Essential Insight Exam Guide

Physics

Year 12 WACE
Western Australian Curriculum

2025 Edition

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Essential Insight Exam Guide
Physics
Year 12 WACE

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Acknowledgements
School Curriculum and Standards Authority. (2019-2023). ATAR Examinations and Marking Keys. The School Curriculum and Standards Authority does not endorse this publication or product.

Contents

Notes	• Some question material has not been released by SCSA due to copyright restrictions and are not able to be included in this exam guide. This has been flagged in the relevant questions in the exam guide. Teachers may still be able to locate many of these sources and provide these to students by following the links at the end of the original SCSA exams on the SCSA website.

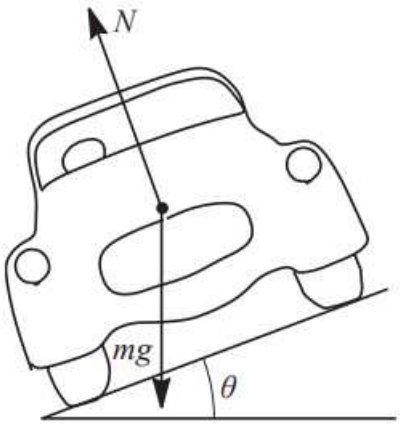
Unit 3 – Gravity and electromagnetism

Unit 3 – Gravity and motion

Section 1

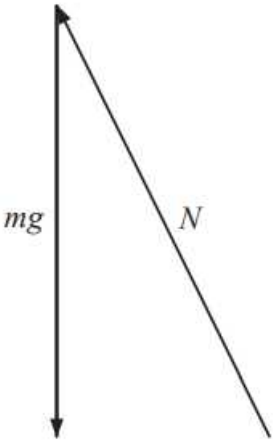
2023 Section 1 Question 2

Gravity and motion

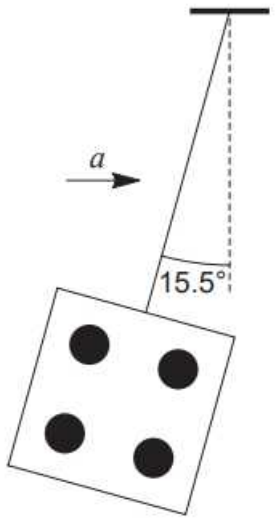


The free body diagram above shows a car going clockwise around a corner on a banked track without relying on friction.

(a) Complete the vector diagram, showing how these two forces result in a centripetal force. Indicate where the angle θ is on your diagram. (2 marks)

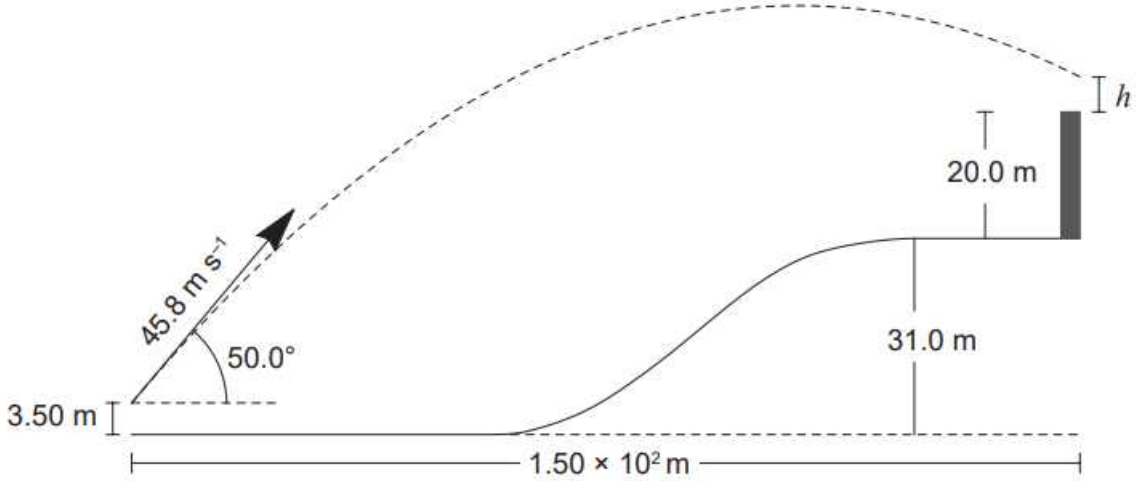


(b) With reference to your diagram in part (a), describe why increasing the angle of the track allows the cars to go around the same radius curve at a greater speed. (2 marks)

2023 **Section 1** **Question 3** **Gravity and motion**	A 370 g single fluffy die on a string is hanging from a baby carriage travelling on a Melbourne tram. The tram accelerates away from the tram stop. At the point of acceleration, the angle between the string and the vertical is 15.5°. Calculate the magnitude of the acceleration of the tram.  Answer: _____ m s^{-2}

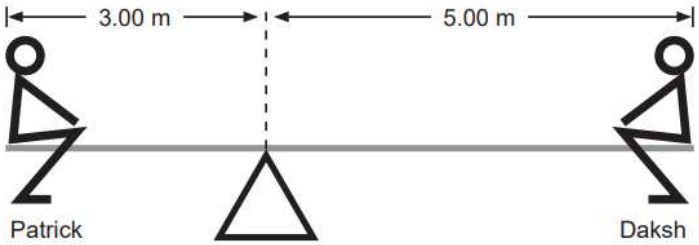
2023 Section 1 Question 5

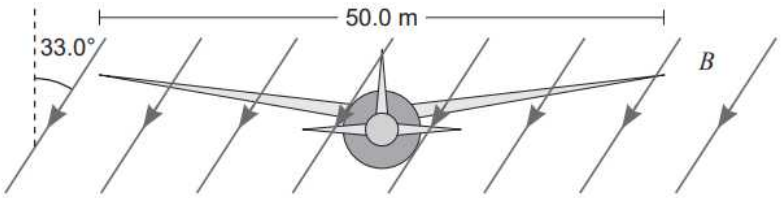
Gravity and motion

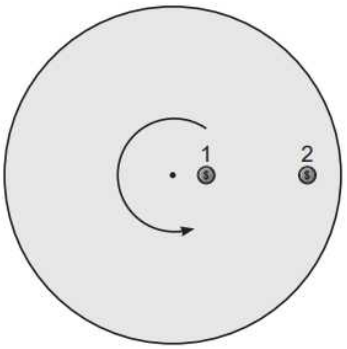


A catapult is 1.50×10^2 m away from a 20.0 m high castle wall on top of a 31.0 m hill. It launches a metal ball at 50.0° to the horizontal 3.50 m above the ground at 45.8 m s^{-1}. Calculate how far above the castle wall the ball passes (*h*). (6 marks)

Answer: _____ m

2022 Section 1 Question 2 **Gravity and motion**	Patrick and Daksh are sitting on a seesaw discussing physics. They decide to place the uniform 15.0 kg beam on the pivot as shown in the diagram below. Daksh estimates that the system is balanced and tells Patrick to lift his feet off the ground. As usual, Daksh is correct and the system is balanced with neither of them touching the ground. Daksh has a mass of 60.0 kg. What is Patrick's mass? (4 marks)  Answer: _____ kg

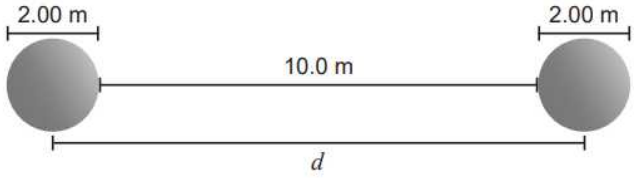
2022 **Section 1** **Question 5** **Gravity and motion**	An aircraft with a wingspan of 50.0 m flies due east parallel to the Earth's surface. The Earth's magnetic field strength at that location is 5.84×10^{-5} T and it makes an angle of 33.0° to the vertical. The aircraft is travelling at 7.20×10^{2} km hr^{-1}.  (a) Using the appropriate component of the magnetic field, calculate the electromotive force (EMF) induced between the ends of the aircraft's wings. (4 marks) Answer: _____ V (b) A wire runs between the ends of the wings, parallel to each wing, so as to set up a complete circuit. A sensitive ammeter is placed in the circuit. If the total resistance of the circuit is 1.78 Ω, what will be the reading on the ammeter? (1 mark) Answer: _____ A

2022 **Section 1** **Question 6** **Gravity and motion**	Two identical 25.0 g coins are placed on a rotating disc, 0.30 m and 1.20 m respectively from the centre of the disc. The disc begins to rotate. When the frequency of rotation reaches 2.00 Hz, the outer coin flies off the disc. Calculate the frequency of rotation when the inner coin flies off. (6 marks)  Answer: _____ Hz

2022 Section 1 Question 8

Gravity and motion

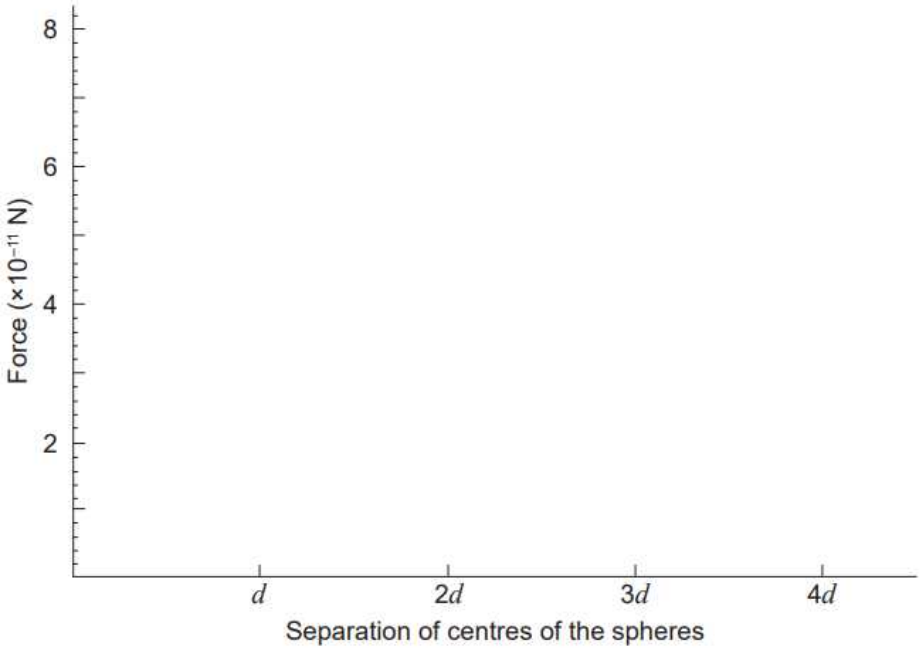
Two identical solid and uniform spheres are separated by a distance of 10.0 m from surface to surface. The distance between their centres is called *d*.



(a) If each sphere has a mass of 12.50 kg and a diameter of 2.00 m, calculate the gravitational force between them. (3 marks)

Answer: _____ N

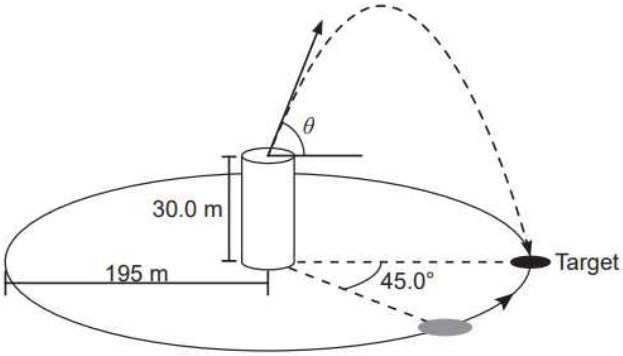
(b) On the axes below, show how the gravitational force between the two spheres varies as they move apart. Indicate the magnitude of the forces on the y-axis at the points 2*d* and 4*d* on the x-axis. If you could not obtain an answer to part (a), use 7.50×10^{-11} N. (4 marks)



2022 Section 1 Question 10

Gravity and motion

In a video game, the players fire arrows from the top of a 30.0 m high castle tower at a flat, 4.00 m wide target moving in a circular path (r = 195 m) around the castle. The player can adjust the vertical angle but the direction of fire is fixed. The launch speed is also fixed at 50.0 m s^{-1}. It takes 32.0 s for the target to complete one revolution of the tower. The shooter fires the arrow when the target has 45.0° of a full revolution to go, as shown in the diagram below.



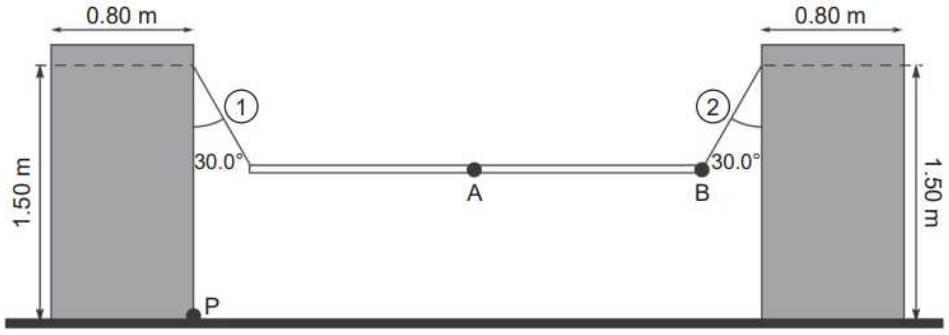
(a) At what angle θ must the shooter fire the arrow above horizontal for it to hit the centre of the target? (4 marks)

Answer: _____ °

(b) With the use of a calculation, confirm that the arrow hits the target. (3 marks)

2022 Section 2 Question 12

Gravity and motion



An ultra-lightweight 2.00 kg aluminium plank is suspended between two 70.0 kg uniform free-standing supports as part of a children's obstacle course. It is attached to the supports by two chains of equal length. Due to safety restrictions, the apparatus has a maximum load of 60.0 kg. A father with a mass of 80.0 kg mistakenly sits on the plank, halfway between the two supports at point A. His mass exceeds the safety limit, so the free-standing supports should tip inward.

