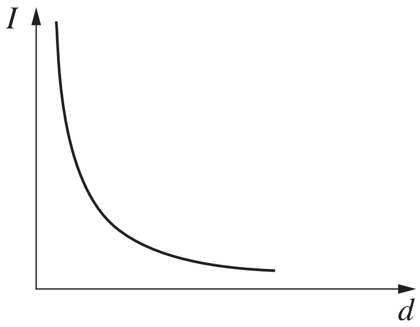
Mod 6 – Question 3

Two parallel conducting rods are connected by a wire as shown and carry current I. They are separated by distance d and repel each other with a force F.

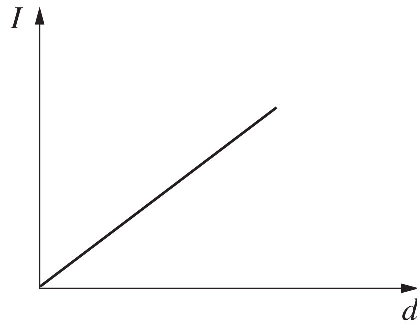


Which graph best shows how the current I would need to be varied with distance d to keep the force F constant?

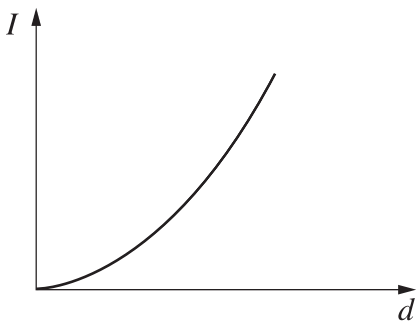
A.



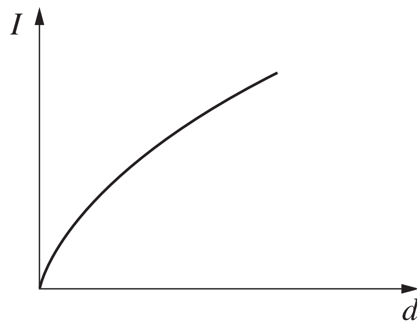
B.



C.



D.



Content	Syllabus outcomes	Bands	Key
Mod 6 The Motor Effect	PH12–5, PH12–6, PH12–13	5–6	D

Mod 6 – Question 4

What is the role of a transformer at a power station?

A. To reduce heating in the transmission lines by stepping up the current

B. To reduce heating in the transmission lines by stepping up the voltage

C. To increase heating in the transmission lines by stepping up the current

D. To increase heating in the transmission lines by stepping up the voltage

Content	Syllabus outcomes	Bands	Key
Mod 6 Electromagnetic Induction	PH12–13	2–3	B

Mod 6 – Question 5

The total flux in the core of an electrical machine is 40 mWb and its flux density is 0.5 T.

What is the cross-sectional area of the core?

A. 0.01 m^2

B. 0.08 m^2

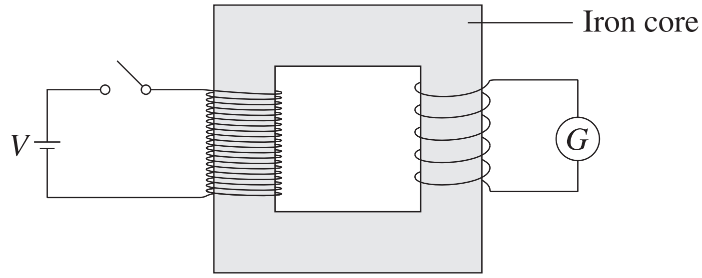
C. 12.5 m^2

D. 80 m^2

Content	Syllabus outcomes	Bands	Key
Mod 6 Electromagnetic Induction	PH12–6, PH12–13	3–4	B

Mod 6 – Question 6

The diagram shows an ideal transformer.



When the switch is closed, the pointer on the galvanometer deflects.

How could the size of this deflection be increased?

A. Decrease the number of primary coils.

B. Decrease the number of secondary coils.

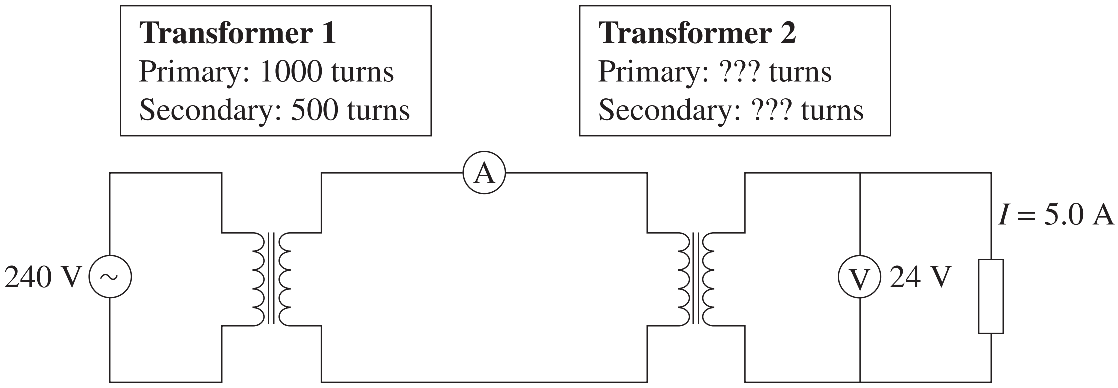
C. Replace the iron core with a copper core.

D. Place a resistor in series with the galvanometer.

Content	Syllabus outcomes	Bands	Key
Mod 6 Electromagnetic Induction	PH12–5, PH12–6, PH12–13	4–5	B

Mod 6 – Question 7

The diagram shows a circuit containing two ideal transformers connected with an ammeter. The current through the load is 5.0 A.



What is the reading on the ammeter?

A. 0.25 A

B. 0.50 A

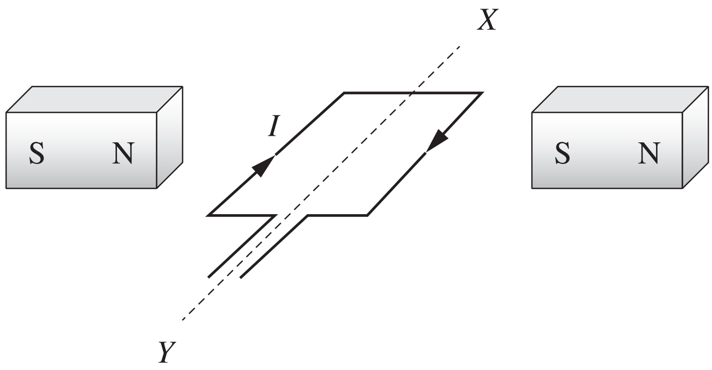
C. 1.0 A

D. 2.5 A

Content	Syllabus outcomes	Bands	Key
Mod 6 Electromagnetic Induction	PH12–4, PH12–6, PH12–13	5–6	C

Mod 6 – Question 8

A rectangular loop of wire passes between two magnets as shown and is free to rotate about *XY*. The loop has a current flowing through it.



Without changing the current, which of the following would result in the greatest increase in torque?

A. Increase the thickness of the wire in the loop.

B. Decrease the thickness of the wire in the loop.

C. Extend the length of the loop in the *XY* direction.

D. Extend the width of the loop towards the magnets.

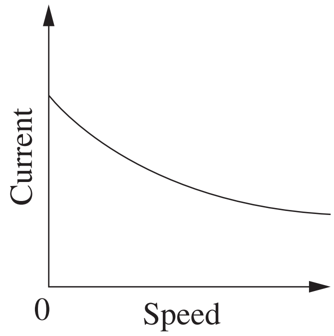
Content	Syllabus outcomes	Bands	Key
Mod 6 Applications of the Motor Effect	PH12–6, PH12–13	3–4	D

Mod 6 – Question 9

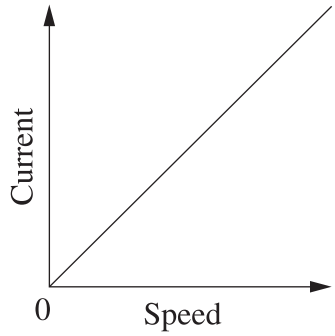
An electric motor is connected to a power supply of constant voltage. The motor runs at different speeds by adjusting a brake.

Which graph best shows the relationship between the current through the motor and its speed?

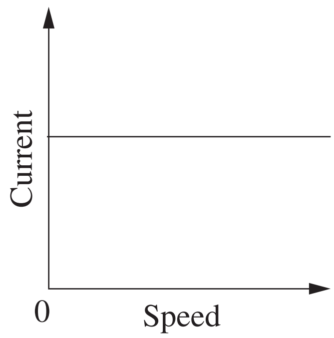
A.



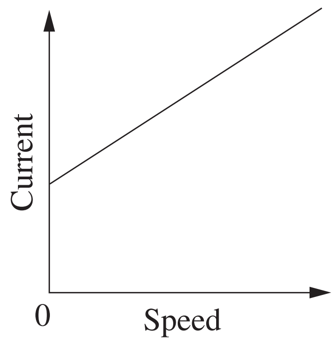
B.



C.



D.



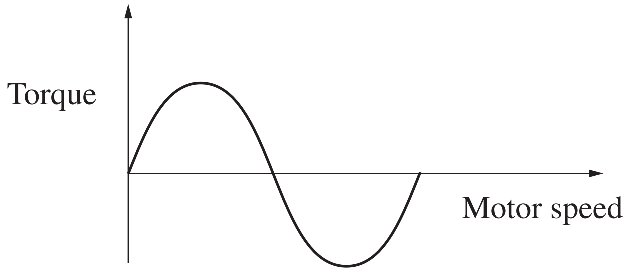
Content	Syllabus outcomes	Bands	Key
Mod 6 Applications of the Motor Effect	PH12–5, PH12–13	4–5	A

Mod 6 – Question 10

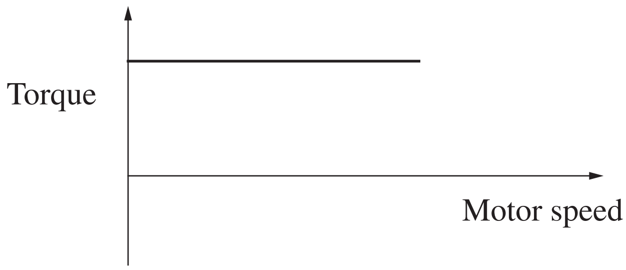
An experiment was carried out to investigate the change in torque for a DC motor with a radial magnetic field. The data from start up to operating speed were graphed.

Which graph is most likely to represent this set of data?

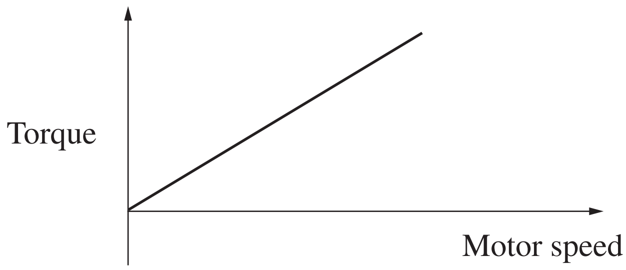
A.



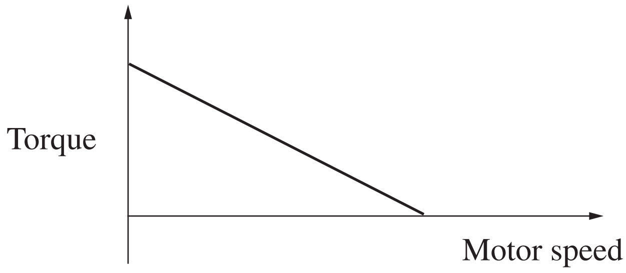
B.



C.



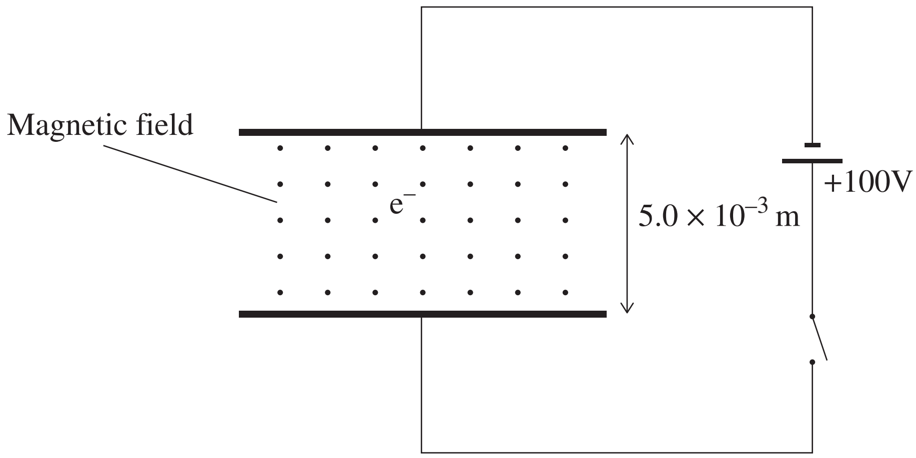
D.