(a) Calculate the tension in each chain when the father sits on the plank, assuming the supports do not tip over. (4 marks)

Answer: _____ N

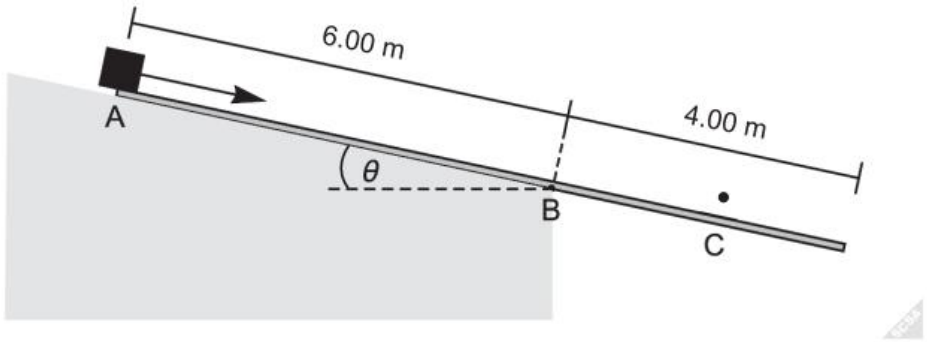
(b) Calculate the horizontal component of the tension in each chain. (1 mark)

Answer: _____ N

(c) With the use of a calculation, confirm that the supports do tip over when the father sits on the plank. Take moments around P. (5 marks)

(d) Without the use of additional calculations, describe how the tension in each chain would be affected if a 50.0 kg person sitting at A moved to B? Select either increases, decreases or remains constant. (2 marks)

Chain 1	Chain 2

2021 **Section 1** **Question 6** **Gravity and motion**	A student is set the task of determining the slope of a concrete structure using only a 15.0 kg beam, a ruler, a 5.00 kg mass with one smooth face and one rough face, and a stopwatch. She places the 10.0 m long uniform beam on top of the sloping structure with 4.00 m of the beam hanging over the end of the structure as shown in the cross-sectional diagram below. The student then places the 5.00 kg mass rough side down at increasing distances from B until the beam starts to tip over. She marks that place as C. The student then lets the 5.00 kg mass slide on its smooth side down the smooth beam from rest at A. She measures the time to reach C as 3.30 s.  (a) Calculate the distance between A and C. (3 marks) Answer _____ m (b) Ignoring friction, calculate the angle of the slope measured from the horizontal. (2 marks) Answer _____ °

2021 Section 1 Question 7 **Gravity and motion**	A bobo doll, as shown below, can never be tipped over. Even if its head is held on the ground, it will stand back up when released. Explain how this works. You must include in your answer the relevant conditions required for static equilibrium. Use the diagram on the right to illustrate your answer. (4 marks) ***Copyright restrictions prohibit the release of this SCSA exam material.***

2021 Section 1 Question 9 **Gravity and motion**	A space station is shaped like a huge hollow doughnut that is rotating uniformly. The outer radius is 4.60×10^2 m. What is the period of rotation of the station if a person standing on the outer wall inside the station experiences the same weight force she would experience on Earth? (5 marks) ***Copyright restrictions prohibit the release of this SCSA exam material.*** Answer _____ s

2021 Section 2 Question 15

Gravity and motion

A 42.5 kg gymnast performs her dismount from the 1.25 m high beam. She leaves the beam with a velocity of 3.10 m s^{-1} at an angle of 55.0° to the horizontal.

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(a) Calculate the vertical and horizontal components of her launch velocity. (2 marks)

Answer v_V _____ m s^{-1} Answer v_H _____ m s^{-1}

(b) Calculate the time it takes for her to reach the ground, assuming she is vertical at impact. (5 marks)

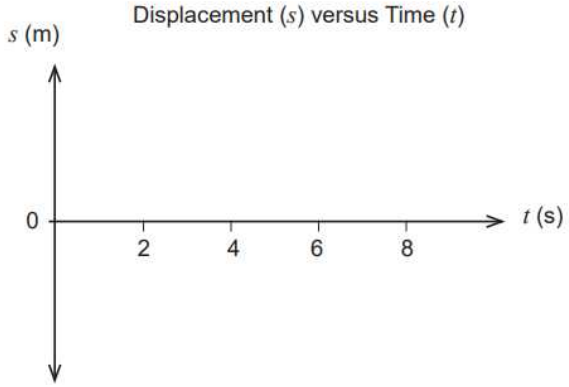
Answer _____ s

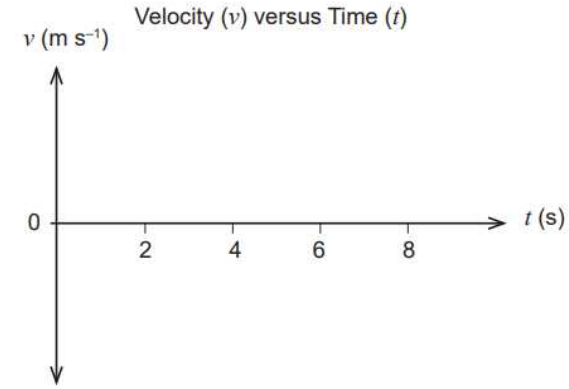
(c) Calculate her range R. (2 marks)

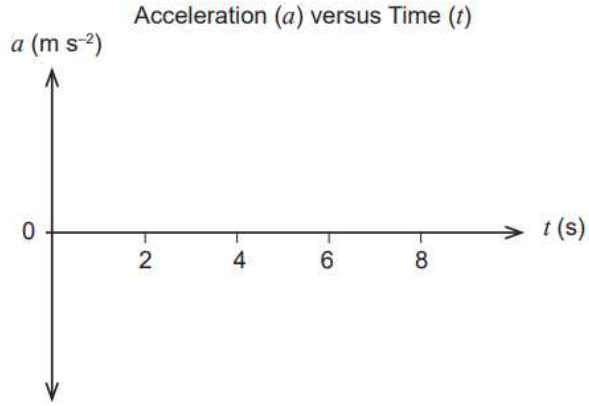
Answer _____ s

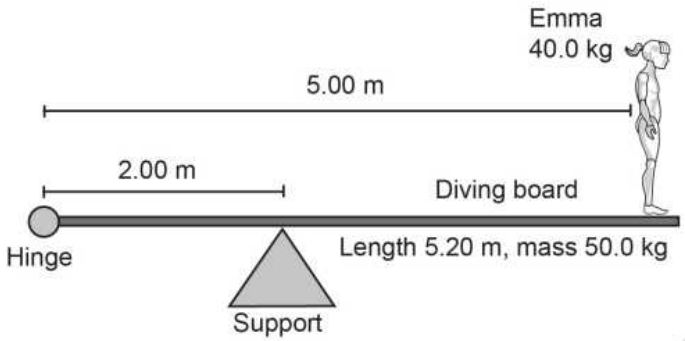
	(d) Calculate the gymnast's kinetic energy at the top of her flight. (2 marks) Answer _____ J

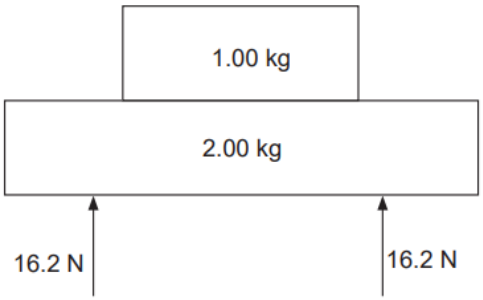
2020 Section 1 Question 1 **Gravity and motion**	A ball is launched vertically into the air with an initial velocity at $t = 0$ from ground level ($s = 0$) and returns to ground level. It takes four seconds for it to reach its maximum height. Taking upwards as positive, graph the ball's displacement, velocity and acceleration versus time from take-off to landing. Ignore air resistance and do not place any values on the y-axis.







2020 Section 1 Question 5 **Gravity and motion**	Emma stands 20.0 cm from the end of a 5.20 m long uniform diving board. Calculate the upwards force the support must exert on the 50.0 kg board for the system to remain in equilibrium. (4 marks)  _____ N
2020 Section 1 Question 10 **Gravity and motion**	A golfer hits a ball at 37.0 m s^{-1} at 31.0° to the horizontal on a flat fairway. It travels 123 m. She wants to hit a target 135 m away, so she increases the angle at which she hits the ball, without changing the launch speed. Calculate the smallest increase of angle that allows her to reach the target. (Hint: $2\sin\theta\cos\theta = \sin 2\theta$) _____ °

2020 Section 1 Question 11 **Gravity and motion**	Jake is lifting two books of mass 1.00 kg and 2.00 kg respectively. The lighter book sits on top of the heavier book, and each of Jake's hands exerts a vertical force of 16.2 N on the lower book, as shown in the diagram.  (a) What is the magnitude of the acceleration of the books? (3 marks) _____ m s^{-2} (b) What is the magnitude of the force that the 2.00 kg book exerts on the 1.00 kg book during this acceleration? (3 marks) _____ N

2019 Section 1 Question 4

Gravity and motion

Titan is the largest of Saturn's moons. Its orbital radius is 1.22×10^6 km. Use the Formulae and Data booklet and the data in the table below to determine the strength of Saturn's gravitational field where Titan orbits. Give your answer in N kg^{-1} and m s^{-2}.

Planet	Mass (Earth masses)
Mercury	0.055
Venus	0.815
Earth	1.000
Mars	0.107
Jupiter	318
Saturn	95
Uranus	14.5
Neptune	17.2
Pluto	0.002

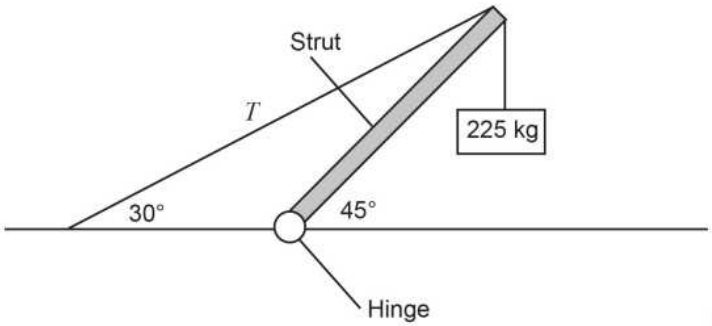
_____ N kg^{-1}

_____ m s^{-2}

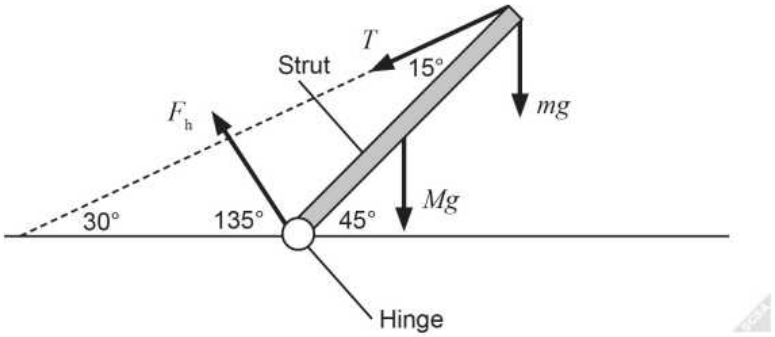
2019 Section 1 Question 6

Gravity and motion

The diagram below shows a system in equilibrium.

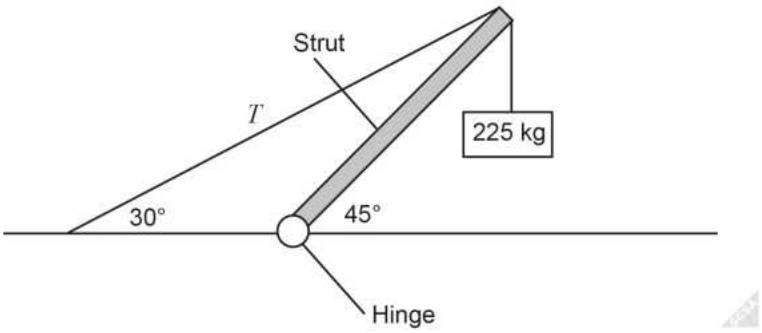


A student drew a diagram of the forces acting on the strut. That diagram is shown below. It is not drawn to scale.



(a) With specific reference to the conditions required for equilibrium, explain why the diagram of the forces is incorrect. (2 marks)

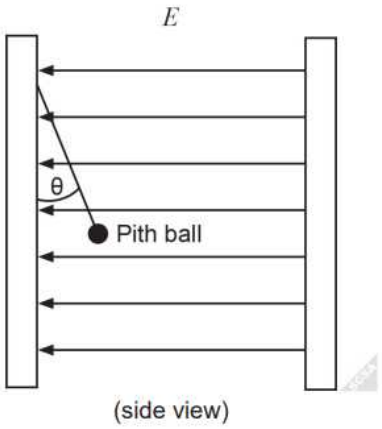
(b) Using the diagram below, show what change(s) should be made to correct it. (Calculations are not required.) (2 marks)



2019 Section 1 Question 7

Gravity and motion

A pith ball is a very small, lightweight object that readily picks up electric charge. A pith ball with a mass of 75.0×10^{-6} kg is suspended by a string attached to a charged plate. The pith ball has an excess of 2.00×10^{12} electrons on it and the electric field strength between the charged plates is 95.0 N C^{-1}.



(side view)

(a) In the space below, draw a vector diagram of the forces acting on the pith ball. (3 marks)

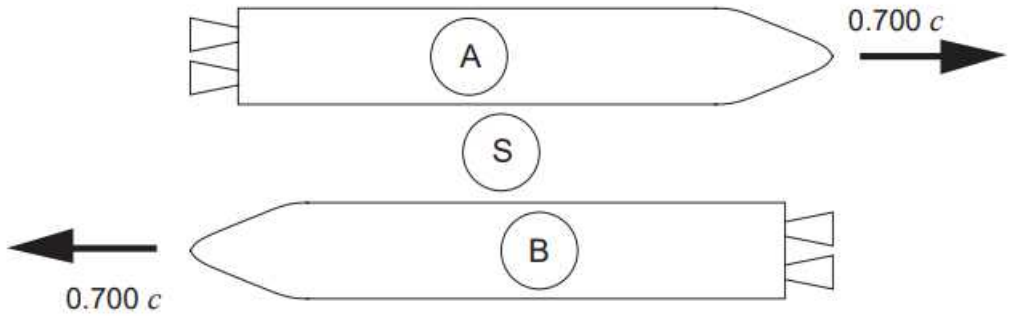
(b) Calculate the angle between the string and the charged plate. (5 marks)

_____ °

2019 Section 1 Question 8 **Gravity and motion**	A cyclist is travelling at 6.0 m s^{-1} over a hump in the road that is part of a circle of radius 4.80 m. Calculate the magnitude of the total reaction force of the ground on the cyclist at the top of the hump. The total mass of the cyclist and bicycle is 72 kg. (Note: diagram not to scale, ignore friction.) ***Copyright restrictions prohibit the release of this SCSA exam material.*** _____ N

2023 Section 2 Question 14

Gravity and motion



Two 5.00×10^2 m long identical spaceships, 'A' and 'B', pass by an observer S while moving in opposite directions. The observer S measures the velocity of spaceship A as 0.700 c and spaceship B as –0.700 c.

(a) (i) Calculate the velocity of A (in m s^{-1}) as measured by B. (4 marks)

Answer: _____ m s^{-1}

(ii) Explain why the magnitude of the velocity of B as measured by A would be the same as your answer for part (a)(i), only in the opposite direction. (3 marks)

(b) Calculate the duration of one second on A as measured by the observer S. (3 marks)

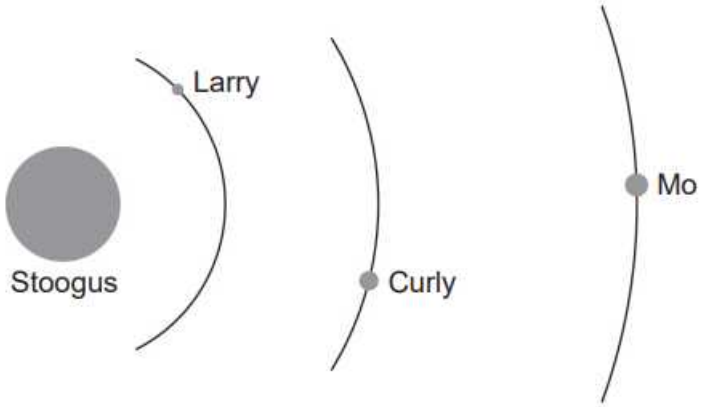
Answer: _____ s

(c) Calculate the length of B as measured by A. If you could not obtain an answer to part (a)(i), use 0.870 *c*. (3 marks)

Answer: _____ m

2023 Section 2 Question 15

Gravity and motion



A recently discovered planet (Stoogus) in a distant solar system has three moons (Larry, Curly and Mo) orbiting at different distances. Stoogus has a mass of 2.37×10^{24} kg and a day on Stoogus lasts 7.50 Earth hours. Assume all three moons have circular orbits as their masses are insignificant compared to that of Stoogus.

(a) Curly is a geosynchronous satellite that orbits above one specific spot on Stoogus' surface. Calculate the radius of Curly's orbit. (5 marks)

Answer: _____ m

(b) The gravitational field strength that Mo experiences due to Stoogus is 4.50×10^{-3} m s^{-2}. Calculate the distance between the centre of mass of Mo and the centre of mass of Stoogus. (4 marks)

Answer: _____ m

(c) (i) Derive the mathematical relationship between a moon's orbital speed *v* and its distance r from the planet's centre of mass. (3 marks)

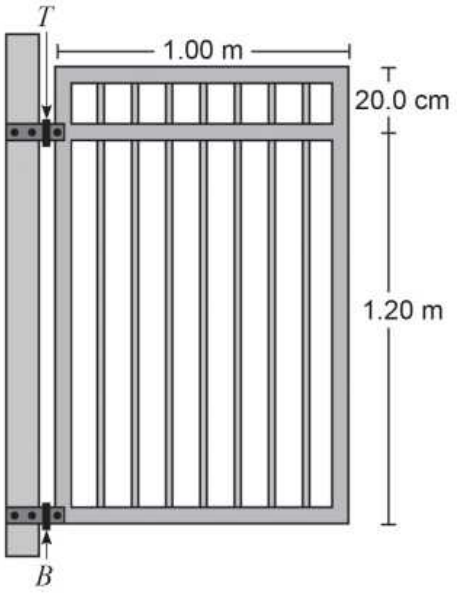
Answer: _____

(ii) Use this relationship from part (c)(i) to identify which moon of Stoogus has the greatest orbiting speed. Justify your answer. (2 marks)

2023 Section 2 Question 17

Gravity and motion

A uniform garden gate is attached to its support by two hinges (T and B). The top hinge (T) is fixed 20.0 cm below the top of the gate and the bottom hinge is fixed to the bottom of the gate. The gate has a mass of 25.7 kg. It is 1.00 m wide and 1.40 m tall.



Note: The top hinge takes all of the vertical weight force of the gate. The bottom hinge keeps the gate lined up correctly.

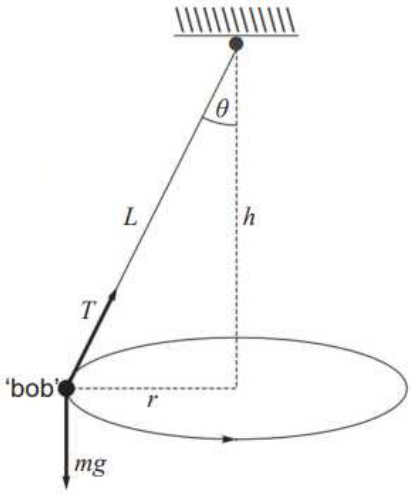
(a) By taking moments around B, calculate the horizontal component of the reaction force of T on the gate. Include a direction in your answer. (5 marks)

Answer: _____ N Direction: _____

(b) Calculate the overall reaction force of T on the gate. Include an angle to the horizontal in your answer. If you could not obtain an answer to part (a), use 1.40×10^2 N. (5 marks)

Answer: _____ N at _____ ° to the horizontal

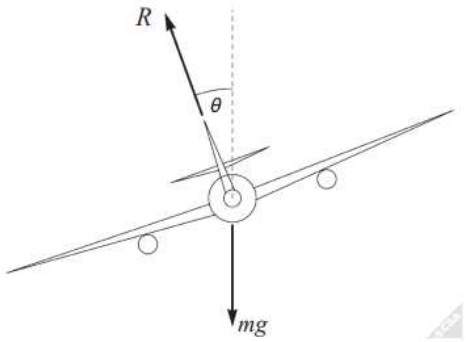
	(c) Discuss how the angle in part (b) would be affected if the top hinge was fixed at the top of the gate. Include a mathematical expression in your answer. (4 marks)

2022 Section 2 Question 17 **Gravity and motion**	The diagram to the right shows the two forces acting on a conical pendulum as it spins at a set frequency. The vector addition of these two forces provides the centripetal force on the 'bob'. The mass of the 'bob' is 255 g and the length of the pendulum string *L* is 1.20 m. When the frequency of rotation is 0.490 Hz, the angle $\theta = 30.0°$.  (a) Calculate the tension in the string when θ = 30.0°. (4 marks) Answer: _____ N (b) Calculate the radius of the circular path the 'bob' is moving in when the angle is 30.0°. (2 marks) Answer: _____ m

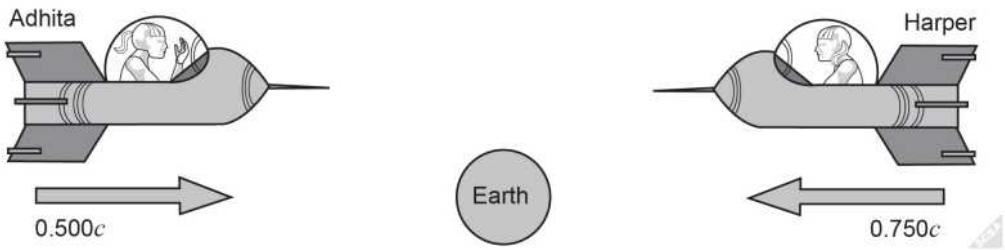
(c) Calculate the new angle between the pendulum string and the vertical if the frequency of rotation is doubled. (6 marks)

Answer: _____ °

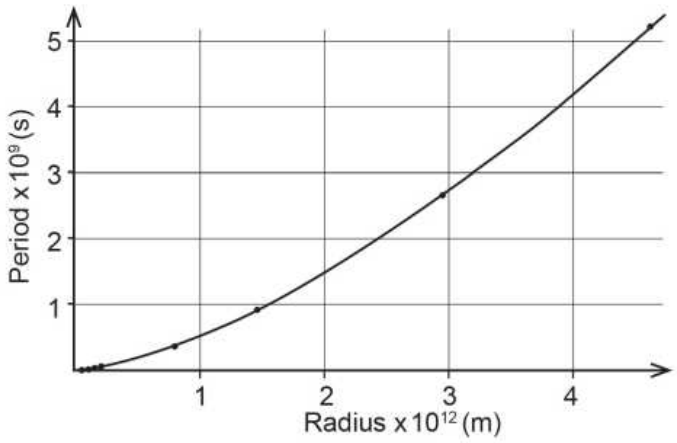
(d) Explain why θ can never equal 90.0°, regardless of how great the frequency of the pendulum becomes. You may use mathematical relationships in your answer. (4 marks)

2021 Section 2 Question 17 **Gravity and motion**	Aeroplanes are designed to produce an upthrust that counters their weight force. This allows them to maintain altitude. The magnitude of this upthrust (R) is directly proportional to the forward speed of the aircraft. It always acts perpendicular to the wings. When changing direction, the aeroplane banks in a circular path. A free body diagram of a banking aeroplane is shown below.  (a) Draw a vector diagram showing how the weight force and the upthrust produce a resultant centripetal force. Label the resultant force and include the angle Θ shown in the free body diagram. (3 marks) (b) Calculate the centripetal force on a 5.60 × 103 kg aeroplane banking at an angle of 15.0° to the vertical while maintaining constant altitude. (3 marks) Answer _____ N (c) If the aeroplane is travelling at 4.50×10^2 km h–1, calculate the radius of the circular path it takes when banking while maintaining constant altitude. (3 marks) Answer _____ m

	(d) With reference to your vector diagram in part (a) and the text, explain why aeroplanes need to increase their speed to maintain altitude when banking. (4 marks)

2020 Section 2 Question 15 **Gravity and motion**	Two spaceships, captained by Adhita and Harper, are travelling toward each other. They are observed by a person on the Earth to be travelling at the velocities shown in the diagram. Take all velocities to the left as positive.  (a) Calculate the velocity of Harper as measured by Adhita. (4 marks) _____ c (b) Harper fires a missile with a velocity of 0.600c with respect to her in the direction of Adhita. Calculate the velocity of the missile as measured by an observer on the Earth. (4 marks) _____ c

	(c) Calculate the velocity of the missile as measured by Adhita. (4 marks) _____ c
2020 Section 2 Question 17 **Gravity and motion**	A satellite is orbiting the Earth 4.00 x 10^3 km above its surface. (a) Calculate the period of the satellite. (5 marks) _____ hours



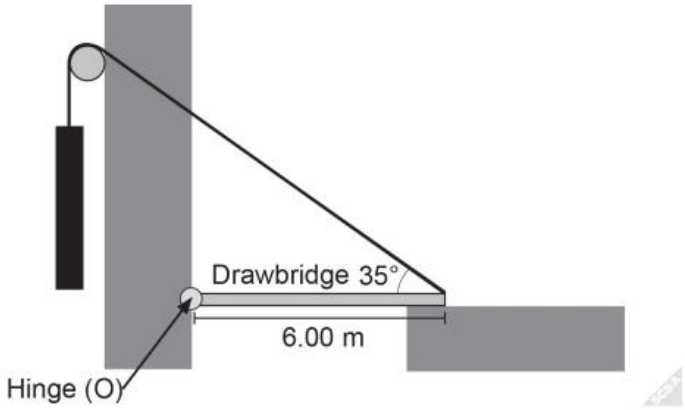
The graph shows the relationship between the period (T) and the orbiting radius (r) of all the planets in our solar system.

(b) (i) With reference to Kepler's Third Law, describe how a straight line graph could be generated using the same two variables. (Do not refer to logarithms.) (2 marks)

(ii) Explain how you could use the gradient of this straight line and Kepler's Third Law to estimate the magnitude of the Newtonian constant of gravitation (G). (Do not try to calculate G from the graph.) (3 marks)

2020 Section 2 Question 18

Gravity and motion



A castle has a 6.00 m long drawbridge with a mass of 500 kg over its moat. It is attached to a winch by an extremely strong rope at an angle 35.0° to the horizontal.

(a) Calculate the tension in the rope when the drawbridge is just lifted off the rest on the other side of the moat. (4 marks)

_____ N

(b) Calculate the reaction force of the hinge (O) on the drawbridge at this point. (5 marks)

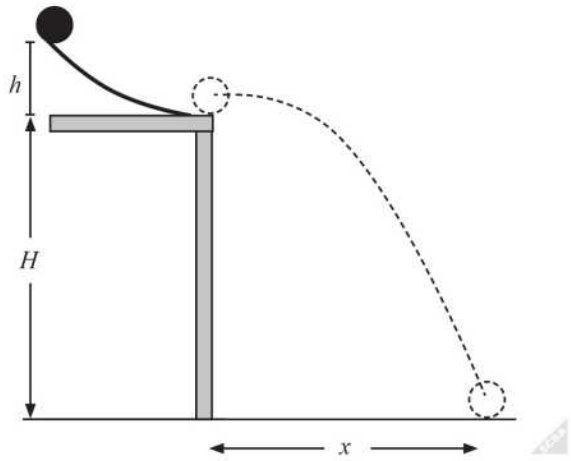
_____ N at _____° to the horizontal.

	The castle comes under attack. The people inside the castle begin to raise the drawbridge. When it is at an angle of 15.0° above horizontal, the angle between the drawbridge and the rope is 40.0°. At this moment, a 95.0 kg soldier being chased by the enemy jumps onto the very end of the drawbridge. (c) Calculate the new tension in the rope as he hangs from the end. Assume the drawbridge is stationary at this time. (5 marks) _____ N

2019 Section 2 Question 12

Gravity and motion

A ball is rolled from rest down a curved slope, across a flat, smooth table leaving the table horizontally and falling to the floor.



If h = 30.0 cm and H = 1.20 m

(a) Using conservation of energy, calculate the speed with which the ball leaves the table. Assume no energy is lost to friction, air resistance or is transferred to rotational energy. (2 marks)

_____ m s^{-1}

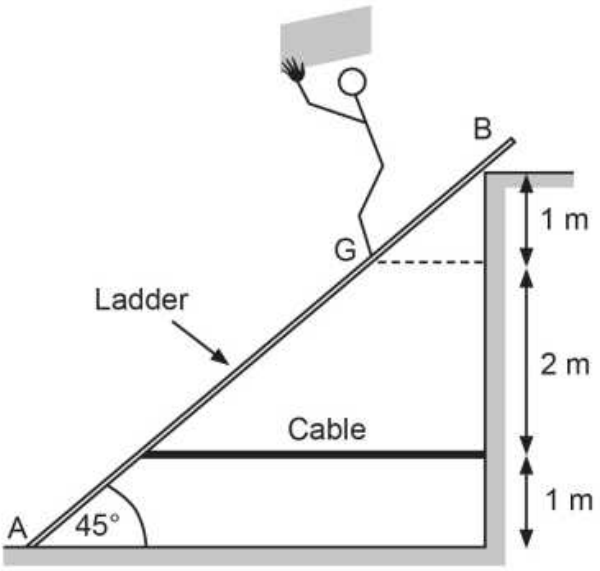
(b) Calculate the distance x. (4 marks)

_____ m

(c) Calculate the velocity of the ball when it hits the floor. (5 marks)

_____ m s^{-1} Angle: _____ ° above horizontal

	(d) Derive an expression for x in terms of h and H only. (Note: may include numbers.) (4 marks)

2019 Section 2 Question 13 **Gravity and motion**	Workers at an ice skating venue use a ladder to fix a sign 5.0 m above the surface of the ice. To prevent the 6.00 m long ladder from slipping on the ice, they tie a cable between the ladder and the 4.00 m high wall. The cable is at right angles to the wall. The uniform 15.0 kg ladder is placed at an angle of 45° between the frictionless surfaces at A and B. A 90.0 kg worker is standing still on the ladder at G.  (a) On the diagram above, draw and label the forces acting on the ladder. Assume the reaction force at B acts at right angles to the ladder. (4 marks)

(b) By taking moments around A, calculate the tension in the cable. (6 marks)

_____ N

2019 Section 2 Question 16

Gravity and motion

A ball is being swung around in a vertical circle on a string.

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(a) In the table below, match the statements with A, B, C and/or D. (4 marks)

Statement	A, B, C and/or D
point(s) where the centripetal acceleration is the greatest	
point(s) where the tension in the string is the lowest	
point(s) where the net force is not toward the centre of the circle	
point(s) where the ball's weight force is perpendicular to the tension	

(b) Write an expression for the net force acting on the string at point C in terms of the weight force and the tension in the string. (1 mark)

_____

(c) Calculate how fast the 500 g ball can be moving at point A for the 1.20 m long string not to break, if the maximum tension it can withstand at point A is 172 N. (4 marks)

_____ $m\ s^{-1}$

	(d) Calculate the maximum speed at which the ball can be moving at point C for the string not to break at point A. (3 marks) _____ $m\ s^{-1}$

2022 Section 3 Question 19

Gravity and motion

Kepler's three laws of planetary motion can be stated as follows:

1. All planets move about the Sun in elliptical orbits, having the Sun as one of the foci.
2. A radius vector joining any planet to the Sun sweeps out equal areas in equal lengths of time.
3. The squares of the periods (of revolution) of the planets are directly proportional to the cubes of their mean distances from the Sun.