Content	Syllabus outcomes	Bands	Key
Mod 6 Applications of the Motor Effect	PH12–4, PH12–13	5–6	D

Mod 6 – Question 11 (5 marks)

The diagram shows a stationary electron in a magnetic field. The magnetic field is surrounded by two parallel plates separated by a distance of 5.0×10^{-3} m and connected to a power supply and a switch. **5**



The switch is initially open. At a later time the switch is closed.

Analyse the effects of the magnetic and electric fields on the acceleration of the electron both before and immediately after the switch is closed. In your answer, include calculation of the acceleration of the electron immediately after the switch is closed.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–5, PH12–13	2–6

Question 11 continues on page 39

Question 11 (continued)

Marking guidelines:

Criteria	Marks
• Analyses the effects of both the magnetic and electric fields on the electron before and after closing the switch • Correctly calculates the acceleration of the electron	5
• Describes some effects of both the magnetic and electric fields on the electron before and after closing the switch • Applies a correct process to calculate the acceleration of the electron	4
• Describes the effects of both the magnetic and electric fields on the electron OR • Applies a correct process to calculate the acceleration of the electron and describes some effects of the magnetic/electric field OR • Provides some correct steps in calculating the acceleration of the electron and describes some effects of both the magnetic and electric fields on the electron	3
• Provides correct steps in calculating the acceleration of the electron OR • Outlines some effects of the magnetic and/or electric fields on the electron	2
• Provides some relevant information	1

Sample answer:

Before the switch is closed, there is no electric field and the magnetic field has no effect on the electron due to it being stationary. After the switch is closed the electric field will accelerate the electron downwards (towards the positive plate).

The acceleration of the electron immediately after the switch is closed is given by a = F/m where F = Eq and E = V/d.

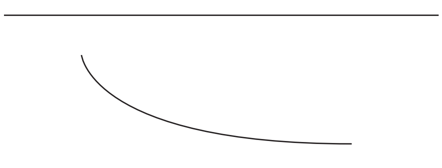
$E = 100 / 0.005 = 20\ 000\ \text{Vm}^{-1}$

$F = \text{Eq} = 20\ 000 \times 1.602 \times 10^{-19} = 3.2 \times 10^{-15}$ N

$a = \text{F/m} = 3.2 \times 10^{-19} / 9.109 \times 10^{-31}$

$= 3.5 \times 10^{15}\ \text{ms}^{-2}$ downwards (towards the positive plate)

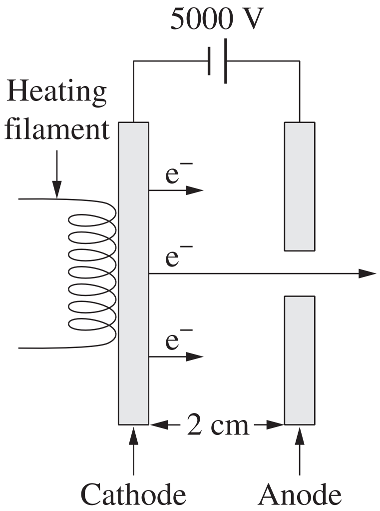
Now that the electron is moving, the magnetic field will force the electron towards the right. The exact direction and path it follows will depend on the strength of the magnetic field. However, the force due to the magnetic field will be increasing due to the increasing velocity of the electron. It will therefore travel in a curved path.



End of Question 11

Mod 6 – Question 12 (4 marks)

An ‘electron gun’ like that used by JJ Thomson is shown.



Electrons leave the cathode and are accelerated towards the anode.

(a) Show that the acceleration of the electrons as they just leave the cathode is $4 \times 10^{16}\ \text{m s}^{-2}$. **2**

(b) Calculate the velocity of an electron as it reaches the anode. **2**

Question 12 continues on page 41

Question 12 (continued)

Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–6 PH12–13	3–5

Marking guidelines (a):

Criteria	Marks
• Applies a correct process to calculate acceleration • Includes correct units	2
• Shows some relevant calculations	1

Sample answer:

$$E = \frac{V}{d}, \quad \vec{F} = q\vec{E}, \quad \therefore F = \frac{Vq}{d}$$

$$\vec{F}_{\text{net}} = m\vec{a}, \quad \therefore a = \frac{Vq}{dm}$$

$$a = \frac{5000 \times 1.602 \times 10^{-19}}{0.02 \times 9.109 \times 10^{-31}}, \quad \therefore a = 4 \times 10^{16} \text{ m s}^{-2}$$

Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–6 PH12–13	3–4

Marking guidelines (b):

Criteria	Marks
• Correctly calculates the velocity with correct units	2
• Provides some relevant information	1

Sample answer:

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

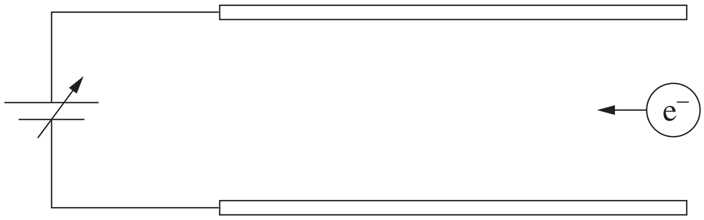
$$v = \sqrt{0 + 2 \times 4 \times 10^{16} \times 0.02}$$

$$= 4 \times 10^7 \text{ m s}^{-1}$$

End of Question 12

Mod 6 – Question 13 (6 marks)

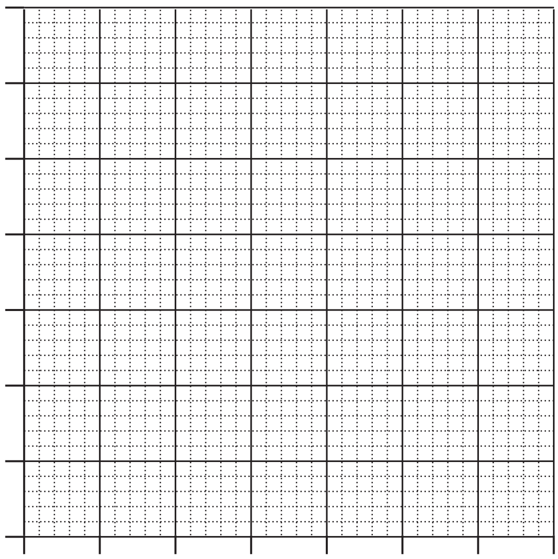
Negatively charged particles were accelerated from rest between a pair of parallel metal plates. The potential difference between the plates was varied, and the final velocity of the particles was measured for each variation.



The data in the table show the potential difference between the plates and the square of the corresponding final velocity of the particles.

Potential difference (V)	v^2 ($\times 10^9$ m^2 s^{-2})
100	0.8
200	2.1
300	3.1
400	4.1
500	5.2

(a) Plot the data on the grid provided and draw a line of best fit. **3**



Question 13 continues on page 43

Question 13 (continued)

(b) A student hypothesised that the charged particles are electrons. Justify whether the student's hypothesis is correct or not. Support your answer using the data provided and relevant calculations. **3**

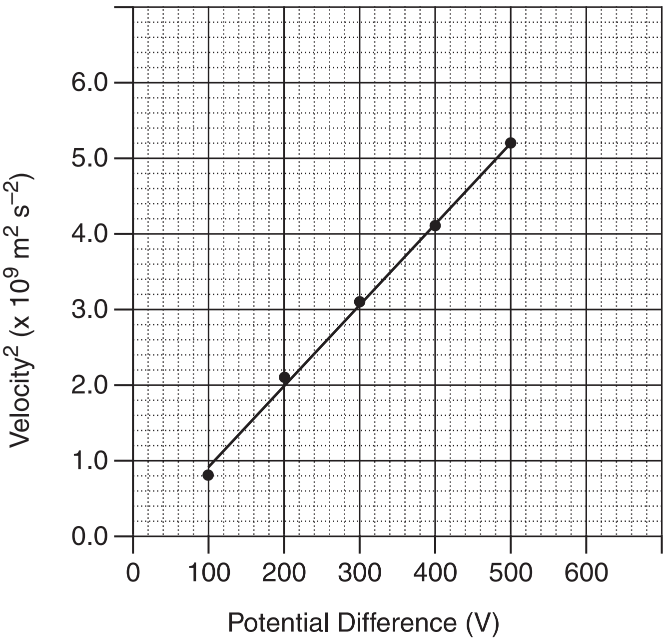
Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–4, PH12–13	2–4

Marking guidelines (a):

Criteria	Marks
• Uses appropriate scale • Labels axes correctly with units • Plots points accurately • Draws a line of best fit	3
• Provides a substantially correct graph	2
• Provides some basic features of the graph	1

Sample answer:



Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 6 Charged Particles, Conductors and Electric and Magnetic Fields	PH12–5, PH12–6, PH12–13	4–6

Question 13 continues on page 44

Marking guidelines (b):

Criteria	Marks
• Applies an appropriate method to determine if the charged particles could be electrons • Provides relevant data and calculations • Justifies their argument logically	3
• Applies an appropriate method to determine if the charged particles could be electrons • Provides some relevant data and/or calculations	2
• Provides some relevant information	1

Sample answer:

The change in kinetic energy is equal to the work done by the electric field:

$$W = \Delta K$$

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

As $qV = \frac{1}{2}mv^2$, $\frac{v^2}{V} = \frac{2q}{m}$.

The gradient of the line of best fit is equal to the rise divided by the run:

gradient $\frac{v^2}{V} = \frac{2q}{m}$.

The gradient of the line of best fit $= \frac{(5.2 - 0.9)\times 10^9}{500 - 100}$

$= 1.1\times 10^7\,\text{m}^2\,\text{s}^{-2}\,\text{V}^{-1}$.

So, $\frac{q}{m} = \frac{\text{gradient}}{2}$

$= 5.4 \times 10^6$ C kg^{-1}.

But, for an electron:

$$\frac{q}{m} = \frac{1.602\times 10^{-19}}{9.11\times 10^{-31}}$$

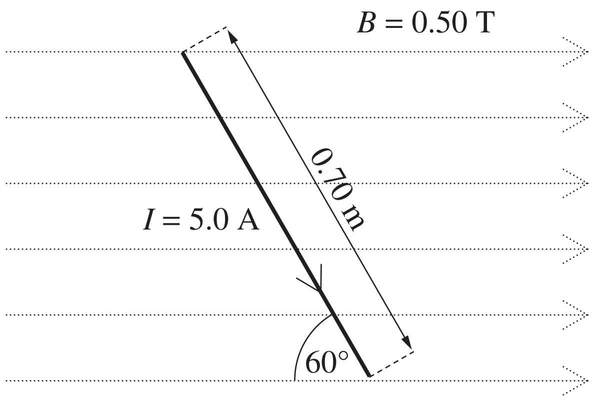
$$= 1.8\times 10^{11}\,\text{C kg}^{-1}$$

Therefore, the particles in this experiment cannot be electrons.

End of Question 13

Mod 6 – Question 14 (2 marks)

A current of 5.0 A flows in a wire that is placed in a magnetic field of 0.50 T. The wire is 0.70 m long and is at an angle of 60° to the field. **2**



Calculate the force on the wire.

Mapping grid:

Content	**Syllabus outcomes**	**Bands**
Mod 6 The Motor Effect	PH12–4, PH12–13	2–4

Marking guidelines:

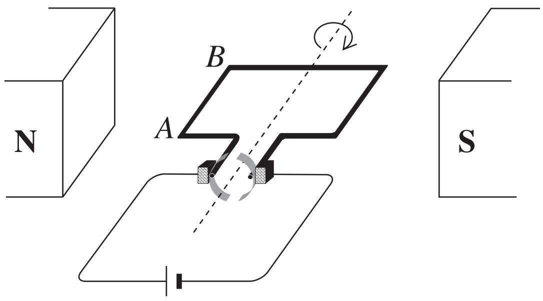
Criteria	**Marks**
• Correctly calculates the magnitude of the force and provides the direction	2
• Substitutes into a relevant formula OR • Provides the correct direction	1

Sample answer:

$$F = lIB\sin\theta$$
$$= 0.7 \times 5.0 \times 0.5 \times \sin 60°$$
$$= 1.5 \text{ N out of the page}$$

Mod 6 – Question 15 (4 marks)

The diagram shows a DC motor with a constant current flowing to the rotor. **4**



Sketch graphs to compare the behaviour of the force F on wire AB and the torque τ on the rotor, as functions of time t.