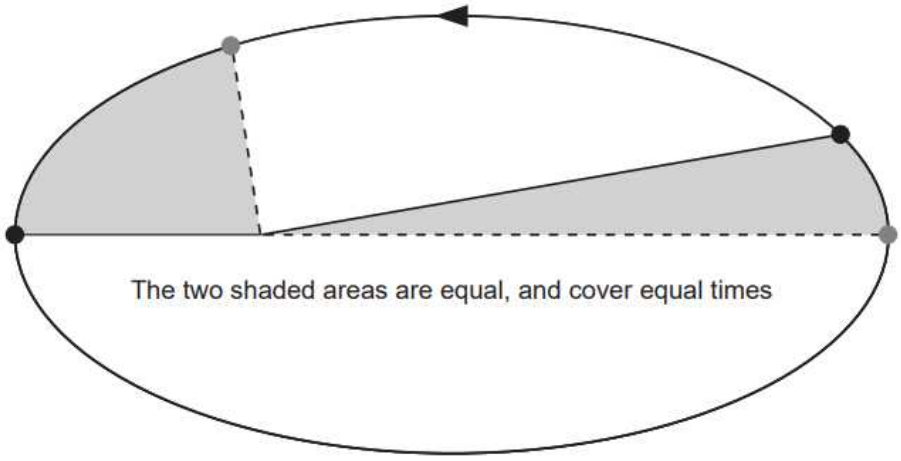

Figure 1: Kepler's 2nd Law

Kepler's 3rd Law, which appears on the Formulae and Data booklet, can be derived for a circular orbit from first principles: the centripetal force between the planet and the Sun is provided by Newton's Law of Gravitation, and $S = vT$, where S is the orbiting circumference and T is the period.

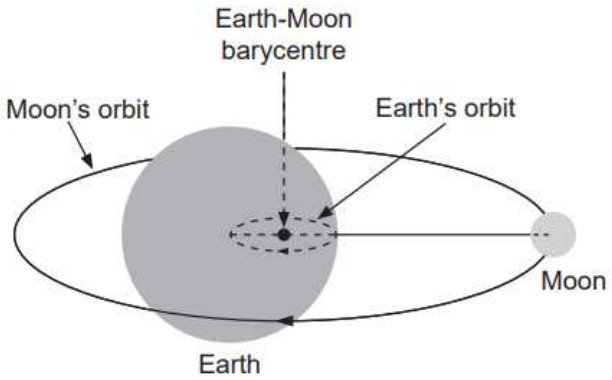

Figure 2: Location of Earth-Moon barycentre

The system of any large celestial body, and its satellite, orbits around a 'barycentre'. This represents the centre of mass of the system. The barycentre of the Earth–Moon system is shown in Figure 2. The system could be seen as a balance beam, with the barycentre located where the fulcrum would be placed to achieve equilibrium. The gravitational field strength due to the Sun is identical for both the Earth and Moon and therefore cancels out when calculating moments around the barycentre.

When the mass of the satellite represents a significant percentage of the system, the barycentre is outside either body. When its mass is significantly less, the barycentre is usually found within the more massive body which appears to 'wobble'. When the mass of the orbiting satellite is insignificant compared to the mass of the body it is orbiting, the barycentre can be assumed to be the centre of mass of the larger body.

(a) (i) Using Kepler's 2nd Law, describe the relationship between the distance a planet is from the Sun it orbits and its orbiting speed by filling in the blank below. (1 mark)

As the distance from the planet increases, the orbiting speed _____.

(ii) Without completing a calculation, justify this relationship with reference to Figure 1. (3 marks)

(b) Using the instructions given in the article, derive Kepler's 3rd Law from first principles, showing each step of the derivation. The final expression must match the equation in the Formulae and Data booklet. Assume the orbit is perfectly circular and the mass of the satellite is insignificant compared to the mass of the body it is orbiting. (5 marks)

(c) Using moments, estimate how far the barycentre of the Earth–Moon system is from the centre of the Earth. (4 marks)

Answer: _____ m

(d) With the use of a calculation and your answer to part (c), show that the Moon is travelling roughly 81 times faster than Earth as they orbit the barycentre. If you could not get an answer to part (c), use 4.81×10^6 m and show that the ratio of the Moon's orbiting velocity to that of the Earth is roughly 80. (4 marks)

2020 Section 3 Question 21

Gravity and motion

Wind turbines

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How do wind turbines work?

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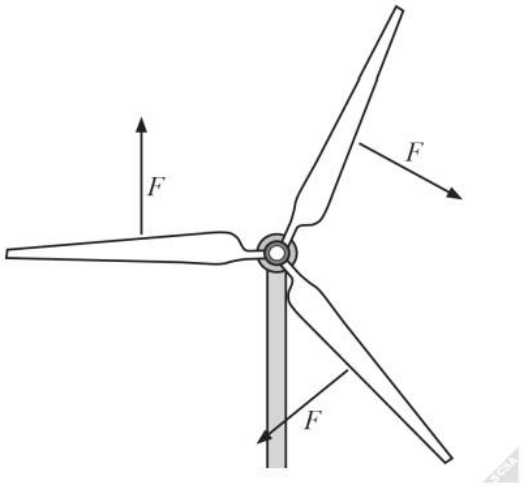

Wind turbine blades vary in length between 40 and 80 m.

A major problem with wind turbines is varying wind speed. The input power must match the output power. The output power depends entirely on rotational speed and torque so how do we keep rotational frequency constant when wind speed keeps changing? The solution is mechanical. The operators use blade pitch control which changes the angle of the blades and reduces the surface area facing the wind. This reduces the amount of energy collected by the turbine and controls the force applied to each blade.

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How the pitch is altered to control the rotational speed.

Each blade experiences a gravitational torque. If the clockwise and anticlockwise gravitational torques add up to zero, the turbine is considered balanced. A symmetrical three-blade turbine is considered balanced at all times.

(a) (i) Explain why a step-up transformer is used to increase the voltage before transporting the electricity into the National Grid. Use specific equations in your answer. (4 marks)

(ii) Calculate the output voltage of the transformer if the turbine produces 690 V and the ratio of turns is 100 in the primary coil to 2500 in the secondary coil. (2 marks)

_____ kV

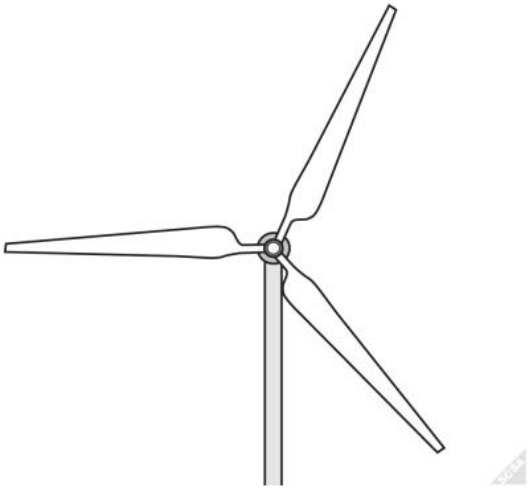
(b) With specific reference to the text, explain why the pitch of the rotor blades is changed by the operators of the turbine. (4 marks)

(c) If the 60 m long blades on an average-sized turbine are rotating at 0.20 Hz, estimate the speed of the centre of mass of one of the blades. (4 marks)

_____ m s^{-1}

Consider the three-blade turbine in the diagram to be rotating clockwise. The blade on the left hand side is parallel to the ground. The blades are identical in size and mass.

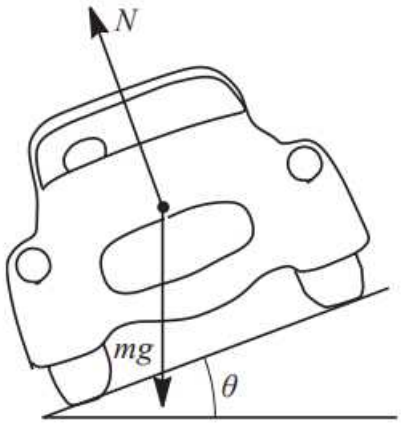
(d) (i) Draw the weight forces acting on the blades. (2 marks)



(ii) Show mathematically that the turbine is balanced in this position. (4 marks)

2023 Section 1 Question 2

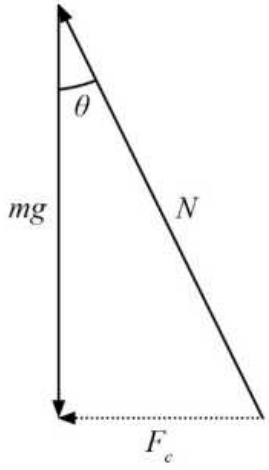
Gravity and motion



The free body diagram above shows a car going clockwise around a corner on a banked track without relying on friction.

(a) Complete the vector diagram, showing how these two forces result in a centripetal force. Indicate where the angle θ is on your diagram. (2 marks)

Description	Marks
θ is in correct position	1
net force is horizontal and labelled F_c	1
Total	**2**



(b) With reference to your diagram in part (a), describe why increasing the angle of the track allows the cars to go around the same radius curve at a greater speed. (2 marks)

Description	Marks
as θ increases and mg remains constant, F_c increases	1
$F_c = mv^2/r$. If m and r remain constant, then for F_c to increase v must increase	1
Total	**2**

2023 Section 1 Question 3

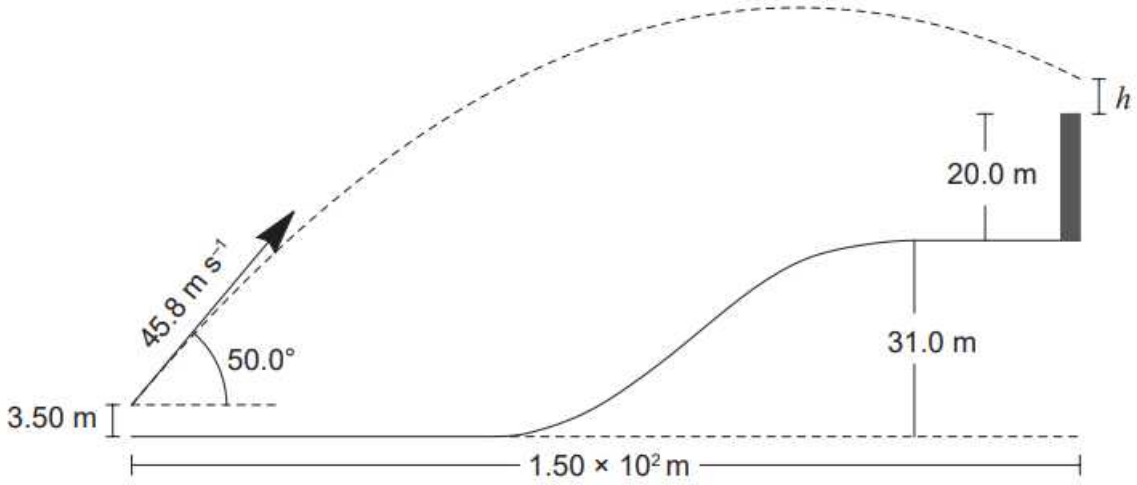
Gravity and motion

A 370 g single fluffy die on a string is hanging from a baby carriage travelling on a Melbourne tram. The tram accelerates away from the tram stop. At the point of acceleration, the angle between the string and the vertical is 15.5°. Calculate the magnitude of the acceleration of the tram.

Element	Description	Marks
Realises net force is vector addition of tension and weight		1
Uses tan θ	$\tan\theta = \frac{ma}{mg}$	1
Rearranges for a	a = tan 15.5° × 9.80	1
Calculates answer	a = 2.72 m s^{-2}	1
	Total	**4**

2023 Section 1 Question 5

Gravity and motion



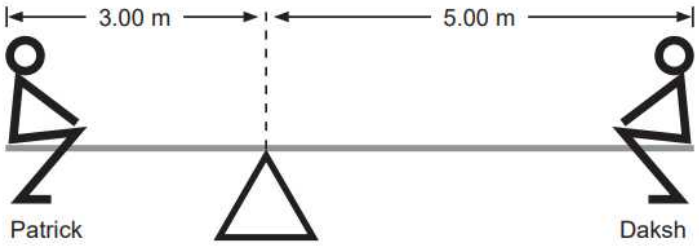
A catapult is 1.50 × 10^2 m away from a 20.0 m high castle wall on top of a 31.0 m hill. It launches a metal ball at 50.0° to the horizontal 3.50 m above the ground at 45.8 m s^{-1}. Calculate how far above the castle wall the ball passes (h). (6 marks)

Element	Description	Marks
Calculates horizontal component of velocity	v_H = 45.8 × cos 50.0° = 29.4 m s^{-1}	1
Calculates vertical component of velocity	v_V = 45.8 × sin 50.0° = 35.1 m s^{-1}	1
Calculates t from horizontal	$t = \frac{1.50\times10^2}{29.4} = 5.10$ s	1
Substitutes correct values for vertical displacement after t	s_V = (35.1 × 5.10) – (4.90 × (5.10)^2) + 3.50	1
Calculates vertical displacement	s_V = 179.01 – 127.5 + 3.50 = 55.06 m	1
Calculates clearance	55.06 – 51.0 = 4.06 m	1
	Total	**6**

2022 Section 1 Question 2

Gravity and motion

Patrick and Daksh are sitting on a seesaw discussing physics. They decide to place the uniform 15.0 kg beam on the pivot as shown in the diagram below. Daksh estimates that the system is balanced and tells Patrick to lift his feet off the ground. As usual, Daksh is correct and the system is balanced with neither of them touching the ground. Daksh has a mass of 60.0 kg. What is Patrick's mass? (4 marks)

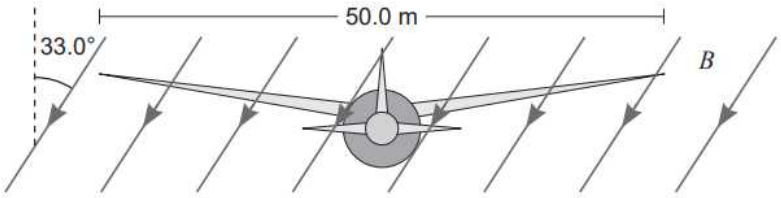


Element	Description	Marks
Takes moments around the pivot	$\Sigma cm = \Sigma acm$	1
Includes mass of beam		1
Uses correct distances from pivot	$m_p g \times 3.00 = (m_b g \times 1.00) + (m_d g \times 5.00)$	1
Calculates the correct answer	$m_p = 105$ kg	1
	Total	**4**
Note: If mass of beam is not included, award maximum 2 marks.		

2022 Section 1 Question 5

Gravity and motion

An aircraft with a wingspan of 50.0 m flies due east parallel to the Earth's surface. The Earth's magnetic field strength at that location is 5.84×10^{-5} T and it makes an angle of 33.0° to the vertical. The aircraft is travelling at 7.20×10^2 km hr^{-1}.



(a) Using the appropriate component of the magnetic field, calculate the electromotive force (EMF) induced between the ends of the aircraft's wings. (4 marks)

Element	Description	Marks
Converts km hr^{-1} to m s^{-1}	$7.20 \times 10^2 \div 3.6 = 2.00 \times 10^2$ m s^{-1}	1
Calculates vertical component of B	$B \cos 33.0° = 4.90 \times 10^{-5}$ T	1
Substitutes values into correct equation, using calculated component	EMF $= 4.90 \times 10^{-5} \times 2.00 \times 10^2 \times 50.0$	1
Calculates correct answer	EMF = 0.490 V	1
	Total	**4**

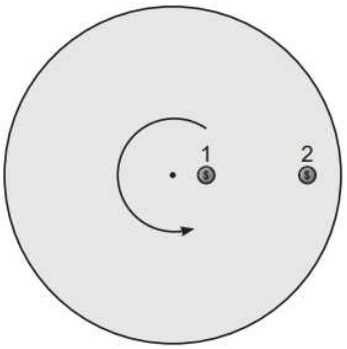
(b) A wire runs between the ends of the wings, parallel to each wing, so as to set up a complete circuit. A sensitive ammeter is placed in the circuit. If the total resistance of the circuit is 1.78 Ω, what will be the reading on the ammeter? (1 mark)

Description	Marks
0.00 A	1
Total	**1**

2022 Section 1 Question 6

Gravity and motion

Two identical 25.0 g coins are placed on a rotating disc, 0.30 m and 1.20 m respectively from the centre of the disc. The disc begins to rotate. When the frequency of rotation reaches 2.00 Hz, the outer coin flies off the disc. Calculate the frequency of rotation when the inner coin flies off. (6 marks)

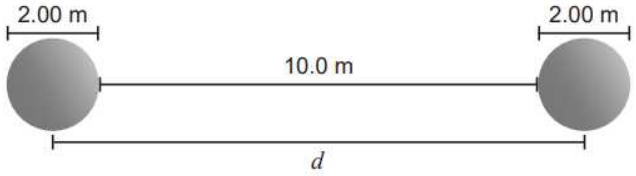


Element	Description	Marks
Realises the centripetal force is supplied by the frictional force	$m_1v_1^2/0.30 = m_2v_2^2/1.20$	1
Cancels m and obtains ratio of velocities.	$v_2^2/v_1^2 = 4$ $v_2/v_1 = 2$ or $v_2 = 2v_1$	1
Substitutes $2\pi r/T$ for v		1
Uses 0.500 s for T_2	$1.20/0.500 = 2 \times 0.30/T_1$	1
Calculates T_1	$T_1 = 0.250$ s	1
Calculates frequency of rotation	$f = 1/T_1 = 4.00$ Hz	1
	Total	**6**

2022 Section 1 Question 8

Gravity and motion

Two identical solid and uniform spheres are separated by a distance of 10.0 m from surface to surface. The distance between their centres is called *d*.

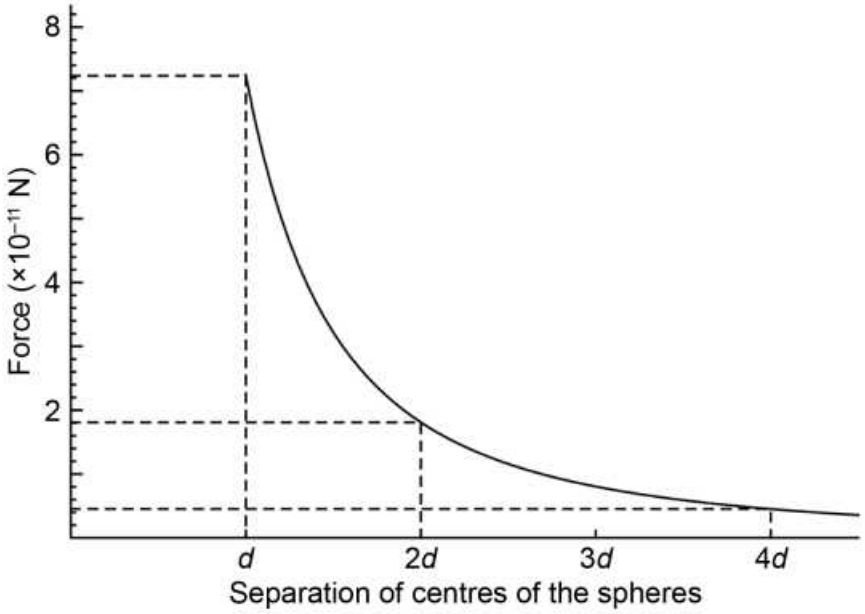


(a) If each sphere has a mass of 12.50 kg and a diameter of 2.00 m, calculate the gravitational force between them. (3 marks)

Element	Description	Marks
Uses 12.0 m as d		1
Uses gravitational force formula correctly	$F = 12.50 \times 12.50 \times 6.67 \times 10^{-11}/144.0$	1
Calculates correct answer	7.24×10^{-11} N	1
	Total	**3**

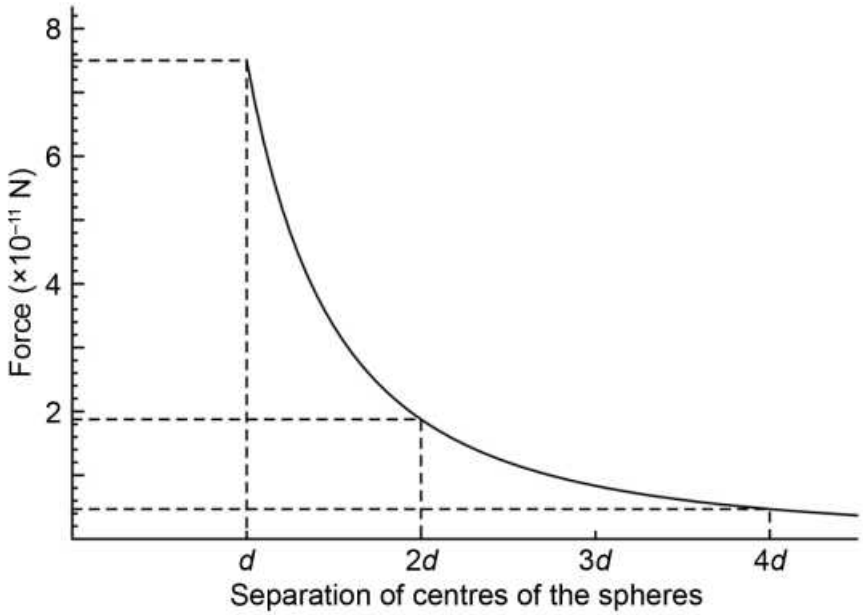
(b) On the axes below, show how the gravitational force between the two spheres varies as they move apart. Indicate the magnitude of the forces on the y-axis at the points 2*d* and 4*d* on the x-axis. If you could not obtain an answer to part (a), use 7.50×10^{-11} N. (4 marks)

Description	Marks
three points plotted	1
indicates on y-axis, or shows by calculation, correct values	1
accurately plotted	1
curve accurately drawn indicating relationship	1
Total	**4**



$F(d) = 7.24 \times 10^{-11}$ N, $F(2d) = 1.81 \times 10^{-11}$ N, $F(4d) = 0.45 \times 10^{-11}$ N

If used $F(d) = 7.50 \times 10^{-11}$ N:

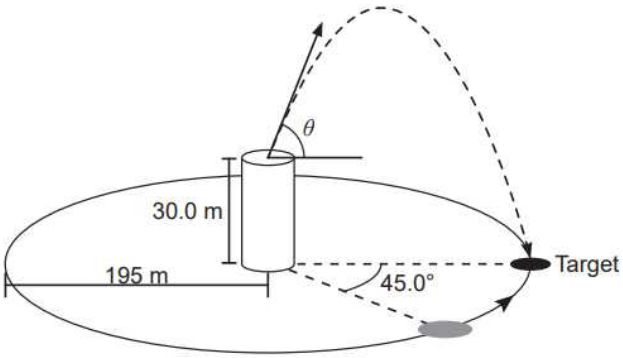


$F(d) = 7.50 \times 10^{-11}$ N, $F(2d) = 1.88 \times 10^{-11}$ N, $F(4d) = 0.47 \times 10^{-11}$ N

2022 Section 1 Question 10

Gravity and motion

In a video game, the players fire arrows from the top of a 30.0 m high castle tower at a flat, 4.00 m wide target moving in a circular path (r = 195 m) around the castle. The player can adjust the vertical angle but the direction of fire is fixed. The launch speed is also fixed at 50.0 m s^{-1}. It takes 32.0 s for the target to complete one revolution of the tower. The shooter fires the arrow when the target has 45.0° of a full revolution to go, as shown in the diagram below.



(a) At what angle θ must the shooter fire the arrow above horizontal for it to hit the centre of the target? (4 marks)

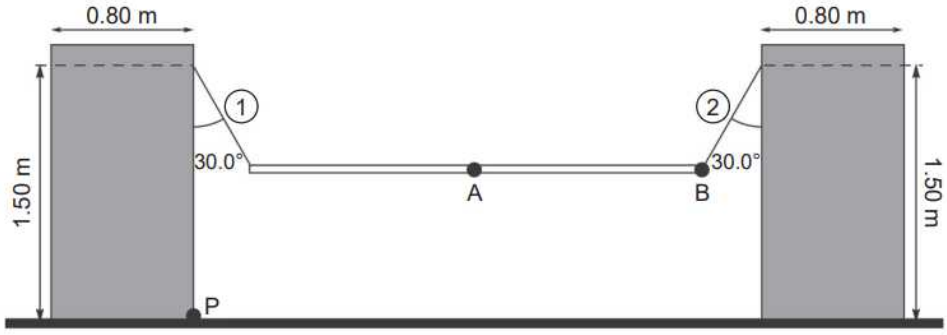
Element	Description	Marks
Calculates time for target to reach destination	32.0/8 = 4.00 s	1
Uses correct vertical component		1
Uses vertical displacement of velocity	$-30.0 = 50.0 \sin\theta \times 4.00 - 4.90 \times 16.00$	1
Calculates correct angle	$\theta = 14.0°$	1
	Total	**4**
Accept other relevant methods of calculation e.g. using horizontal component.		

(b) With the use of a calculation, confirm that the arrow hits the target. (3 marks)

Element	Description	Marks
Uses correct horizontal component		1
Uses horizontal component of velocity	$s = vt = 50.0 \times \cos 14.0° \times 4.00 = 194$ m	1
Confirms arrow hits target	194 is between 193 and 197 m	1
	Total	**3**
Note: Candidate must use the alternate component of velocity in part (b) to the component they used in part (a).		

2022 Section 2 Question 12

Gravity and motion



An ultra-lightweight 2.00 kg aluminium plank is suspended between two 70.0 kg uniform free-standing supports as part of a children's obstacle course. It is attached to the supports by two chains of equal length. Due to safety restrictions, the apparatus has a maximum load of 60.0 kg. A father with a mass of 80.0 kg mistakenly sits on the plank, halfway between the two supports at point A. His mass exceeds the safety limit, so the free-standing supports should tip inward.

(a) Calculate the tension in each chain when the father sits on the plank, assuming the supports do not tip over. (4 marks)

Element	Description	Marks
Uses sum of vertical forces = 0		1
Correct equation	$2T \times \cos 30.0° = \Sigma mg$	1
Includes mass of plank		1
Correctly calculates answer	$T = 82.0 \times 9.80/(2 \cos 30.0°) = 464$ N	1
	Total	**4**

(b) Calculate the horizontal component of the tension in each chain. (1 mark)

Description	Marks
$T_h = T \times \sin 30.0° = 464 \times 0.500 = 232$ N	1
Total	**1**

(c) With the use of a calculation, confirm that the supports do tip over when the father sits on the plank. Take moments around P. (5 marks)

Element	Description	Marks
Takes moments around inside base of support	$\Sigma cm > \Sigma acm$ if tips over	1
Uses 1.50 m as distance to pivot of T_h		1
Uses 0.40 m as distance to pivot of m_s		1
Correctly calculates moments	$232 \times 1.50 > 70.0 \times 9.80 \times 0.400$	1
Confirms support tips over	348 N m > 274 N m	1
	Total	**5**

(d) Without the use of additional calculations, describe how the tension in each chain would be affected if a 50.0 kg person sitting at A moved to B? Select either increases, decreases or remains constant. (2 marks)

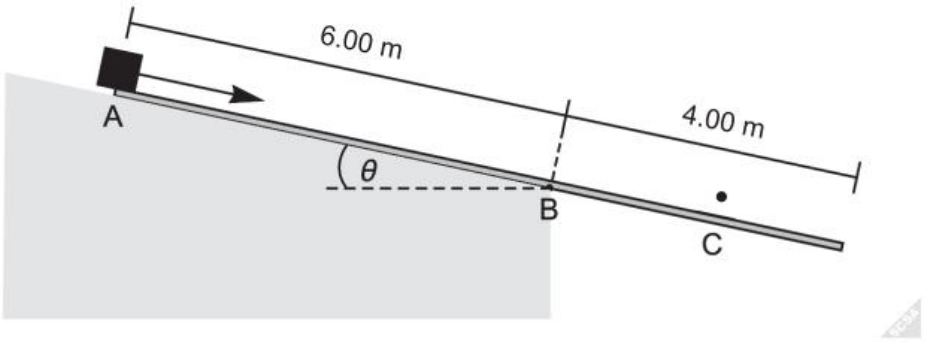
Chain 1	Chain 2
decreases	increases

Description	Marks
chain 1 decreases	1
chain 2 increases	1
Total	**2**

2021 Section 1 Question 6

Gravity and motion

A student is set the task of determining the slope of a concrete structure using only a 15.0 kg beam, a ruler, a 5.00 kg mass with one smooth face and one rough face, and a stopwatch. She places the 10.0 m long uniform beam on top of the sloping structure with 4.00 m of the beam hanging over the end of the structure as shown in the cross-sectional diagram below. The student then places the 5.00 kg mass rough side down at increasing distances from B until the beam starts to tip over. She marks that place as C. The student then lets the 5.00 kg mass slide on its smooth side down the smooth beam from rest at A. She measures the time to reach C as 3.30 s.