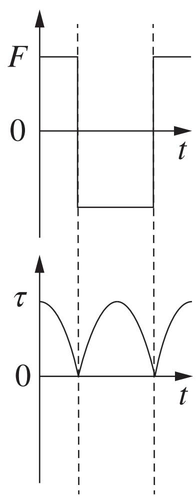
Mapping grid:

Content	Syllabus outcomes	Bands
Mod 6 The Motor Effect Mod 6 Applications of the Motor Effect	PH12–7, PH12–13	2–5

Marking guidelines:

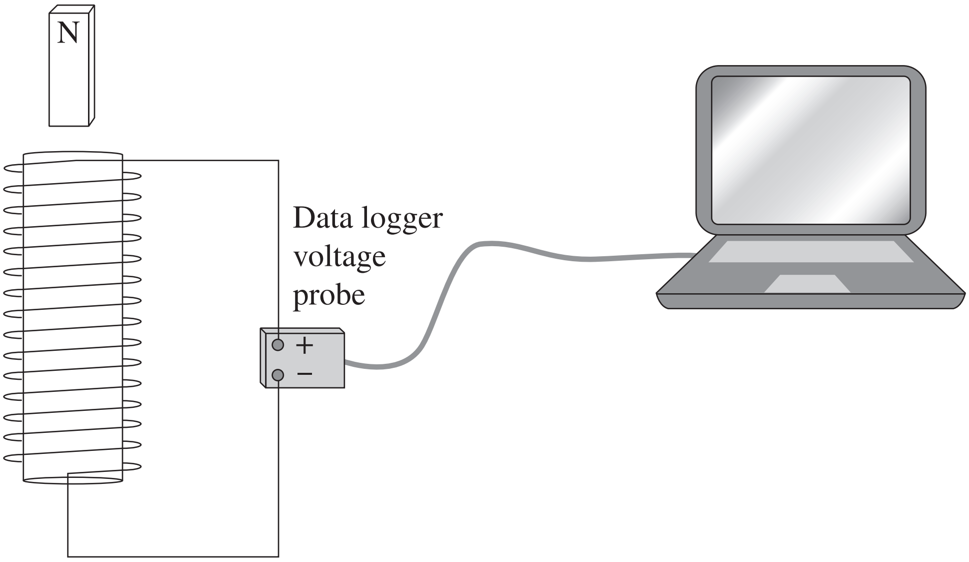
Criteria	Marks
• Draws graphs to compare the force on the wire and torque on the rotor as functions of time	4
• Draws graphs to show the force on the wire and torque on the rotor	3
• Draws a substantially correct graph to show the force on the wire OR torque on the rotor as a function of time	2
• Provides some relevant information	1

Sample answer:



Mod 6 – Question 16 (3 marks)

A solenoid was connected to a data logger to measure voltage. A magnet was dropped through the solenoid from above as shown. **3**



On the axes provided, sketch a graph showing the change in voltage as the magnet falls completely through the solenoid.

Question 16 continues on page 48

Question 16 (continued)

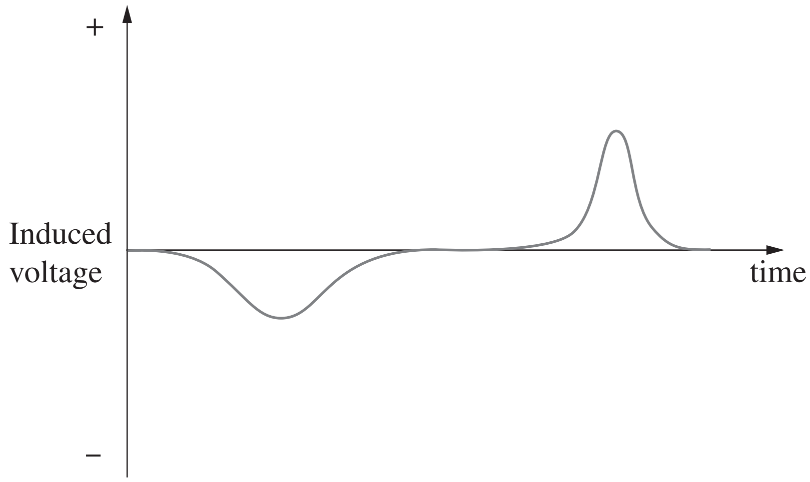
Mapping grid:

Content	Syllabus outcomes	Bands
Mod 6 Electromagnetic Induction	PH12–4, PH12–6, PH12–13	3–6

Marking guidelines:

Criteria	Marks
• Sketches a graph showing the correct changes in voltage with time	3
• Sketches some correct features	2
• Sketches a correct feature	1

Sample answer:



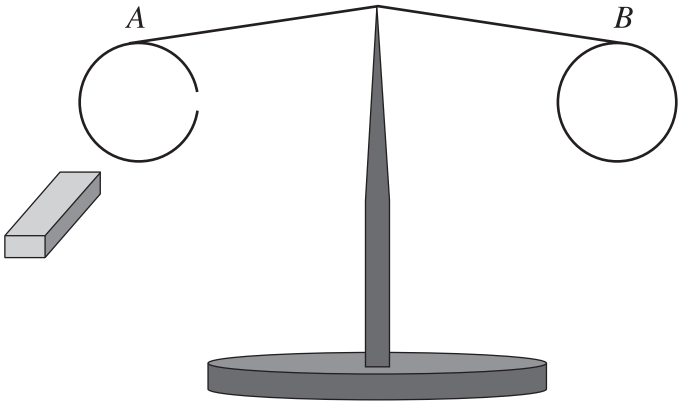
Note:

- Two peaks
- Peaks separate from each other in time
- First peak wider and smaller amplitude than second peak
- First peak negative, second peak positive.

End of Question 16

Mod 6 – Question 17 (5 marks)

The diagram shows two rings *A* and *B*, connected to a balancing arm which swings freely on a pivot. Ring *A* has a split in it as shown. **5**



When a bar magnet is pushed into one of the rings, the whole balancing arm begins to rotate on the pivot. When the magnet is pulled out, the balancing arm begins to rotate in the opposite direction. When the magnet is pushed in and out of the other ring, the apparatus does not move at all.

Account for these observations using Lenz's Law and conservation of energy.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 6 Applications of the Motor Effect	PH12–6, PH12–13	2–6

Question 17 continues on page 50

Question 17 (continued)

Marking guidelines:

Criteria	Marks
• Provides reasons for the observations • Clearly relates the observations to Lenz's Law and conservation of energy	5
• Provides reasons for the observations • Applies both Lenz's Law and conservation of energy	4
• Provides some reasons for the observations • Uses Lenz's Law and/or conservation of energy	3
• Shows some understanding of Lenz's Law and/or conservation of energy	2
• Provides some relevant information	1

Sample answer:

When the magnet is pushed into ring *B* the ring is repelled, but is attracted when the magnet is pulled back out. This is due to the fact that the moving magnet induces a current in the ring. Lenz's Law states that the induced current is in the direction such that the magnetic field produced by this current opposes the original change caused by the moving magnet. This means that pushing a magnet into the ring creates a 'like' pole, repelling the magnet, and pulling the ring out creates an 'opposite' pole, attracting the magnet. This is an application of the law of conservation of energy, as, if the current were in the other direction, the field produced would cause a movement that increases the change in flux even more, thereby producing even more current, and violating conservation of energy. When the magnet is pushed into ring *A*, no repulsive or attractive force is observed because the gap in the ring prevents a current from being induced, so no magnetic field is created as a result.

End of Question 17

Module 7 The Nature of Light

Mod 7 – Question 1

James Clerk Maxwell made significant contributions to physics.

Which of the following did Maxwell NOT contribute to our understanding of physics?

A. Predicting the velocity of electromagnetic waves

B. Predicting the existence of electromagnetic waves

C. Validating the existence of electromagnetic waves

D. Unifying electricity and magnetism through equations

Content	Syllabus outcomes	Bands	Key
Mod 7 Electromagnetic Spectrum	PH12–14	2–3	C

Mod 7 – Question 2

Betelgeuse is a red giant star in our galaxy. The following are facts about this star:

Fact 1: Its distance from us is 640 light years.

Fact 2: It has a surface temperature of 3500 K.

Fact 3: Its atmosphere contains titanium dioxide.

Fact 4: It is moving away from us at a speed of 21.9 km s^{-1}.

Which of the given facts about Betelgeuse CANNOT be determined from its spectrum?

A. Fact 1

B. Fact 2

C. Fact 3

D. Fact 4

Content	Syllabus outcomes	Bands	Key
Mod 7 Electromagnetic Spectrum	PH12–5, PH12–14	3–4	A

Mod 7 – Question 3

Which statement describes how an electromagnetic wave is propagated?

A. An oscillating electric field causes a constant magnetic field parallel to the electric field.

B. An oscillating magnetic field causes an oscillating electric field parallel to the magnetic field.

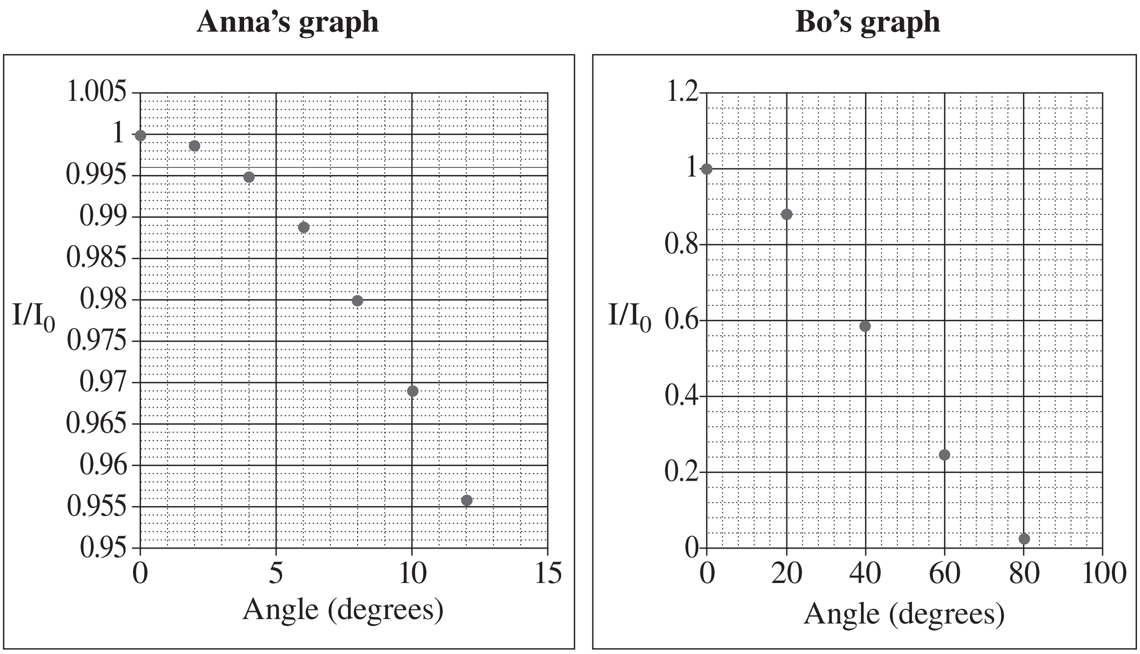
C. An oscillating electric field causes an oscillating magnetic field perpendicular to the electric field.

D. An oscillating magnetic field causes a constant electric field perpendicular to the magnetic field.

Content	Syllabus outcomes	Bands	Key
Mod 7 Electromagnetic Spectrum	PH12–14	3–4	C

Mod 7 – Question 4

Anna and Bo carried out independent experiments to investigate Malus's Law. They graphed the results of their experiments. The graphs are shown below.



Based on the two graphs, which of the following is correct?

A. Anna has taken more measurements but Bo has used a better data range.

B. Bo's graph is more precise as the angles in Anna's graph are too small.

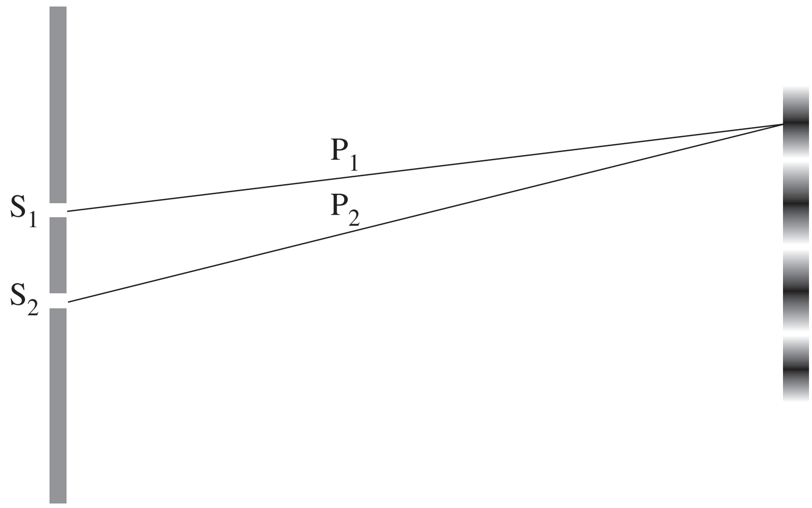
C. Anna's graph is more valid as Bo's graph shows a straight line relationship.

D. Anna's measurements are more reliable than Bo's as a line of best fit cannot be drawn for Bo's graph.

Content	Syllabus outcomes	Bands	Key
Mod 7 Light: Wave Model	PH12–2, PH12–14	3–4	A

Mod 7 – Question 5

Monochromatic light of wavelength λ strikes a double slit and produces bright and dark fringes on a screen. Light from slit S_1 travels along path P_1 and light from slit S_2 travels along P_2 to produce the dark fringe shown.



What is the difference in length between P_1 and P_2?

A. $\frac{\lambda}{2}$

B. λ

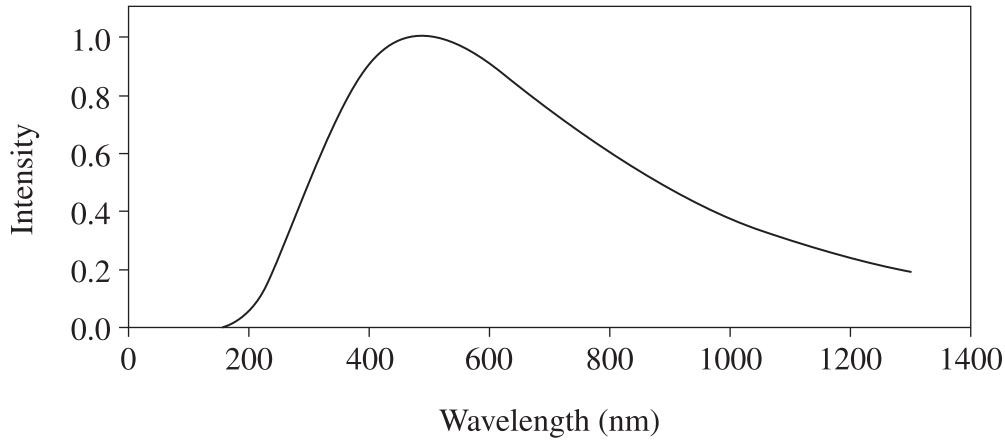
C. $\frac{3\lambda}{2}$

D. 2λ

Content	Syllabus outcomes	Bands	Key
Mod 7 Light: Wave Model	PH12–5, PH12–14	4–5	C

Mod 7 – Question 6

The graph shows the electromagnetic radiation emitted from a black body cavity.



What is the best estimate of the temperature of this black body?

A. 5.9×10^3 K

B. 7.2×10^3 K

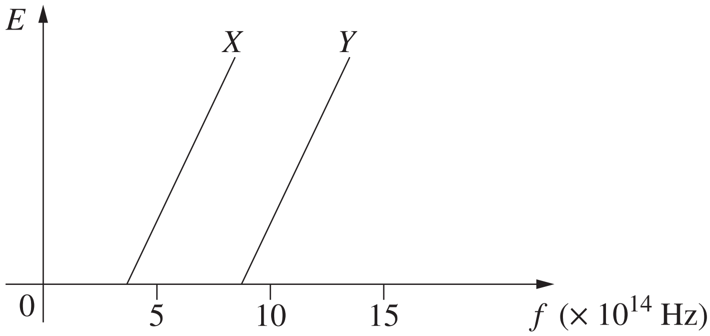
C. 1.7×10^5 K

D. 5.9×10^6 K

Content	Syllabus outcomes	Bands	Key
Mod 7 Light: Quantum Model	PH12–5, PH12–6, PH12–14	4–5	A

Mod 7 – Question 7

The graph shows the maximum kinetic energy (K) with which photoelectrons are emitted as a function of frequency (f) for two different metals X and Y.



The metals are illuminated with light of wavelength 450 nm.

What would be the effect of doubling the intensity of this light without changing the wavelength?

A. For metal X, the number of photoelectrons emitted would not change but the maximum kinetic energy would increase.

B. For metal X, the number of photoelectrons emitted would increase but the maximum kinetic energy remains unchanged.

C. For metals X and Y, the number of photoelectrons emitted would not change but the maximum kinetic energy would increase.

D. For metals X and Y, the number of photoelectrons emitted would increase but the maximum kinetic energy remains unchanged.

Content	Syllabus outcomes	Bands	Key
Mod 7 Light: Quantum Model	PH12–5, PH12–6, PH12–14	5–6	B

Mod 7 – Question 8

A spaceship sitting on its launch pad is measured to have a length *L*. This spaceship passes an outer planet at a speed of $0.95c$.

Which observations of the length of the spaceship are correct?

	Observer on the spaceship	*Observer on the planet*
A.	No change	Shorter than *L*
B.	No change	Greater than *L*
C.	Shorter than *L*	No change
D.	Greater than *L*	No change

Content	Syllabus outcomes	Bands	Key
Mod 7 Light and Special Relativity	PH12–6, PH12–14	2–3	A

Mod 7 – Question 9

What is the magnitude of the momentum (in $kg\,m\,s^{-1}$) of an electron travelling at $0.8c$?

A. 2.19×10^{-22}

B. 3.64×10^{-22}

C. 4.89×10^{-22}

D. 5.99×10^{-22}

Content	Syllabus outcomes	Bands	Key
Mod 7 Light and Special Relativity	PH12–6, PH12–14	3–4	B

Mod 7 – Question 10

In 1972, four caesium clocks were flown twice around the world on commercial jet flights, once eastward and once westward. The travelling clocks were compared with reference clocks at the US Naval Observatory and the results were compared with predictions from Einstein's theory of special relativity.

	Time difference between travelling clocks and stationary reference clocks (nanoseconds)	
	Eastward journey	Westward journey
Predicted	– 40 ± 23	275 ± 21
Observed	– 59 ± 10	273 ± 7

Which of the following is correct about the observed results in relation to Einstein's theory?

A. Both of the results are inconclusive.

B. Both of the results support the theory.

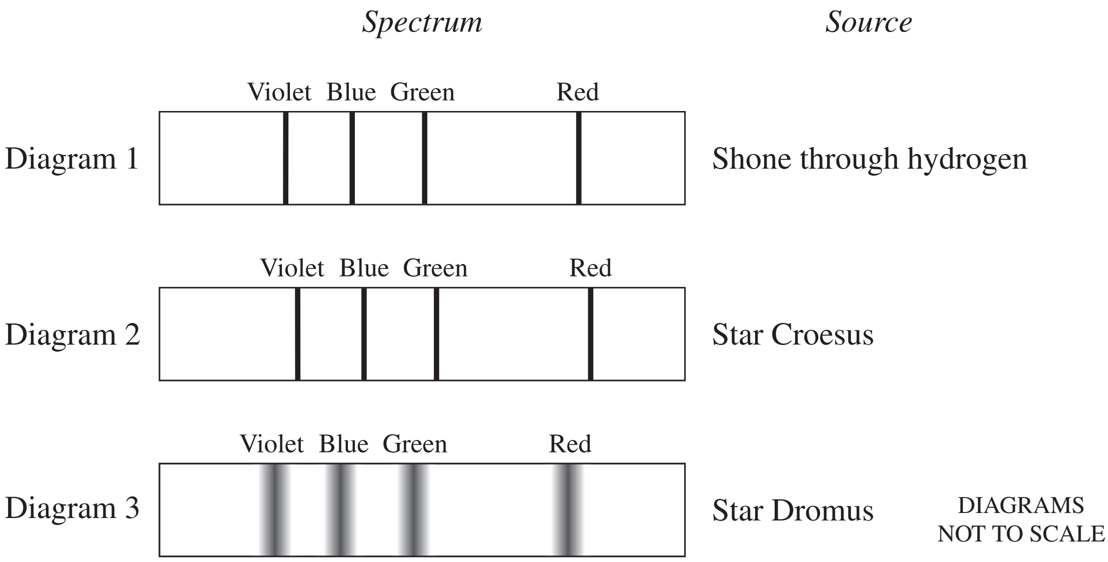
C. One of the results supports the theory and the other is inconclusive.

D. One of the results supports the theory and the other rejects the theory.

Content	**Syllabus outcomes**	**Bands**	**Key**
Mod 7 Light and Special Relativity	PH12–5, PH12–14	5–6	B

Mod 7 – Question 11 (3 marks)

Diagram 1 shows the absorption spectrum of light produced by an incandescent filament, after it has been shone through a quantity of hydrogen gas. Diagrams 2 and 3 show the spectra obtained from two stars: Croesus and Dromus. The dark lines in the diagrams are absorption bands. **3**



Explain what the spectrum of each star, Croesus and Dromus, tells us about the motion of that star.

Mapping grid:

Content	**Syllabus outcomes**	**Bands**
Mod 7 Electromagnetic Spectrum	PH12–4, PH12–5, PH12–14	3–5

Marking guidelines:

Criteria	**Marks**
• Relates the spectrum of each star to its motion	3
• Describes the motion of each star OR • Relates the spectrum of ONE star to its motion	2
• Provides some relevant information	1

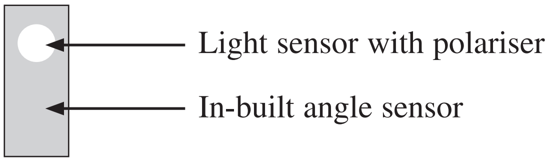
Sample answer:

Croesus is not rotating, indicated by the thin lines, and is moving away from the observer, indicated by the red shifting.

Dromus has wider spectral lines, indicating simultaneous red and blue shifting, so it is rotating and travelling slightly towards the observer, indicated by the blue shifting.

Mod 7 – Question 12 (6 marks)

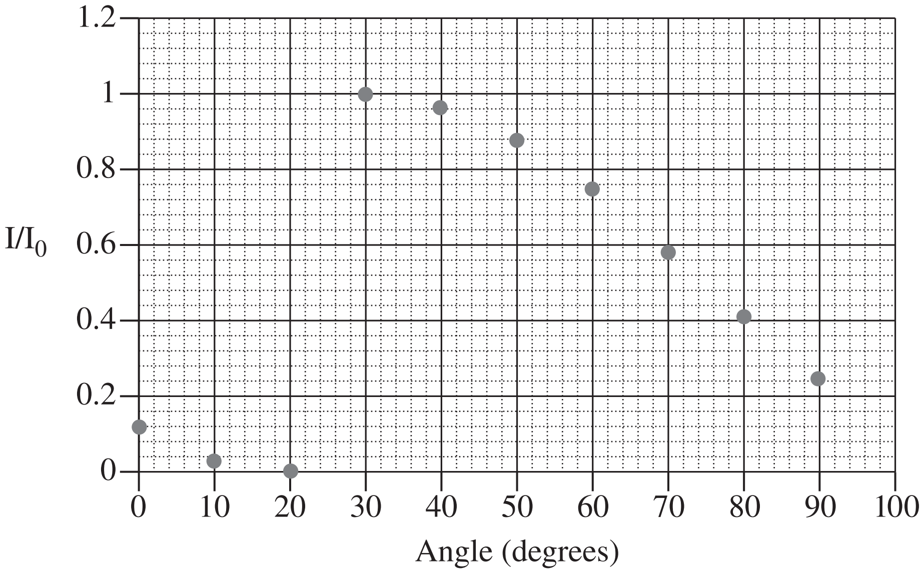
(a) A student was given a smartphone with a light sensor and an angle sensor, and a computer screen which emitted polarised light. A polariser was fixed over the top of the light sensor in the smartphone. **3**



Smartphone

The student wants to use this equipment to investigate Malus's Law of polarised light. Describe a procedure that is suitable for carrying out this investigation.

(b) An experiment was conducted to demonstrate Malus's Law for plane polarisation of light. The results are shown in the graph. **3**



Based on the graph shown, how effective was the experiment in meeting its aim?