(a) Calculate the distance between A and C. (3 marks)

Element	Description	Marks
Uses moments to solve problem	$\Sigma cm = \Sigma acm$	1
Uses 1.00 m as distance from B to COM of beam	(5.00)(9.80) x BC $\cos\theta$ = (15.0)(9.80) x 1.00 $\cos\theta$ BC = 3.00 m	1
Correctly calculates answer	AC = 6.00 + 3.00 = 9.00 m	1
	Total	**3**

(b) Ignoring friction, calculate the angle of the slope measured from the horizontal. (2 marks)

Element	Description	Marks
Uses $s = ut + 0.5\,at^2$ where $u = 0$ and $a = g\sin\theta$	$9.00 = 0.5 \times 9.80 \sin\theta \times 3.30^2$	1
Correctly calculates answer	$\sin\theta = 0.1687$ $\theta = 9.71°$	1
	Total	**2**

2021 Section 1 Question 7

Gravity and motion

A bobo doll, as shown below, can never be tipped over. Even if its head is held on the ground, it will stand back up when released. Explain how this works. You must include in your answer the relevant conditions required for static equilibrium. Use the diagram on the right to illustrate your answer. (4 marks)

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Description	Marks
Diagram shows labelled line of action of the weight force to the left of the pivot (where the base of the bobo doll touches the ground).	2
Person holding doll down provides a balancing torque to keep the doll in static equilibrium	1
When opposing moment holding head on the ground is removed, the restoring moment of the weight force rights the doll	1
Total	**4**

2021 Section 1 Question 9

Gravity and motion

A space station is shaped like a huge hollow doughnut that is rotating uniformly. The outer radius is 4.60×10^2 m. What is the period of rotation of the station if a person standing on the outer wall inside the station experiences the same weight force she would experience on Earth? (5 marks)

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Element	Description	Marks
Centripetal force is supplied by the reaction force.	$mv^2/r = R$	1
Reaction force equals mg	$mv^2/r = mg$	1
Correctly rearranges formula to calculate velocity	$v = \sqrt{rg} = \sqrt{4.60 \times 10^2 \times 9.80} = 67.1$ m s^{-1}	1
Period is circumference over time	$T = 2\pi r/v$	1
Correctly calculates period	$T = 43.0$ s	1
	Total	**5**

2021 Section 2 Question 15

Gravity and motion

A 42.5 kg gymnast performs her dismount from the 1.25 m high beam. She leaves the beam with a velocity of 3.10 m s^{-1} at an angle of 55.0° to the horizontal.

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(a) Calculate the vertical and horizontal components of her launch velocity. (2 marks)

Element	Description	Marks
Vertical component	$v_V = 3.10 \times \sin 55.0° = 2.54$ m s^{-1}	1
Horizontal component	$v_H = 3.10 \times \cos 55.0° = 1.78$ m s^{-1}	1
	Total	**2**

(b) Calculate the time it takes for her to reach the ground, assuming she is vertical at impact. (5 marks)

There are 3 different alternatives to solve this problem.

1. Quadratic equation

Element	Description	Marks
$s = ut + 0.5\ at^2$		
s and a are negative, u is positive.	$-1.25 = 2.54t - 4.90t^2$	1
Uses v_V for u		1
Rearranges equation correctly to equal 0	$4.90t^2 - 2.54t - 1.25 = 0$	1
Substitutes correct values into quadratic formula	$t = 2.54 \pm \sqrt{-2.54^2 - 4 \times 4.90 \times -1.25} / 2 \times 4.90$	1
Correctly calculates answer	$t = 0.827$ s	1
	Total	**5**

2. Calculates final vertical velocity

Element	Description	Marks
$v^2 = u^2 + 2as$		
a and s are negative	$v_V^2 = 2.54^2 + (2 \times -9.80 \times -1.25)$	1
uses v_V		1
Solves for v correctly	$v_V = \pm 5.56$ m s^{-1}	1
$v = u + at$, v and a are negative	$-5.56 = 2.54 - 9.80t$	1
Correctly calculates answer	$t = 0.827$ s	1
	Total	**5**

3. Splits flight into up and down sections

Element	Description	Marks
Calculate time to apex using v_V	$v = u + at$ $t = 0.259$ s	1
Calculates how high she goes	$s = ut + 0.5\ at^2$ $s = 0.329$ m	1
Adds 1.25 to answer	$s = 1.58$ m	1
Calculates how long to fall to ground	$s = ut + 0.5\ at^2$ $t = 0.568$ s	1
Adds two times correctly	0.827 s	1
	Total	**5**

(c) Calculate her range R. (2 marks)

Element	Description	Marks
$s = vt$ Uses v_H	$s = 1.78 \times 0.827$	1
Correctly calculates answer	$s = 1.47$ m	1
	Total	**2**

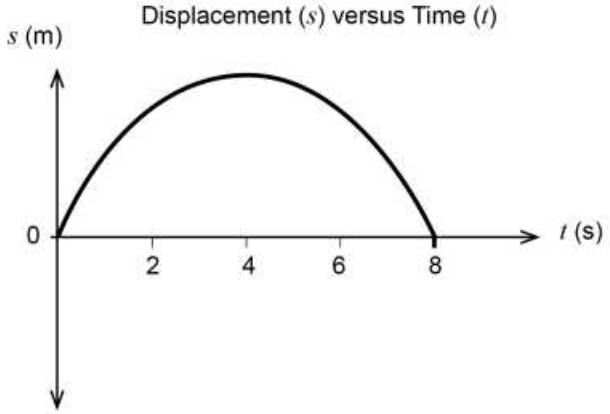
(d) Calculate the gymnast's kinetic energy at the top of her flight. (2 marks)

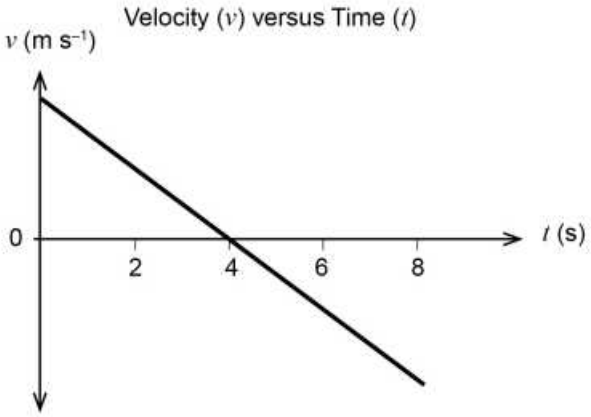
Element	Description	Marks
Uses v_H	$E_k = 0.5 \times 42.5 \times 1.78^2$	1
Correctly calculates answer	67.3 J	1
	Total	**2**

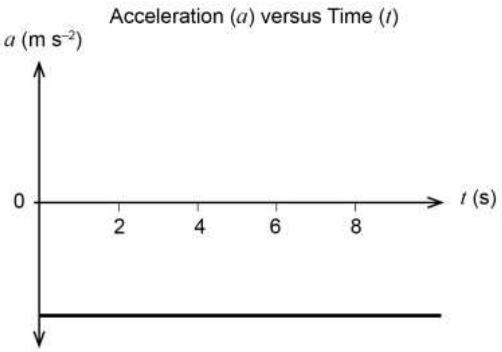
2020 Section 1 Question 1

Gravity and motion

A ball is launched vertically into the air with an initial velocity at $t = 0$ from ground level ($s = 0$) and returns to ground level. It takes four seconds for it to reach its maximum height. Taking upwards as positive, graph the ball's displacement, velocity and acceleration versus time from take-off to landing. Ignore air resistance and do not place any values on the y-axis.





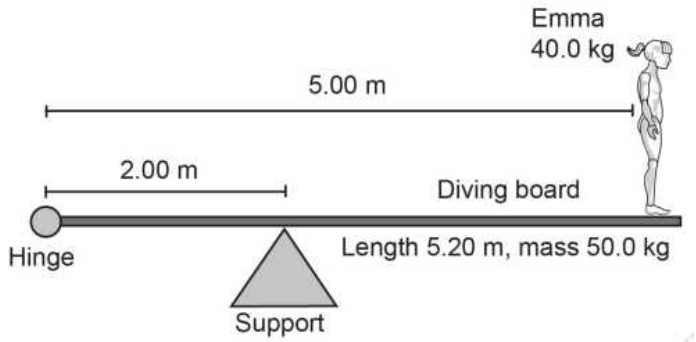


Description	Marks
1 mark for each graph completely correct.	1–3
apex of parabola must be at 4.0 s. Velocity graph must go through (4,0).	
Total	**3**

2020 Section 1 Question 5

Gravity and motion

Emma stands 20.0 cm from the end of a 5.20 m long uniform diving board. Calculate the upwards force the support must exert on the 50.0 kg board for the system to remain in equilibrium. (4 marks)



Element	Description	Marks
takes moments around hinge	$\Sigma acm = \Sigma cm$	1
correctly identifies direction of moments	$(m_E \times g \times 5.0) + (m_b \times 9.8 \times 2.6) = 2F$	1
uses 5.0 m not 5.2 m, 2.6 m not 2.5 m	$(40 \times 9.8 \times 5.0) + (50 \times 9.8 \times 2.6) = 2F$	1
correct/consistent answer	1620 N or 1.62×10^3 N	1
	Total	**4**

2020 Section 1 Question 10

Gravity and motion

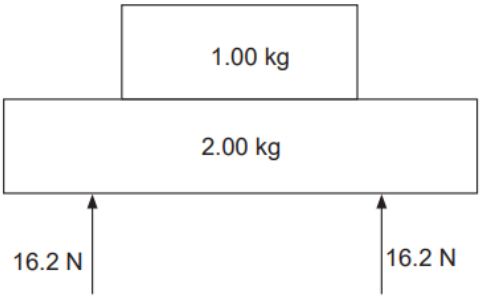
A golfer hits a ball at 37.0 m s^{-1} at 31.0° to the horizontal on a flat fairway. It travels 123 m. She wants to hit a target 135 m away, so she increases the angle at which she hits the ball, without changing the launch speed. Calculate the smallest increase of angle that allows her to reach the target. (Hint: $2\sin\Theta\cos\Theta = \sin 2\Theta$)

Element	Description	Marks
expresses t as range over horizontal velocity	$t = 135/37 \cos\theta$	1
substitutes time into equation for vertical displacement ($s = 0$)	$0 = 37 \sin\theta - 4.9\,(135/37 \cos\theta)$ $37^2 \sin\theta\cos\theta = 4.9 \times 135$	1–2
solves for angle using expression given	$\sin 2\theta = 2 \times 4.9 \times 135/37^2$ $2\theta = 75.1°$ $\theta = 37.5°$	1–2
subtracts initial angle to find change of angle	$37.5 - 31 = 6.5°$	1
	Total	**6**
Note: other equivalent methods can be used, such as $v = u + at$ or $s = ut + \frac{1}{2}at^2$ to get an expression that eliminates t		

2020 Section 1 Question 11

Gravity and motion

Jake is lifting two books of mass 1.00 kg and 2.00 kg respectively. The lighter book sits on top of the heavier book, and each of Jake's hands exerts a vertical force of 16.2 N on the lower book, as shown in the diagram.



(a) What is the magnitude of the acceleration of the books? (3 marks)

Element	Description	Marks
subtracts the weight force from the total upwards force	$F_{net} = 32.4 - (3 \times 9.8) = 3.0$ N	1–2
uses net force to calculate the acceleration	$a = F/m = 3.0/3.0 = 1.00$ m s^{-2}	1
	Total	**3**

(b) What is the magnitude of the force that the 2.00 kg book exerts on the 1.00 kg book during this acceleration? (3 marks)

Element	Description	Marks
adds weight force to net force to get total force	$F_{Tot} = mg + ma$ $= 9.8 + 1.0$	1–2
correct/consistent answer	10.8 N	1
	Total	**3**

2019 Section 1 Question 4

Gravity and motion

Titan is the largest of Saturn's moons. Its orbital radius is 1.22×10^6 km. Use the Formulae and Data booklet and the data in the table below to determine the strength of Saturn's gravitational field where Titan orbits. Give your answer in N kg^{-1} and m s^{-2}.

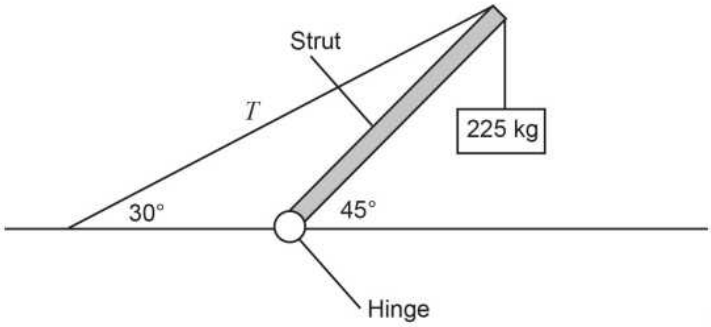
Planet	Mass (Earth masses)
Mercury	0.055
Venus	0.815
Earth	1.000
Mars	0.107
Jupiter	318
Saturn	95
Uranus	14.5
Neptune	17.2
Pluto	0.002

Description	Marks
$r = 1.22 \times 10^9$ m	1
$M = 95\ M_E = 5.67 \times 10^{26}$ kg	1
$g = MG/r^2$ $g = 5.67 \times 10^{26} \times 6.67 \times 10^{-11}/(1.22 \times 10^9)^2$ $g = 2.54 \times 10^{-2}$ N kg^{-1}	1–2
$g = 2.54 \times 10^{-2}$ m s^{-2}	1
Total	**5**

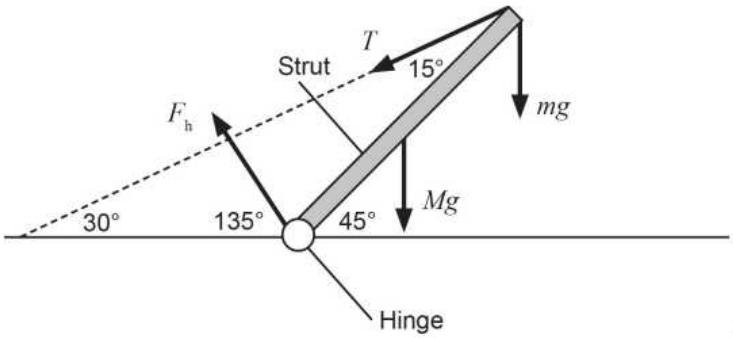
2019 Section 1 Question 6

Gravity and motion

The diagram below shows a system in equilibrium.



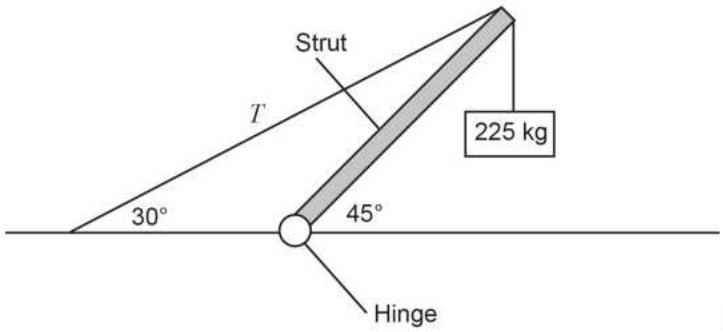
A student drew a diagram of the forces acting on the strut. That diagram is shown below. It is not drawn to scale.



(a) With specific reference to the conditions required for equilibrium, explain why the diagram of the forces is incorrect. (2 marks)

Description	Marks
Σ horizontal forces should = 0	1
No F_H to the right to counter component of T to the left: unbalanced	1
Total	**2**

(b) Using the diagram below, show what change(s) should be made to correct it. (Calculations are not required.) (2 marks)

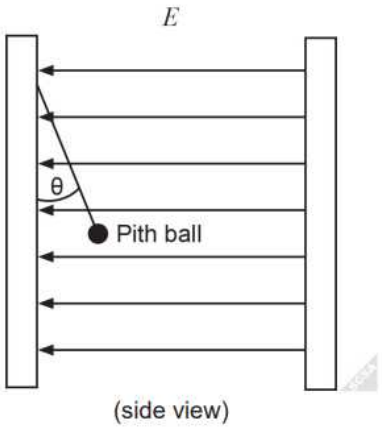


Description	Marks
F_{hinge} must be to the right	1
and a vertical component	1
Total	**2**

2019 Section 1 Question 7

Gravity and motion

A pith ball is a very small, lightweight object that readily picks up electric charge. A pith ball with a mass of 75.0×10^{-6} kg is suspended by a string attached to a charged plate. The pith ball has an excess of 2.00×10^{12} electrons on it and the electric field strength between the charged plates is 95.0 N C^{-1}.