Question 12 continues on page 61

Question 12 (continued)

Mapping grid (a):

Content	**Syllabus outcomes**	**Bands**
Mod 7 Light: Wave Model	PH12–2, PH12–14	2–4

Marking guidelines (a):

Criteria	**Marks**
• Describes a suitable procedure	3
• Outlines some relevant steps	2
• Provides some relevant information	1

Sample answer:

The computer is set to a constant intensity of light. The distance from the computer screen to the smartphone is measured. The phone is secured in place so that it can rotate but not change its distance from the screen. The smartphone angle sensor is set to zero when its position obtains maximum intensity. The light intensity and angle are then measured and recorded. The phone is rotated and the intensity of light at many different angles is measured. The results are plotted on a graph and the relationship determined via analysis.

Mapping grid (b):

Content	**Syllabus outcomes**	**Bands**
Mod 7 Light: Wave Model	PH12–2, PH12–14	2–4

Marking guidelines (b):

Criteria	**Marks**
• Provides an informed assessment of the effectiveness of the experiment based on the graph	3
• Outlines strength(s) and/or weakness(es) of the data shown on the graph	2
• Identifies a strength or weakness of the data shown on the graph OR • Shows a basic understanding of Malus's Law	1

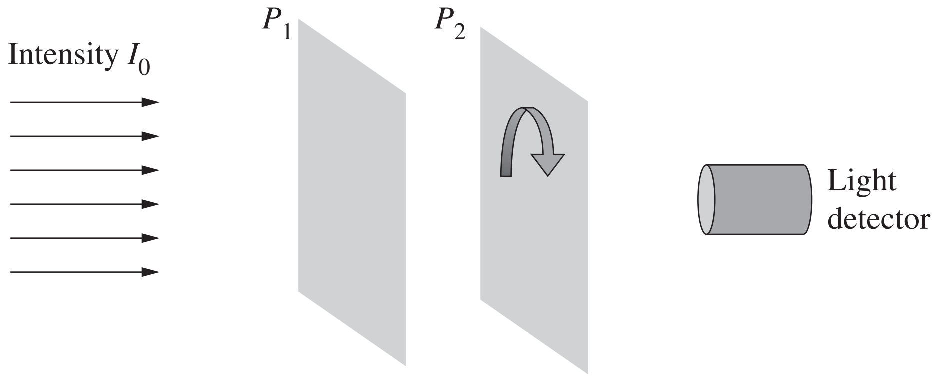
Sample answer:

The range of data is good and the points collected give a good indication of the shape of the expected curve according to Malus's Law $\left(I = I_{max} \cos^2 \theta\right)$. However, the first three measurements seem to be incorrectly taken as the maximum intensity of light should be at 0° (not 30°).

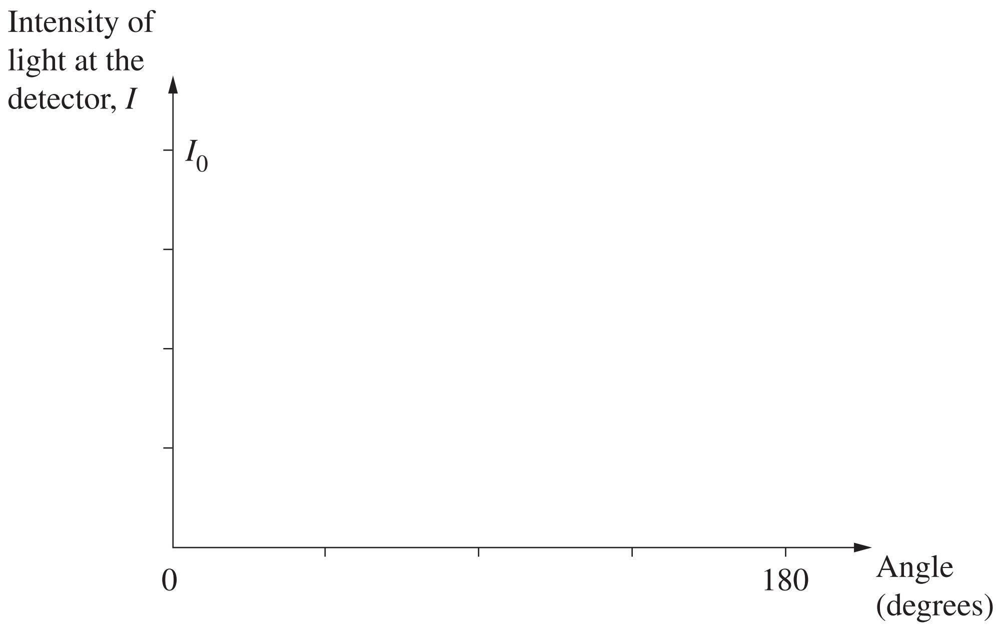
End of Question 12

Mod 7 – Question 13 (5 marks)

Parallel light rays of intensity I_0 pass through two polarising filters P_1 and P_2 to a detector. The filters are initially aligned so that they produce the maximum amount of light, then filter P_2 is slowly rotated through 180° as shown.



(a) On the axes provided sketch a graph showing how the intensity of light at the detector, I, changes as P_2 rotates from zero to 180°. **2**



(b) P_2 is now rotated to a position such that no light reaches the detector. Without moving P_1 or P_2, a third polarising filter is inserted between P_1 and P_2 and rotated at an angle of 30° from P_1. **3**

Explain, with the aid of calculations, why the light intensity at the detector is no longer zero.

Question 13 continues on page 63

Question 13 (continued)

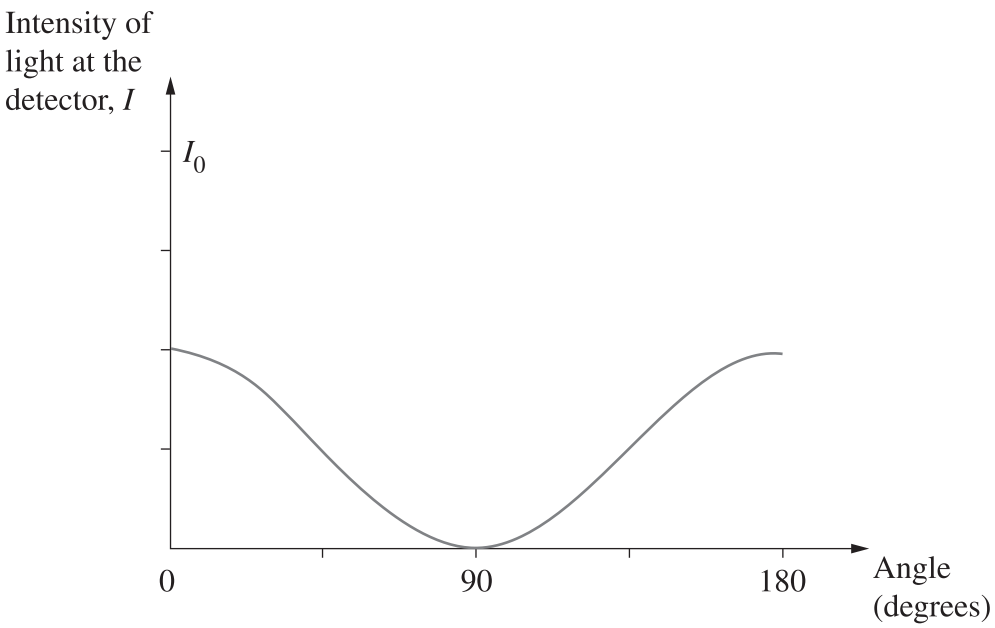
Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 7 Light: Wave Model	PH12–5, PH12–14	2–4

Marking guidelines (a):

Criteria	Marks
• Sketches a graph showing the correct changes in intensity with angle	2
• Sketches a correct feature	1

Sample answer:



- Graph starts as maximum, reaches 0 at 90° and returns to maximum at 180°.
- Maximum no greater than 0.5 I_0.

Question 13 continues on page 64

Question 13 (continued)

Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 7 Light: Wave Model	PH12–4, PH12–6, PH12–14	3–5

Marking guidelines (b):

Criteria	Marks
• Provides explanation supported with calculations	3
• Provides some explanation supported with a calculation OR • Calculates the final intensity of the light	2
• Provides some relevant information	1

Sample answer:

The amount of light passing through the middle polariser is
$I_m = I_1 \cos^2 30° = 0.75\ I_1$, where I_1 is the amount of light passing through P_1.

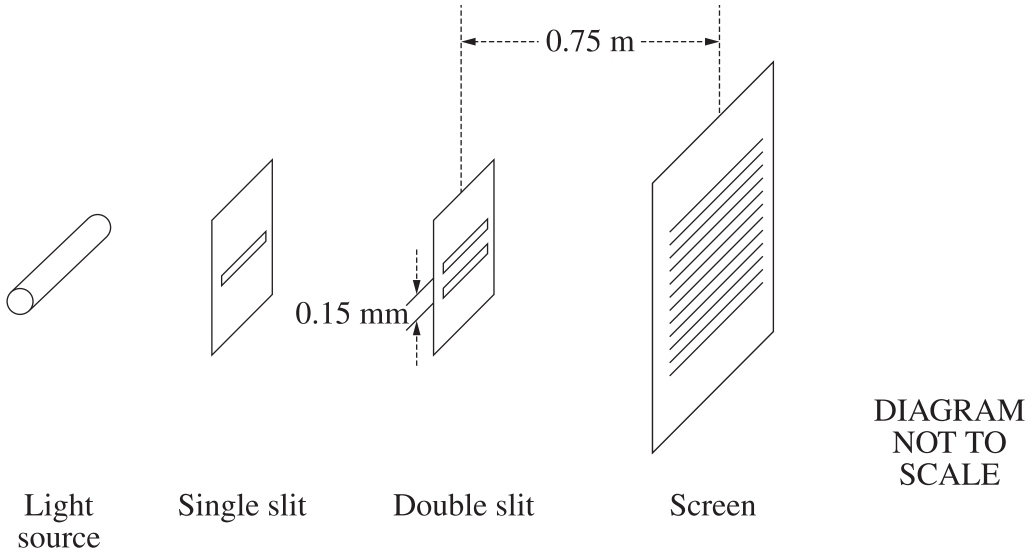
This light is polarised now at 30° which means it is rotated 60° to P_2.
$I_2 = 0.75\ I_1 \times \cos^2 60° = 0.75\ I_1 \times 0.25 = 0.1875 \times I_1$

Therefore the light reaching the detector is no longer zero.

End of Question 13

Mod 7 – Question 14 (6 marks)

The diagram shows a light source, slits and a translucent screen arranged for an experiment on light. Light and dark bands form on the screen. The light has a wavelength of 590 nm. The diagram is not to scale.



(a) Explain how any one of the dark bands forms on the screen. **3**

(b) The distance between the centres of the double slit is 0.15 mm, and the distance between the double slit and the screen is 0.75 m. **3**

Calculate the distance on the screen from the centre of the central maximum to the centre of a second-order bright band.

Question 14 continues on page 66

Question 14 (continued)

Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 7 Light: Wave Model	PH12–6, PH12–14	3–5

Marking guidelines (a):

Criteria	Marks
• Relates the formation of the interference pattern to the position of the slits	3
• Shows some understanding of the interference pattern	2
• Provides some relevant information	1

Sample answer:

Diffraction occurs when it travels through the double slit. Since the double slits are 180° out of phase there is destructive interference, where the waves superimpose and cancel each other out, creating the dark bands.

Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 7 Light: Wave Model	PH12–4, PH12–6, PH12–14	4–6

Marking guidelines (b):

Criteria	Marks
• Correctly calculates the distance	3
• Shows some relevant calculations	2
• Provides some relevant information	1

Sample answer:

$d \sin\theta = m\lambda$

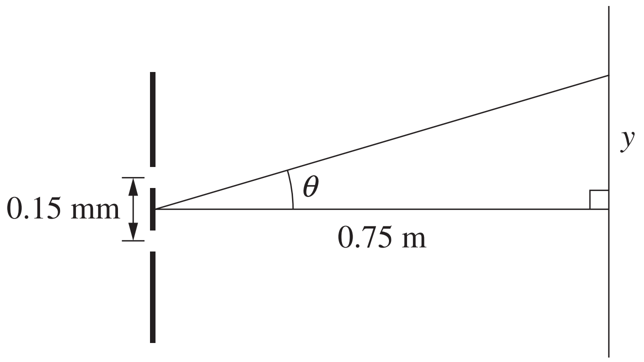
$0.15 \times 10^{-3} \sin\theta = 2 \times 590 \times 10^{-9}$

$\therefore \sin\theta = 0.007867$

$\sin\theta = 0.007867 = \dfrac{y}{0.75}$

$\therefore y = 0.007867 \times 0.75$

$= 0.0059 \text{ m}$



End of Question 14

Mod 7 – Question 15 (6 marks)

An experiment was conducted to model Millikan's oil drop experiment. In the experiment, different numbers of dominoes were placed inside seven identical boxes. The boxes were then sealed and weighed. The table shows the mass of each sealed box and some preliminary analysis. **6**

Box number	*Mass of box (including dominoes)* (g)	*Difference in mass between this box and the next box* (g)
1	15.45	17.2
2	32.65	25.8
3	58.45	4.3
4	62.75	8.6
5	71.35	12.9
6	84.25	43
7	127.25	

Analyse this experiment to assess its effectiveness in modelling Millikan's oil drop experiment.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 7 Light: Wave Model	PH12–4, PH12–14	2–6

Marking guidelines:

Criteria	Marks
• Provides an appropriate analysis of the results • Compares the method of analysis to that of Millikan's oil drop experiment • Makes an informed judgement about the effectiveness of the experiment in modelling Millikan's experiment	6
• Provides an appropriate analysis of the results • Shows a sound understanding of Millikan's oil drop experiment • Links the analysis of the results to the analysis used in Millikan's oil drop experiment	5
• Provides an appropriate analysis of the results • Shows some understanding of Millikan's oil drop experiment	4
• Analyses the results AND/OR • Shows some understanding of Millikan's oil drop experiment	2–3
• Provides some relevant information	1

Question 15 continues on page 68

Question 15 (continued)

Sample answer:

In this experiment, the smallest difference between two boxes is 4.3 g (between box 3 and box 4) and all other differences are multiples of 4.3. These characteristics indicate the quantised nature of the results and that the experiment was done accurately. While it cannot be certain that the smallest difference is the mass of one domino, further tests could improve the probability that this is true. If we assume that the difference is due to one domino, then the mass of a single domino would be 4.3 g, the fundamental quantity of the mass of a domino. This method of analysis is similar to that used in Millikan's oil-drop experiment, in which he sought to determine the charge of an electron. He tested many charged oil drops and found that the value of the charge on an oil drop was always an integer multiple of a certain base value: 1.6×10^{-19} C. Thus, the domino experiment is very effective in demonstrating the analysis of Millikan's oil drop experiment even though the method and components are completely different. It allows us to think about the assumptions and the problems Millikan must have had, such as whether only one electron was being measured.

End of Question 15

Mod 7 – Question 16 (3 marks)

Applying the law of conservation of energy, explain why $K_{max} = hf - \phi$. **3**

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 7 Light: Quantum Model	PH12–7, PH12–14	3–5

Marking guidelines:

Criteria	Marks
• Applying the law of conservation of energy, explains why $K_{max} = hf - \phi$.	3
• Shows some understanding of the law of conservation of energy and/or $K_{max} = hf - \phi$.	2
• Provides some relevant information	1

Sample answer:

The law of conservation of energy states that energy cannot be created or destroyed. It is transferred or transformed. The initial energy of a photon of light is hf. If this photon hits a metal surface, the energy is passed onto an electron, which can be released from the metal surface. For the electron to be released, it will possess kinetic energy (K_{max}) and some energy to remove the electron from the metal surface (the work function of ϕ). Therefore, $hf = K_{max} + \phi$ which is $K_{max} = hf - \phi$.

Mod 7 – Question 17 (7 marks)

In an experiment to investigate the photoelectric effect, a group of students used a piece of equipment containing a metal cathode inside a glass tube. The students were able to accurately measure both the current produced and the maximum energy of electrons in response to light hitting the cathode. **7**

Explain how the choice of independent variable would give rise to different results. Sketch graphs to illustrate your answer.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 7 Light: Quantum Model	PH12–2, PH12–4, PH12–6, PH12–7, PH12–14	2–6

Marking guidelines:

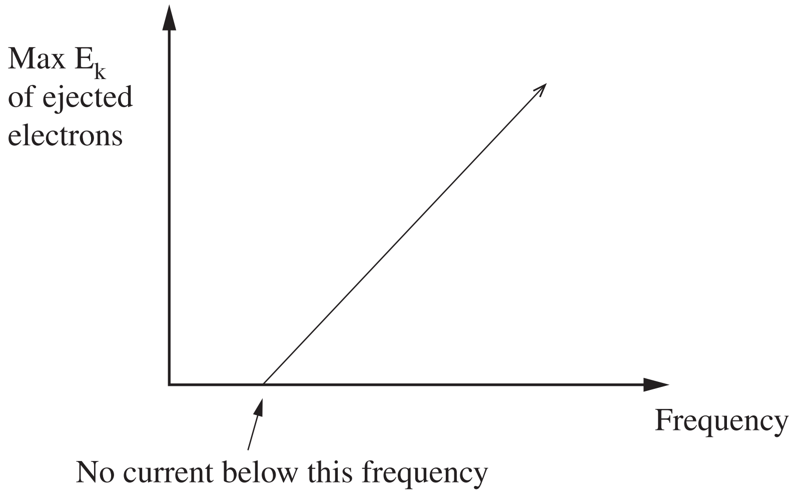
Criteria	Marks
• Explains the results obtained due to different choices of independent variable • Supports answer with graphs	7
• Explains the results obtained due to different choices of independent variable • Supports answer with a graph	6
• Explains the results from different independent variables	5
• Outlines the different results from different independent variables • Explains at least one set of results	4
• Outlines the different results from different independent variables OR • Explains the results from a suitable independent variable	3
• Identifies different independent variables appropriate to the investigation OR • Identifies a suitable independent variable and outlines its results	2
• Provides some relevant information	1

Sample answer:

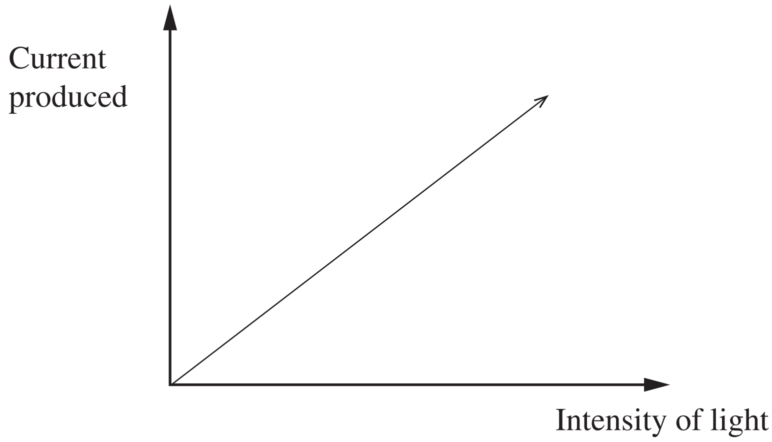
The students could choose to change the frequency (or wavelength) of the light as their independent variable. What they would observe is that below a certain threshold frequency no current would be produced. However, above that frequency a current would be produced. The current would not change as the frequency increased, but the maximum kinetic energy of the electrons would increase in proportion to the change in frequency. The proportion is Planck's constant, shown as the gradient in the graph.

Question 17 continues on page 71

Question 17 (continued)



The students could instead choose to change the intensity of the light as their independent variable. In this case, as long as their frequency is above the threshold, a current will be produced in proportion to the intensity of the light.



However, if their freqency were below the threshold, then no matter how intense they make the light, the current would still be zero.

Answers could include:

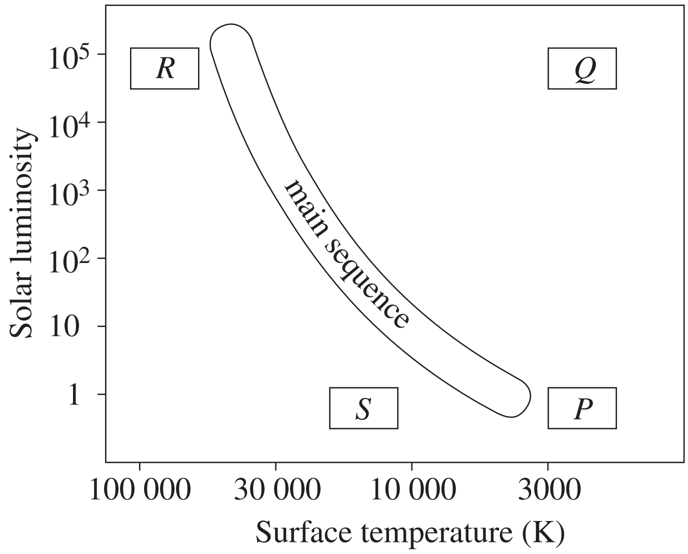
- Results of choosing a different metal as the independent variable.

End of Question 17

Module 8 From the Universe to the Atom

Mod 8 – Question 1

A Hertzsprung–Russell diagram is shown.



In which region would a star have the same surface temperature as a star on the main sequence?

A. *P*

B. *Q*

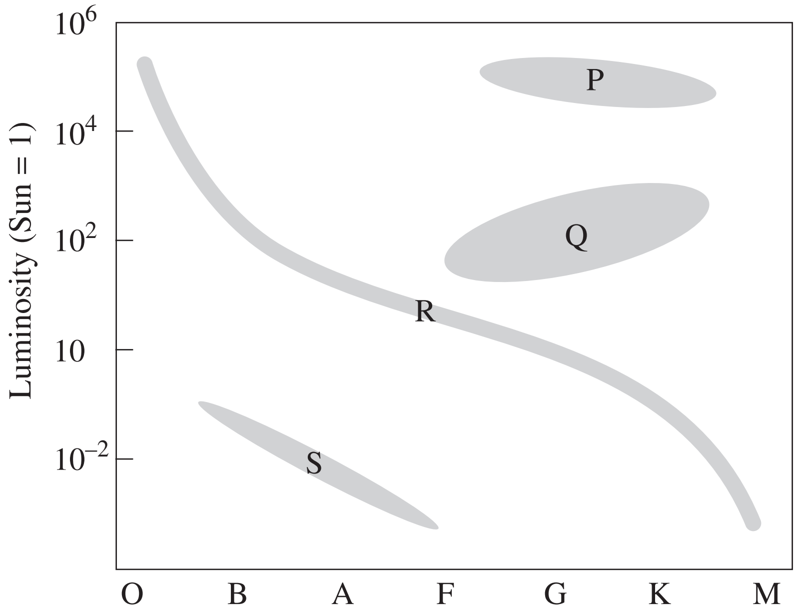
C. *R*

D. *S*

Content	Syllabus outcomes	Bands	Key
Mod 8 Origins of the Elements	PH12–5, PH12–15	2–3	D

Mod 8 – Question 2

The Hertzsprung-Russell diagram shown is used to classify stars.



Stars in region *S* of the diagram are much dimmer than other stars in the same spectral class.

What property of the stars in region *S* explains their relatively low luminosity?

A. They are cooler than other stars.

B. They have a smaller mass than other stars.

C. They have a smaller surface area than other stars.

D. They are further away from Earth than other stars.

Content	Syllabus outcomes	Bands	Key
Mod 8 Origins of the Elements	PH12–6, PH12–15	4–5	C

Mod 8 – Question 3

After DC voltage was applied to an apparatus containing hydrogen gas, the hydrogen separated into streams of oppositely charged particles.

What could be concluded from this observation?

A. Hydrogen gas conducts electricity.

B. Hydrogen is the simplest element.

C. Hydrogen atoms have components.

D. Hydrogen atoms have a neutral charge.

Content	Syllabus outcomes	Bands	Key
Mod 8 Structure of the Atom	PH12–15	2–3	C

Mod 8 – Question 4

Which of the following is true in relation to Millikan's oil drop experiment?

	Aim of the experiment	*Type of field used in experiment*
A.	Measure the charge-to-mass ratio of electrons	Electric and magnetic
B.	Measure the charge-to-mass ratio of electrons	Magnetic
C.	Measure the charge of electrons	Electric and magnetic
D.	Measure the charge of electrons	Electric

Content	Syllabus outcomes	Bands	Key
Mod 8 Structure of the Atom	PH12–1, PH12–2, PH12–15	2–3	D

Mod 8 – Question 5

In an experiment, an electrically charged oil drop was suspended in air by an electric field. The electric field could be adjusted to balance the weight of the oil drop.

If more drops were suspended and measurements taken, which of the following properties would all of the oil drops be observed to have in common?

A. The mass of each drop would be a multiple of a fundamental mass.

B. The mass of each drop would be the same as each of the other drops.

C. The charge of each drop would be a multiple of a fundamental charge.

D. The charge of each drop would be the same as each of the other drops.

Content	Syllabus outcomes	Bands	Key
Mod 8 Structure of the Atom	PH12–5, PH12–15	3–4	C

Mod 8 – Question 6

The table shows the quantum numbers of the four lowest states of the hydrogen atom, together with the energies of those states.

Quantum number, n	*Energy* (joules)
1 (ground state)	0
2	1.63×10^{-18}
3	1.94×10^{-18}
4	2.04×10^{-18}

Which quantum transition will absorb a photon of wavelength 102 nm?

A. 1 to 3

B. 3 to 1

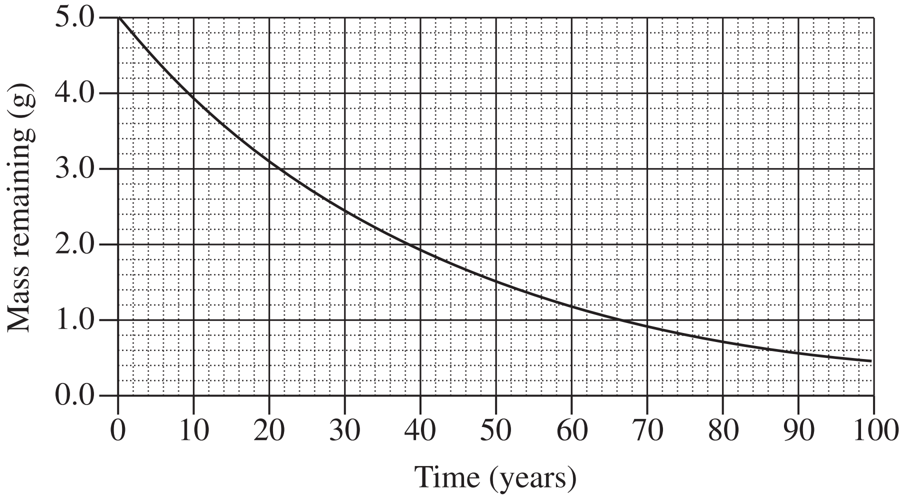
C. 2 to 4

D. 4 to 2

Content	Syllabus outcomes	Bands	Key
Mod 8 Quantum Mechanical Nature of the Atom	PH12–4, PH12–6, PH12–15	5–6	A

Mod 8 – Question 7

A 5-gram sample of radioactive strontium-90 decayed over time. The graph shows the mass of strontium-90 remaining from the initial sample as a function of time.



What is the approximate value of the decay constant, in year^{-1}, for strontium-90?

A. 0.006

B. 0.011

C. 0.014

D. 0.025

Content	Syllabus outcomes	Bands	Key
Mod 8 Properties of the Nucleus	PH12–6, PH12–15	2–3	D

Mod 8 – Question 8

The following equation describes the natural decay process of uranium-238.

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

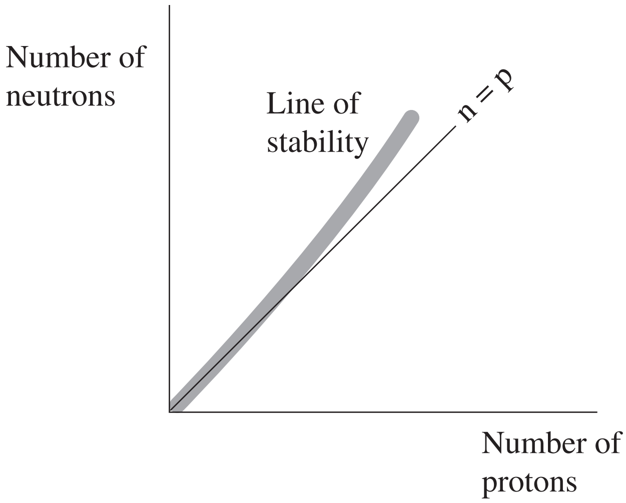
Which row of the table describes the changes in total mass and total binding energy in the decay of uranium-238?

	Total mass	*Total binding energy*
A.	Decreases	Increases
B.	Decreases	Decreases
C.	Increases	Increases
D.	Increases	Decreases

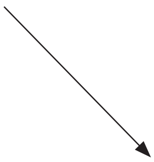
Content	**Syllabus outcomes**	**Bands**	**Key**
Mod 8 Properties of the Nucleus	PH12–6, PH12–15	4–5	A

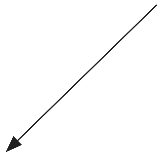
Mod 8 – Question 9

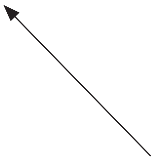
The graph shown plots isotopes in terms of their numbers of protons and neutrons. When an isotope undergoes nuclear decay, it will move to a different location on the graph. The movement can be represented with an arrow.

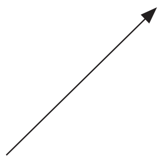


Which arrow would correctly describe beta negative (β^-) decay on the graph?

A. 

B. 

C. 

D. 

Content	Syllabus outcomes	Bands	Key
Mod 8 Properties of the Nucleus	PH12–5, PH12–6, PH12–15	5–6	A

Mod 8 – Question 10

A patient is given an injection containing 6.0×10^{-18} kg of radioactive technetium-99m which has a half-life of 6 hours.

How much remains undecayed when a scan is taken 4 hours later?

A. 2.1×10^{-18} kg

B. 3.0×10^{-18} kg

C. 3.8×10^{-18} kg

D. 4.0×10^{-18} kg

Content	Syllabus outcomes	Bands	Key
Mod 8 Properties of the Nucleus	PH12–4, PH12–6, PH12–15	5–6	C

Mod 8 – Question 11

The table lists the first generation of quarks and antiquarks.

Quarks			*Antiquarks*		
Name	*Symbol*	*Charge*	*Name*	*Symbol*	*Charge*
Up	u	$+\frac{2}{3}e$	Antiup	$\bar{u}$	$-\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$	Antidown	$\bar{d}$	$+\frac{1}{3}e$

The Standard Model of matter states that baryons, such as protons and neutrons, consist of three quarks.

Using the table, which of the following represents the quark composition for a neutron and an antineutron, respectively?

A. uud and $\bar{u}\bar{u}\bar{d}$

B. $\bar{u}\bar{u}\bar{d}$ and uud

C. udd and $\bar{u}\bar{d}\bar{d}$

D. $\bar{u}\bar{d}\bar{d}$ and udd

Content	Syllabus outcomes	Bands	Key
Mod 8 Deep Inside the Atom	PH12–6, PH12–15	3–4	C

Mod 8 – Question 12 (7 marks)

One of the most important equations in all of physics is Einstein's $E = mc^2$. **7**

Justify this statement.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 7 Light and Special Relativity Mod 8 Origins of the Elements Mod 8 Properties of the Nucleus	PH12–5, PH12–6, PH12–7, PH12–14, PH12–15	2–6

Marking guidelines:

Criteria	Marks
• Justifies the statement by relating the application of Einstein's $E = mc^2$ to a range of ideas, processes and phenomena	7
• Explains the importance of Einstein's $E = mc^2$ in relation to its application to some ideas, processes and phenomena	6
• Describes the importance of Einstein's $E = mc^2$ in relation to some ideas and/or processes and/or phenomena	4–5
• Outlines the application and/or importance of Einstein's $E = mc^2$	2–3
• Provides some relevant information	1

Question 12 continues on page 81

Question 12 (continued)

Answers could include:

The equivalence of mass and energy, as summarised in Einstein's $E = mc^2$, is a hugely important concept in physics and helps to explain a range of phenomena and concepts such as:

- nuclear fission and nuclear fusion processes, and the common source of their energy output
- binding energy and mass defect, where apparently 'missing mass' goes
- radioactive decay and the energy associated with it
- mass dilation of objects approaching the speed of light
- nuclear bombs and nuclear reactors, as the fundamental principle upon which they operate
- processes which explain the sources of energy in stars, through nuclear fusion and mass transforming into energy
- processes which allow us to further investigate the structure of matter through particle accelerators, through the high energies of collisions transforming into a range of short-lived particles.

$E = mc^2$ therefore is justified in being called one of the most important equations in physics, as it plays a fundamental role in a range of fields that make up our current understanding and application of physics. Other 'famous' equations like Newton's Universal Law of Gravity do not have the same breadth of impact. Maxwell's equations as a group perhaps have a similar impact as $E = mc^2$, however, the single equation $E = mc^2$ can be considered as one of the most important equations in physics.

End of Question 12

Mod 8 – Question 13 (4 marks)

Describe TWO processes which account for energy production in stars. **4**

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 8 Origins of the Elements	PH12–7, PH12–15	2–5

Marking guidelines:

Criteria	Marks
• Describes TWO relevant processes	4
• Describes ONE process and outlines the other process	3
• Outlines TWO processes OR • Describes ONE process	2
• Provides some relevant information	1

Sample answer:

Stars produce their energy through nuclear fusion. For most stars, this process is dominated by the proton–proton chain reaction, a sequence of events that transforms four hydrogen atoms into one helium atom.

The proton–proton chain reaction fuels most stars and provides them with the energy required to support their enormous masses for most of their lifetimes.

Larger stars, whose crushing weight generates even higher temperatures at their cores, use a more complex fusion process called the CNO cycle. In the CNO cycle, trace amounts of carbon, nitrogen and oxygen serve as catalysts in fusing four hydrogen atoms into one helium atom and high-energy gamma ray photons.

Mod 8 – Question 14 (4 marks)

Compare the features of emission and absorption spectra in terms of how they are produced. **4**

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 8 Origins of the Elements	PH12–6, PH12–7, PH12–15	2–5

Marking guidelines:

Criteria	Marks
• Shows the similarities and/or differences between the features of emission and absorption spectra in terms of their production	4
• Outlines features of emission and absorption spectra in terms of their production	3
• Identifies features of emission and/or absorption spectra in terms of their production OR • Outlines a feature of emission or absorption spectrum in terms of its production	2
• Provides some relevant information	1

Sample answer:

Emission and absorption spectra both arise out of the same process: the transition of electrons between energy levels in an atom. Emission spectra generally form a black background, with specific wavelengths of light evident at various intensities. Absorption spectra generally show a continuum of wavelengths, with specific wavelengths at sufficiently lower intensities. The emission and absorption spectra of a particular element will be the 'negative' of each other.

Emission spectral lines are produced when electrons are excited to move up energy levels which are unstable and fall back to lower more stable levels emitting photons of specific wavelengths of light in the process. The distinct lines represent the difference in energy levels of the electron.

Absorption spectra lines are produced when a continuous spectrum is passed through a substance, such as cool elemental gas. When this occurs, certain wavelengths of light (corresponding to differences in energy levels) are absorbed by the electron as it jumps up into a higher energy level, resulting in a dark line.

Mod 8 – Question 15 (9 marks)

Explain how the analysis of quantitative observations contributed to the development of the concept that certain matter and energy are quantised. **9**

Mapping grid:

Content	**Syllabus outcomes**	**Bands**
Mod 7 Light: Quantum Model Mod 8 Structure of the Atom	PH12–14, PH12–15	2–6

Marking guidelines:

Criteria	**Marks**
• Shows a comprehensive understanding of the analysis of quantitative observations in relation to quantisation • Clearly relates the analysis to the development of the concept of quantisation	9
• Shows a sound understanding of the analysis of quantitative observations in relation to quantisation • Relates the analysis to the development of the concept of quantisation	7–8
• Outlines analyses of quantitative observations • Links these to the development of the concept of quantisation	5–6
• Outlines some quantitative observations and/or shows some understanding of the concept of quantisation	3–4
• Provides some relevant information	1–2

Sample answer:

Experiments such as the ones testing the photoelectric effect and Millikan's measurement of the fundamental unit of charge have demonstrated that certain quantities measured in physics are quantised. That is, they only appear as exact multiples of some fundamental value, or quantum.

Millikan found that the value of the charge on an oil drop was an integer multiple of 1.6×10^{-19} C, and so he concluded that this was the charge on a single electron. In this situation, quantisation was expected since the electron had been determined to be a particle. However, this result provided critical experimental evidence. This, combined with the Thomson experiment, which determined the charge to mass ratio, allowed for the mass of an electron to be determined. Thus the quantum of mass of an electron was shown through quantitative observations.