(side view)

(a) In the space below, draw a vector diagram of the forces acting on the pith ball. (3 marks)

Description	Marks
correct forces	1
closed right triangle	1
correct labels	1
Total	**3**

(b) Calculate the angle between the string and the charged plate. (5 marks)

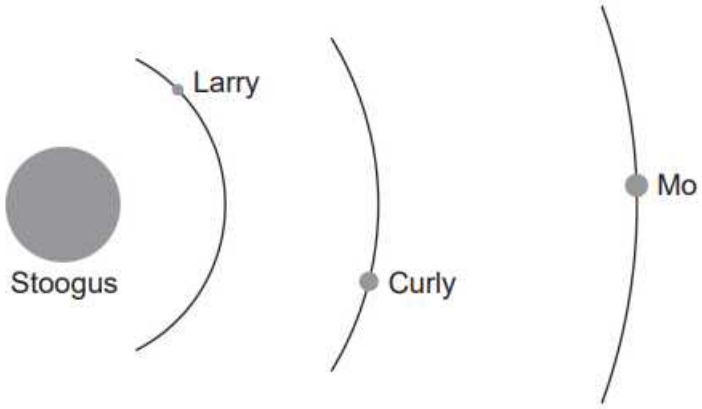
Description	Marks
$\tan\theta = F_E / mg$	1
$F_E = Eq = 95 \times 2 \times 10^{12} \times 1.6 \times 10^{-19} = 3.04 \times 10^{-5}$	1–2
$mg = 75 \times 10^{-6} \times 9.8 = 7.35 \times 10^{-4}$	1
$\tan\theta = 3.04 \times 10^{-5} / 7.35 \times 10^{-4}$ $\quad \theta = 2.37^0$	1
Total	**5**

2019 Section 1 Question 8 **Gravity and motion**	A cyclist is travelling at 6.0 m s^{-1} over a hump in the road that is part of a circle of radius 4.80 m. Calculate the magnitude of the total reaction force of the ground on the cyclist at the top of the hump. The total mass of the cyclist and bicycle is 72 kg. (Note: diagram not to scale, ignore friction.) ***Copyright restrictions prohibit the release of this SCSA exam material.***

Description	Marks
$F_c = mg - R$ $R = mg - mv^2/r$	1–2
= 72(9.8 – 36/4.8)	1
= 166 N	1
Total	**4**

2023 Section 2 Question 15

Gravity and motion



A recently discovered planet (Stoogus) in a distant solar system has three moons (Larry, Curly and Mo) orbiting at different distances. Stoogus has a mass of 2.37×10^{24} kg and a day on Stoogus lasts 7.50 Earth hours. Assume all three moons have circular orbits as their masses are insignificant compared to that of Stoogus.

(a) Curly is a geosynchronous satellite that orbits above one specific spot on Stoogus' surface. Calculate the radius of Curly's orbit. (5 marks)

Element	Description	Marks
Uses Kepler's 3rd law	$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$	1
Rearranges for r^3	$r^3 = \frac{GMT^2}{4\pi^2}$	1
Converts hours to seconds	$T = 7.50 \times 60 \times 60 = 2.70 \times 10^4$ s	1
Substitutes correct values into equation	$r = \left(6.67\times10^{-11} \times 2.37\times10^{24} \times \frac{(2.70\times10^4)^2}{4\pi^2}\right)^{\frac{1}{3}}$	1
Calculates value for r	$r = 1.43 \times 10^7$ m	1
	Total	**5**

(b) The gravitational field strength that Mo experiences due to Stoogus is 4.50×10^{-3} m s^{-2}. Calculate the distance between the centre of mass of Mo and the centre of mass of Stoogus. (4 marks)

Element	Description	Marks
Uses correct equation	$g = \frac{GM}{r^2}$	1
Rearranges for r^2	$r^2 = \frac{GM}{g}$	1
Substitutes correct values	$r = \sqrt{\left(\frac{6.67\times10^{-11} \times 2.37\times10^{24}}{4.50\times10^{-3}}\right)}$	1
Calculates answer	$= 1.87 \times 10^8$ m	1
	Total	**4**

(c) (i) Derive the mathematical relationship between a moon's orbital speed *v* and its distance r from the planet's centre of mass. (3 marks)

Element	Description	Marks
Uses Kepler's 3rd Law and rearranges for T	$T^2 = \frac{4\pi^2 r^3}{GM}$	1
Substitutes $\frac{2\pi r}{v}$ for T	$\frac{4\pi^2 r^2}{v^2} = \frac{4\pi^2 r^3}{GM}$	1
Simplifies and isolates v^2	$v^2 = \frac{GM}{r}$	1
	Total	**3**

Alternative solution

Element	Description	Marks
States F_c is provided by the F_g	$F_c = F_g$	1
Expands formulae correctly	$\frac{mv^2}{r} = \frac{GMm}{r^2}$	1
Simplifies and isolates v	$v^2 = \frac{GM}{r}$	1
	Total	**3**

(ii) Use this relationship from part (c)(i) to identify which moon of Stoogus has the greatest orbiting speed. Justify your answer. (2 marks)

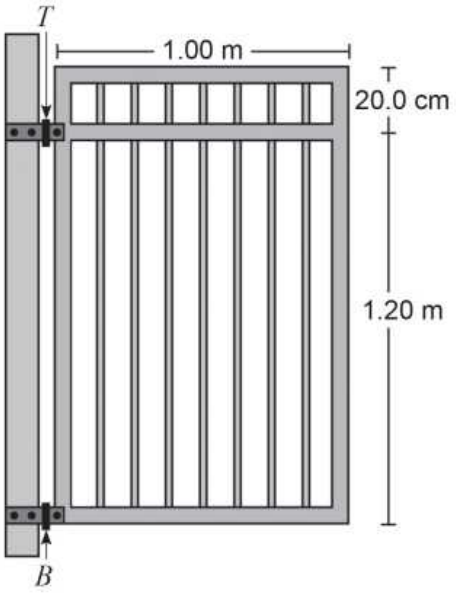
Description	Marks
Larry is travelling the fastest	1
As G and M are constant, as r decreases, velocity increases	1
Total	**2**

2023 Section 2 Question 17

Gravity and motion

A uniform garden gate is attached to its support by two hinges (T and B). The top hinge (T) is fixed 20.0 cm below the top of the gate and the bottom hinge is fixed to the bottom of the gate. The gate has a mass of 25.7 kg. It is 1.00 m wide and 1.40 m tall.

Note: The top hinge takes all of the vertical weight force of the gate. The bottom hinge keeps the gate lined up correctly.



(a) By taking moments around B, calculate the horizontal component of the reaction force of T on the gate. Include a direction in your answer. (5 marks)

Element	Description	Marks
Correctly identifies moments around B	mg and horizontal component of R_T	1
Substitutes correct values into moments equation, specifically distances to pivot	$\Sigma acm = \Sigma cm$ $R_{HT} \times 1.20 = 25.7 \times 9.80 \times 0.50$	1–2
Calculates correct answer for R_{HT}	$R_{HT} = 105$ N	1
Includes direction	left	1
	Total	**5**

(b) Calculate the overall reaction force of T on the gate. Include an angle to the horizontal in your answer. If you could not obtain an answer to part (a), use 1.40×10^2 N. (5 marks)

Element	Description	Marks
Uses Pythagoras to solve for net overall reaction force		1
Substitutes correct values	$R_{net}^2 = (25.7 \times 9.8)^2 + 105^2$	1
Calculates answer	$R_{net} = 273$ N	1
Uses correct trig function to calculate θ	e.g. $\tan\theta = 251.9/105$	1
Calculates θ	$\theta = 67.4°$	1
	Total	**5**
If used 1.40×10^2 N, $R_{net} = 288$ N, $\theta = 60.9°$		

(c) Discuss how the angle in part (b) would be affected if the top hinge was fixed at the top of the gate. Include a mathematical expression in your answer. (4 marks)

Element	Description	Marks
Uses moments equation from part (a)	$\Sigma acm = \Sigma cm$ $R_{HT} \times 1.20 = 25.7 \times 9.80 \times 0.50$	1
Σcm is constant		1
If we increase d from 1.20 to 1.40 m, R_{HT} will decrease		1
If R_{HT} decreases, θ increases		1
	Total	**4**

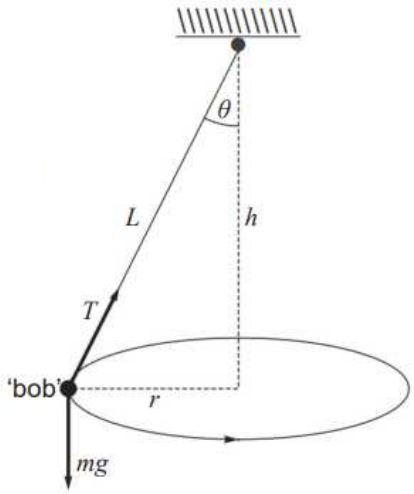
Alternative solution

Element	Description	Marks
Uses moments equation from part (a) and uses distance = d	$\Sigma acm = \Sigma cm$ $R_{HT} \times d = 25.7 \times 9.80 \times 0.50$	1
Σcm is constant	$R_{HT} = 126/d$	1
If we increase d from 1.20 to 1.40 m, R_{HT} will decrease	$\tan\theta = Rv/Rh$ $= 252/(126/d) = 2d$	1
If d increases, $\tan\theta$ and hence θ increases		1
	Total	**4**

2022 Section 2 Question 17

Gravity and motion

The diagram to the right shows the two forces acting on a conical pendulum as it spins at a set frequency. The vector addition of these two forces provides the centripetal force on the 'bob'. The mass of the 'bob' is 255 g and the length of the pendulum string L is 1.20 m. When the frequency of rotation is 0.490 Hz, the angle $\theta = 30.0°$.



(a) Calculate the tension in the string when θ = 30.0°. (4 marks)

Element	Description	Marks
Uses correct relationship	$\cos 30.0° = mg/T$	1
Isolates T correctly	$T = mg/\cos 30.0°$	1
Converts to kg	$T = 0.255 \times 9.80/\cos 30.0°$	1
Calculates correct answer	$T = 2.89$ N	1
	Total	**4**

(b) Calculate the radius of the circular path the 'bob' is moving in when the angle is 30.0°. (2 marks)

Element	Description	Marks
Uses correct identity	$\sin 30.0° = r/L$	1
Calculates correct answer	$r = L \sin 30.0° = 0.600$ m	1
	Total	**2**

(c) Calculate the new angle between the pendulum string and the vertical if the frequency of rotation is doubled. (6 marks)

Element	Description	Marks
Calculates new period	$T = 1/0.980 = 1.02$ s	1
Uses correct relationship	$\tan \theta = mv^2/r/mg = v^2/rg$	1
Substitutes $2\pi r/T$ for v	$9.80 \tan \theta = 4 \pi^2 r/T^2$	1
Substitutes $L \sin \theta$ for r	$9.80 \sin \theta/\cos \theta = 4 \pi^2 \times 1.20 \sin \theta/T^2$	1
Simplifies and isolates $\cos \theta$	$\cos \theta = 9.80 \times 1.02^2/(4 \pi^2 \times 1.20)$	1
Calculates correct angle	$\theta = 77.6°$	1
	Total	**6**
Note: If assumes r or v remains constant, award maximum 3 marks.		

(d) Explain why θ can never equal 90.0°, regardless of how great the frequency of the pendulum becomes. You may use mathematical relationships in your answer. (4 marks)

Description	Marks
Tension consists of two components, vertical and horizontal.	1
The vertical component counters mg.	1
When angle = 90°, the vertical component = 0.	1
This means there is nothing holding the weight of the 'bob', which is impossible.	1
Total	**4**

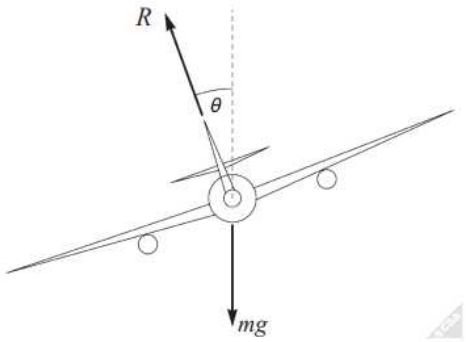
Alternate solution:

Description	Marks
$\cos \theta = mg/T$	1
$T = mg/\cos \theta$	1
As θ approaches 90°, T approaches infinity.	1
Infinite T is impossible.	1
Total	**4**

2021 Section 2 Question 17

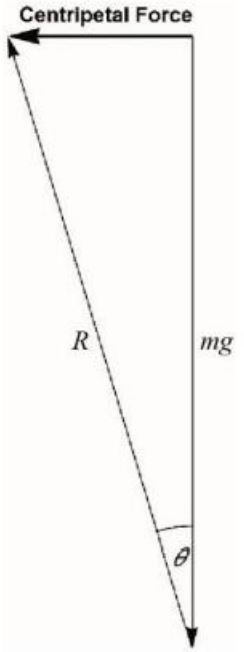
Gravity and motion

Aeroplanes are designed to produce an upthrust that counters their weight force. This allows them to maintain altitude. The magnitude of this upthrust (R) is directly proportional to the forward speed of the aircraft. It always acts perpendicular to the wings. When changing direction, the aeroplane banks in a circular path. A free body diagram of a banking aeroplane is shown below.



(a) Draw a vector diagram showing how the weight force and the upthrust produce a resultant centripetal force. Label the resultant force and include the angle Θ shown in the free body diagram. (3 marks)

Description	Marks
All forces labelled correctly	1
Right angle triangle with resultant horizontal	1
θ correctly placed	1
Total	**3**



(b) Calculate the centripetal force on a 5.60 × 103 kg aeroplane banking at an angle of 15.0° to the vertical while maintaining constant altitude. (3 marks)

Element	Description	Marks
Uses correct trigonometric function	$\tan 15.0° = F_c / mg$	1
Substitutes correct values into equation and isolates F_c correctly	$F_c = mg \tan 15.0° = 5.60 \times 10^3 \times 9.80 \times 0.268$	1
Calculates correct answer	1.47×10^4 N	1
Total		**3**

(c) If the aeroplane is travelling at 4.50×10^2 km h–1, calculate the radius of the circular path it takes when banking while maintaining constant altitude. (3 marks)

Element	Description	Marks
Converts km h^{-1} to m s^{-1}	$450 / 3.6 = 125$ m s^{-1}	1
Substitutes values and rearranges equation correctly	$r = 5.60 \times 10^3 \times 125^2 / 1.47 \times 10^4$	1
Correctly calculates answer	5.95×10^3 m	1
Total		**3**

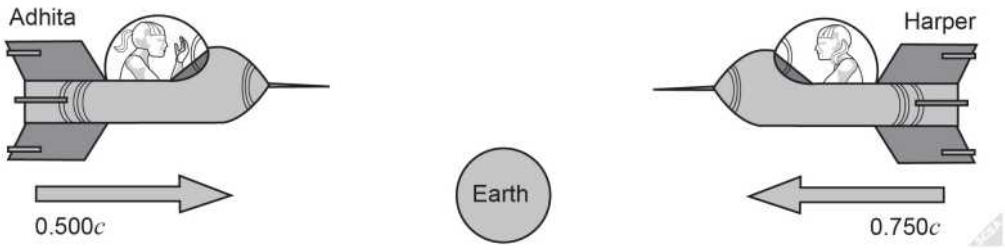
(d) With reference to your vector diagram in part (a) and the text, explain why aeroplanes need to increase their speed to maintain altitude when banking. (4 marks)

Description	Marks
Upthrust counters weight force	1
Upthrust is directly proportional to forward speed	1
Upthrust acts perpendicular to wings	1
As seen in diagram, only vertical component of upthrust counters weight therefore needs to increase speed to maintain altitude	1
Total	**4**

2020 Section 2 Question 15

Gravity and motion

Two spaceships, captained by Adhita and Harper, are travelling toward each other. They are observed by a person on the Earth to be travelling at the velocities shown in the diagram. Take all velocities to the left as positive.