Question 15 continues on page 85

Question 15 (continued)

The discovery of quantisation of light, and hence energy in the form of electromagnetic radiation, as shown in the photoelectric effect experiments, was much more surprising. The understanding that light was a wave was well supported by experimental evidence, and so it was not expected that the energy would be divided into discrete packets. However, when experiments showed that there was a minimum frequency of light that would produce a photocurrent and that the amount or intensity of light did not affect the ability of electrons to be removed from a metal surface, it was explained by one electron receiving one photon or quantum of energy specific to the frequency of that light ($E = hf$). If a photon did not have enough energy, an electron could not be removed. This could only be adequately explained by a quantum model. In this case, experimental evidence generated a change in physicists' concept of energy, requiring a broader understanding of quantisation in physical processes.

Answers could include:

- spectroscopy and the existence of fixed energy levels in the atom
- cathode ray experiments showing the particle nature of the electron
- radioactivity experiments
- scintillation experiments
- blackbody radiation experiments.

End Question 15

Mod 8 – Question 16 (8 marks)

Analyse the way in which scientists use observations and mathematical ideas to improve scientific models. In your answer refer to the work of scientists who have contributed to our understanding of the atom. **8**

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 8 Structure of the Atom Mod 8 Quantum Mechanical Nature of the Atom	PH12–6, PH12–7, PH12–15	2–6

Marking guidelines:

Criteria	Marks
• Shows a comprehensive understanding of the way scientists use observations and mathematical ideas to improve models • Clearly refers to the work of scientists who have contributed to the understanding of the atom • Makes clear the relationship between limitations in models and improvements by new models • Draws out and relates implications	8
• Shows a sound understanding of the way scientists use observations and mathematical ideas to improve models of the atom • Refers to the work of scientists who have contributed to the understanding of the atom • Makes links between limitations in models and improvements by new models	6–7
• Outlines specific observations and features of models of the atom • Links observations and/or models to ways in which scientists improve upon models	4–5
• Outlines some features of a scientific model OR • Shows some understanding of the way scientists have improved on scientific models	2–3
• Provides some relevant information	1

Sample answer:

Scientific models are used to explain observations and help us understand ideas but they are all limited in some way. If an observation is not consistent with the model, then the model needs to be changed.

Question 16 continues on page 87

In the Geiger–Marsden gold foil alpha scattering experiment it was observed that positive alpha particles mostly passed through the atom, but sometimes bounced back. Rutherford took these observations to come up with a model of the atom that had a dense positive nucleus surrounded by orbiting electrons. A limitation with this model, though, is that for an electron to be orbiting it would be accelerating and giving off electromagnetic radiation, thereby losing energy and spiralling into the nucleus.

Niels Bohr improved upon this model based upon evidence from the hydrogen spectrum. He postulated that electrons could occupy only specific energy levels (orbits) and can jump from one level to another without travelling between. He developed a mathematical model that could explain the specific wavelengths of the hydrogen emission and absorption spectra based on electrons jumping between the specific integer levels. The model is conceptual but relies on Rydberg's mathematical equation:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

where λ = wavelength, n_f = final energy level, n_i = initial energy level and R is a constant.

This model was also limited in that it only worked for hydrogen and it was not able to explain why the electrons were quantised in this way.

de Broglie came up with an explanation for why the electrons are quantised. He considered that an electron may behave like a wave, based on the fact that light (waves) had been seen to have particle properties. He made the assumption that an integer number of wavelengths must fit in the circumference of an orbit, just like a standing wave. He determined that the wavelength was given by:

$$\lambda = \frac{h}{mv}$$

where h = Planck's constant, m = mass, v = velocity.

This model produced wavelengths consistent with Bohr's model.

It can be seen from these examples that our understanding of the atom has gradually increased based on testing and improving visual and mathematical models.

Answers could include:

- Thomson's discovery of the electron
- Davisson–Germer observations that provided evidence for de Broglie's model
- Contributions of Schrödinger and Heisenberg
- Answer may be supported with diagrams.

End of Question 16

Mod 8 – Question 17 (9 marks)

Our understanding of matter is still incomplete and the Standard Model of matter is still being validated and tested. Technology plays a substantial role in this. **9**

Explain the role of technology in developing both the Standard Model of matter and our understanding in ONE other area of physics.

Mapping grid:

Content	Syllabus outcomes	Bands
Mod 8 Deep Inside the Atom	PH12–5, PH12–6, PH12–7, PH12–15	2–6

Marking guidelines:

Criteria	Marks
• Explains the role of technology in developing the Standard Model of matter and ONE other area of physics	9
• Explains the role of technology in developing the Standard Model of matter and describes its role in ONE other area of physics OR • Describes the role of technology in developing the Standard Model of matter and explains its role in ONE other area of physics	7–8
• Describes the role of technology in developing the Standard Model of matter and/or ONE other area of physics	5–6
• Outlines the role of specific technologies in developing the Standard Model of matter AND/OR • Outlines the role of technology in another area	3–4
• Provides some relevant information	1–2

Answers could include:

- Trying to understand new physics drives innovation and develops new technologies. For example, the Large Hadron Collider (LHC) and the state-of-the-art equipment associated with it were specifically designed and created to answer questions about the Higgs boson in the Standard Model of matter.
- Technology has had an obvious role in testing and validating aspects of the Standard Model. If the LHC could not detect the Higgs boson, the theory of the Standard Model would have to be altered or changed in a significant way.
- Technology has similarly shaped our understanding of special relativity. Einstein made predictions of time dilation and length contraction long before the technology was advanced and precise enough to validate them. Technology such as atomic clocks and high speed aeroplanes made it possible to test and validate Einstein's predictions. This helped elevate special relativity to 'theory status' with evidence to back up its predictions. Special relativity (and general relativity) calculations, have also now been embedded into modern GPS satellites to allow them to function correctly.

Mod 8 – Question 18 (8 marks)

(a) Explain how particle accelerators provide evidence for the Standard Model of matter. **4**

(b) A proton travels along a particle accelerator at 3.1 m s^{-1} less than the speed of light. **4**

Compare its speed and momentum with a proton travelling at 99% the speed of light. Support your answer with calculations.

Mapping grid (a):

Content	Syllabus outcomes	Bands
Mod 8 Deep Inside the Atom	PH12–6, PH12–7, PH12–15	2–5

Marking guidelines (a):

Criteria	Marks
• Explains how particle accelerators provide evidence for the Standard Model	4
• Links the operation of and/or results obtained from a particle accelerator to the Standard Model	3
• Shows some understanding of particle accelerators and/or the Standard Model	2
• Provides some relevant information	1

Sample answer:

Particle accelerators are used to accelerate protons and other charged particles to very high energies. The speeds are so high that their mass increases due to relativistic effects. They then collide with other particles to form new products which are very unstable and are thus not observable under normal conditions, hence the need for accelerators. These new products are then detected and analysed by computers, measuring variables such as energy and mass to determine the structure of matter in terms of fundamental particles and their interactions. These fundamental particles and their interactions form the basis of the Standard Model.

Question 18 continues on page 90

Question 18 (continued)

Mapping grid (b):

Content	Syllabus outcomes	Bands
Mod 7 Light and Special Relativity	PH12–4, PH12–6, PH12–14	3–6

Marking guidelines (b):

Criteria	Marks
• Compares the momentum and speeds of the protons • Correctly calculates the momentum of each proton	4
• Applies correct process to calculate the momentum of the protons • Compares the speeds of the proton	3
• Correctly calculates the momentum of a proton OR • Provides some steps in calculating the momentum of a proton and compares the speeds of the protons	2
• Provides a relevant step in calculating momentum OR • Compares the speeds of the protons	1

Sample answer:

The first proton is travelling at 3×10^8 m s^{-1}. It is almost exactly the speed of light, so it is 1% faster than the second proton.
Relativistic momentum is given by:

$$p_v = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}}$$

For first proton: $p_{v1} = \dfrac{1.673 \times 10^{-27} \times \left(3.00 \times 10^8 - 3.1\right)}{\sqrt{1 - \left(\dfrac{3.00 \times 10^8 - 3.1}{3.00 \times 10^8}\right)^2}} = 3.49 \times 10^{-15}$ kg ms^{-1}

For second proton: $p_{v2} = \dfrac{1.673 \times 10^{-27} \times 0.99\left(3.00 \times 10^8\right)}{\sqrt{1 - 0.99^2}} = 3.52 \times 10^{-18}$ kg ms^{-1}

Comparing the two: $\dfrac{p_{v1}}{p_{v2}} = \dfrac{3.49 \times 10^{-15}}{3.52 \times 10^{-18}} = 991$

$\therefore$ the momentum of the first proton is almost 1000 times greater than the proton travelling at 99% the speed of light even though it is going only 1% faster.

End of sample questions

Physics

DATA SHEET

Charge on electron, q_e	-1.602×10^{-19} C
Mass of electron, m_e	9.109×10^{-31} kg
Mass of neutron, m_n	1.675×10^{-27} kg
Mass of proton, m_p	1.673×10^{-27} kg
Speed of sound in air	340 m s^{-1}
Earth's gravitational acceleration, g	9.8 m s^{-2}
Speed of light, c	$3.00 \times 10^{8} \text{ m s}^{-1}$
Electric permittivity constant, ε_0	$8.854 \times 10^{-12} \text{ A}^2 \text{ s}^4 \text{ kg}^{-1} \text{ m}^{-3}$
Magnetic permeability constant, μ_0	$4\pi \times 10^{-7} \text{ N A}^{-2}$
Universal gravitational constant, G	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Mass of Earth, M_E	6.0×10^{24} kg
Radius of Earth, r_E	6.371×10^{6} m
Planck constant, h	6.626×10^{-34} J s
Rydberg constant, R (hydrogen)	$1.097 \times 10^{7} \text{ m}^{-1}$
Atomic mass unit, u	1.661×10^{-27} kg $931.5 \text{ MeV}/c^2$
1 eV	1.602×10^{-19} J
Density of water, ρ	$1.00 \times 10^{3} \text{ kg m}^{-3}$
Specific heat capacity of water	$4.18 \times 10^{3} \text{ J kg}^{-1} \text{ K}^{-1}$
Wien's displacement constant, b	2.898×10^{-3} m K

FORMULAE SHEET

Motion, forces and gravity

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

$v = u + at$

$\vec{F}_{\text{net}} = m\vec{a}$

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

$W = F_{||}s = Fs\cos\theta$

$\Delta U = mg\Delta h$

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

$P = \frac{\Delta E}{\Delta t}$

$P = F_{||}v = Fv\cos\theta$

$\sum \frac{1}{2}mv^2_{\text{before}} = \sum \frac{1}{2}mv^2_{\text{after}}$

$\sum m\vec{v}_{\text{before}} = \sum m\vec{v}_{\text{after}}$

$\Delta\vec{p} = \vec{F}_{\text{net}}\Delta t$

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

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

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

$\tau = r_{\perp}F = rF\sin\theta$

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

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

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

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

Waves and thermodynamics

$v = f\lambda$

$f_{\text{beat}} = \left| f_2 - f_1 \right|$

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

$f' = f\frac{(v_{\text{wave}} + v_{\text{observer}})}{(v_{\text{wave}} - v_{\text{source}})}$

$d\sin\theta = m\lambda$

$n_1\sin\theta_1 = n_2\sin\theta_2$

$n_x = \frac{c}{v_x}$

$\sin\theta_c = \frac{n_2}{n_1}$

$I = I_{\max}\cos^2\theta$

$I_1r_1^2 = I_2r_2^2$

$Q = mc\Delta T$

$\frac{Q}{t} = \frac{kA\Delta T}{d}$

Electricity and magnetism

$$E = \frac{V}{d}$$

$$V = \frac{\Delta U}{q}$$

$$W = qV$$

$$W = qEd$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B = \frac{\mu_0 N I}{L}$$

$$\Phi = B_{||} A = BA\cos\theta$$

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

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

$$\vec{F} = q\vec{E}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

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

$$V = IR$$

$$P = VI$$

$$F = qv_{\perp}B = qvB\sin\theta$$

$$F = lI_{\perp}B = lIB\sin\theta$$

$$\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$$

$$\tau = nIA_{\perp}B = nIAB\sin\theta$$

$$V_p I_p = V_s I_s$$

Quantum, special relativity and nuclear

$$\lambda = \frac{h}{mv}$$

$$K_{max} = hf - \phi$$

$$\lambda_{max} = \frac{b}{T}$$

$$E = mc^2$$

$$E = hf$$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$t = \frac{t_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

$$l = l_0\sqrt{\left(1 - \frac{v^2}{c^2}\right)}$$

$$p_v = \frac{m_0 v}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

$$N_t = N_0 e^{-\lambda t}$$

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium

Actinoids

89 Ac Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Standard atomic weights are abridged to four significant figures.
Elements with no reported values in the table have no stable nuclides.
Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version).
The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.