(a) Calculate the velocity of Harper as measured by Adhita. (4 marks)

Element	Description	Marks
uses consistent sign convention.	$v = -0.5c$ $u = 0.75c$	1
correctly identifies frames of reference	looking for u'	1
enters correct values and directions into correct equation.	$u' = (0.75c - (-0.5c))/(1 - (0.75 \times -0.5))$	1
correct answer	$0.909c$	1
can be solved from Earth's perspective finding u', where $u = 0.93c$ and $v = -0.50c$		
	Total	**4**

(b) Harper fires a missile with a velocity of 0.600c with respect to her in the direction of Adhita. Calculate the velocity of the missile as measured by an observer on the Earth. (4 marks)

Element	Description	Marks
uses correct sign convention	all velocities are positive	1
correctly identifies FOR	looking for u	1
enters correct values into correct equation	$(0.75 + 0.6)c/(1 + (0.75 \times 0.6))$	1
correct/consistent answer	$0.931c$	1
	Total	**4**

(c) Calculate the velocity of the missile as measured by Adhita. (4 marks)

Element	Description	Marks
uses consistent sign convention	all velocities are positive	1
correctly identifies FOR	looking for u	1
enters correct values into correct equation	$u = (0.91 + 0.6)c/(1 + (0.91 \times 0.6))$	1
correct/consistent answer	$u = 0.976c$	1
	Total	**4**
Note: The problem can be resolved from Earth's perspective using u', where $u = 0.931c$ and $v = -0.500c$		

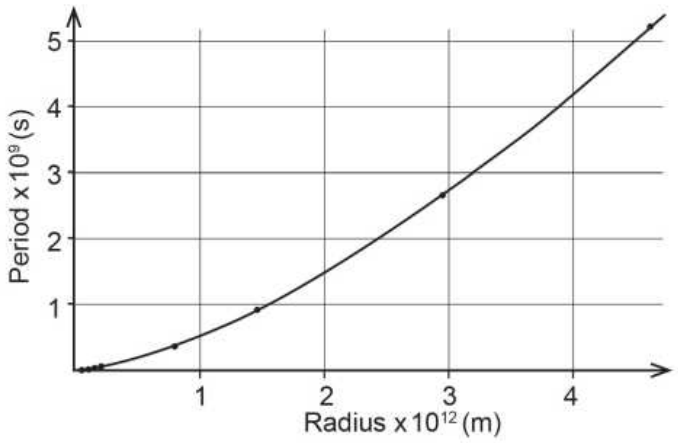
2020 Section 2 Question 17

Gravity and motion

A satellite is orbiting the Earth 4.00 x 10^3 km above its surface.

(a) Calculate the period of the satellite. (5 marks)

Element	Description	Marks
converts km to m	$T^2 = 4\pi^2 (4.0 \times 10^6 + 6.37 \times 10^6)^3 / (6.67 \times 10^{-11} \times 5.97 \times 10^{24})$	1
adds altitude to radius of Earth		1
cubes distance and square roots answer		1
correct answer	1.05×10^4 s	1
converts to hours	2.92 hours	1
	Total	**5**



The graph shows the relationship between the period (T) and the orbiting radius (r) of all the planets in our solar system.

(b) (i) With reference to Kepler's Third Law, describe how a straight line graph could be generated using the same two variables. (Do not refer to logarithms.) (2 marks)

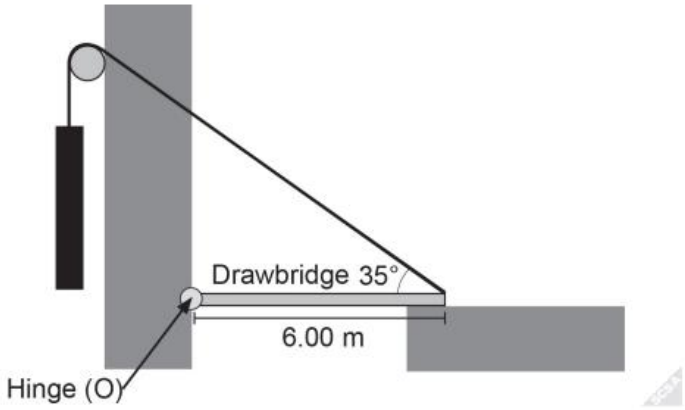
Description	Marks
in Kepler's 3rd Law, T^2 is proportional to r^3	1
graph T^2 vs r^3	1
Total	**2**

(ii) Explain how you could use the gradient of this straight line and Kepler's Third Law to estimate the magnitude of the Newtonian constant of gravitation (G). (Do not try to calculate G from the graph.) (3 marks)

Element	Description	Marks
isolates expression for gradient from Kepler's Third Law.	gradient = $T^2/r^3 = 4\pi^2/GM$	1
isolates G from equation including gradient	G = 1/gradient × $4\pi^2/M$	1
recognises M (of the Sun) is constant therefore G can be calculated		1
	Total	**3**

2020 Section 2 Question 18

Gravity and motion



A castle has a 6.00 m long drawbridge with a mass of 500 kg over its moat. It is attached to a winch by an extremely strong rope at an angle 35.0° to the horizontal.

(a) Calculate the tension in the rope when the drawbridge is just lifted off the rest on the other side of the moat. (4 marks)

Element	Description	Marks
takes moments around hinge	$acm = cm$	1
identifies acm and cm	$T \times d = 500 \times 9.80 \times 3.00$	1
calculates perpendicular distance from hinge to rope	$d = 6 \sin 35$	1
correct answer	$T = 4270$ N or 4.27×10^3 N	1
	Total	**4**

(b) Calculate the reaction force of the hinge (O) on the drawbridge at this point. (5 marks)

Element	Description	Marks
Calculates the horizontal component of the reaction force from horizontal component of tension.	$R_H = 4271 \cos 35 = 3500$ N	1
Calculates vertical component of reaction force by subtracting vertical component of T from mg.	$R_V = mg - T_V = 4900 - 4271 \sin 35$ $= 2450$ N	1
Adds the two components using Pythagoras.	$R_N^2 = 3500^2 + 2450^2$	1
correct answer	4271 N	1
calculates angle correctly	$\tan \Theta = 2450/3500$ $\Theta = 35.0°$	1
	Total	**5**
Note: Candidates could identify that $R = T$ through vector diagram but they would have to give a good explanation of what they did.		

The castle comes under attack. The people inside the castle begin to raise the drawbridge. When it is at an angle of 15.0° above horizontal, the angle between the drawbridge and the rope is 40.0°. At this moment, a 95.0 kg soldier being chased by the enemy jumps onto the very end of the drawbridge.

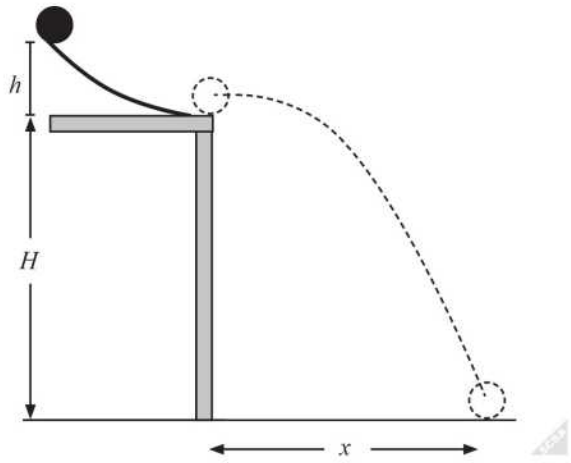
(c) Calculate the new tension in the rope as he hangs from the end. Assume the drawbridge is stationary at this time. (5 marks)

Element	Description	Marks
takes moments around hinge	$acm = cm$	1
correctly identifies acm and cm	$T \times d_1 = (m_d \times g \times d_2) + (m_s \times g \times d_3)$	1
calculates three new distances from pivot	$d_1 = 6.00 \sin 40 = 3.86$ m $d_2 = 3.00 \cos 15 = 2.90$ m $d_3 = 6.00 \cos 15 = 5.80$ m	1–2
correct/consistent answer	5080 N or 5.08×10^3 N	1
	Total	**5**

2019 Section 2 Question 12

Gravity and motion

A ball is rolled from rest down a curved slope, across a flat, smooth table leaving the table horizontally and falling to the floor.



If h = 30.0 cm and H = 1.20 m

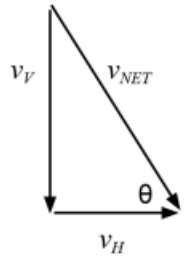
(a) Using conservation of energy, calculate the speed with which the ball leaves the table. Assume no energy is lost to friction, air resistance or is transferred to rotational energy. (2 marks)

Description	Marks
$mgh = mv^2/2$ $v = \sqrt{2gh} = \sqrt{2 \times 9.80 \times 0.3}$	1
= 2.42 m s^{-1}	1
Total	**2**

(b) Calculate the distance *x*. (4 marks)

Description	Marks
$s = 0.5\ a\ t^2$ $t = \sqrt{1.20/4.9}$	1
$= 0.495$ s	1
$x = v_H \times t$	1
$= 2.42 \times 0.495 = 1.20$ m	1
Total	**4**

(c) Calculate the velocity of the ball when it hits the floor. (5 marks)



Description	Marks
$v_V = 0 + 9.8 \times 0.495$	1
$= 4.85$ m s^{-1}	1
$v_{N2} = v_V^2 + v_H^2$ $v_N = \sqrt{4.85^2 + 2.42^2}$	1
$= 5.42$ m s^{-1}	1
$\tan\theta = 4.85/2.42$ $\theta = 63.5°$	1
Total	**5**

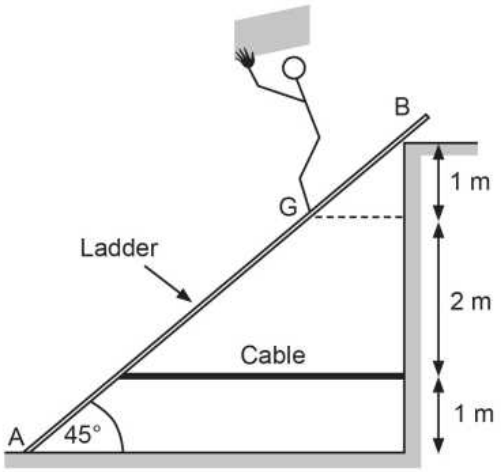
(d) Derive an expression for *x* in terms of *h* and *H* only. (Note: may include numbers.) (4 marks)

Description	Marks
$v_H = \sqrt{2\ g\ h}$	1
$t = \sqrt{2\ H / g}$	1
$x = v_H \times t$ $= \sqrt{2 \times g \times h} \times \sqrt{2H / g}$	1
$= 2\sqrt{h \times H}$	1
Total	**4**

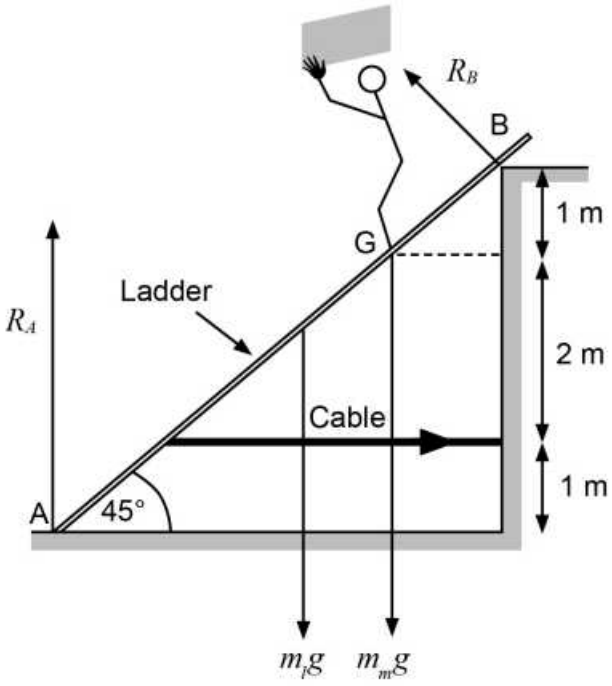
2019 Section 2 Question 13

Gravity and motion

Workers at an ice skating venue use a ladder to fix a sign 5.0 m above the surface of the ice. To prevent the 6.00 m long ladder from slipping on the ice, they tie a cable between the ladder and the 4.00 m high wall. The cable is at right angles to the wall. The uniform 15.0 kg ladder is placed at an angle of 45° between the frictionless surfaces at A and B. A 90.0 kg worker is standing still on the ladder at G.



(a) On the diagram above, draw and label the forces acting on the ladder. Assume the reaction force at B acts at right angles to the ladder. (4 marks)



Description	Marks
forces: R_A, R_B, T, $m_l g$ and $m_m g$	
all five correctly labelled with directions	4
all five, one incorrectly labelled or directed	3
four correctly labelled	3
four, one incorrectly labelled or directed or all five, two incorrectly labelled or directed	2
three correct	1
Total	**4**

(b) By taking moments around A, calculate the tension in the cable. (6 marks)

Description	Marks
$\Sigma F_H = 0$ $T = R_B \cos 45$ $R_B = T/\cos 45$	1–2
Taking moments at A: $(T \times 1) + (90 \times 9.8 \times 3) + (15 \times 9.8 \times 3 \cos 45) = R_B \times 4/\cos 45$	1–2
Sub for R_B: $T + 2650 + 312 = 4T/(\cos 45)^2$	1
$2960 = 8T - T$ $T = 423$ N	1
Total	**6**

2019 Section 2 Question 16

Gravity and motion

A ball is being swung around in a vertical circle on a string.

(a) In the table below, match the statements with A, B, C and/or D. (4 marks)

Description		Marks
point(s) where the centripetal acceleration is the greatest	A	1
point(s) where the tension in the string is the lowest	C	1
point(s) where the net force is not toward the centre of the circle	B and D (no mark for just one)	1
point(s) where the ball's weight force is perpendicular to the tension	B	1
	Total	**4**

(b) Write an expression for the net force acting on the string at point C in terms of the weight force and the tension in the string. (1 mark)

Description	Marks
$F_C = T + mg$ (could use F_{net})	1
Total	**1**

(c) Calculate how fast the 500 g ball can be moving at point A for the 1.20 m long string not to break, if the maximum tension it can withstand at point A is 172 N. (4 marks)

Description	Marks
At A: $T = Fc + mg$	1
$T = 0.5(v^2/1.2 + 9.8)$	1
$172/0.5 - 9.8 = v^2/1.2$ $v = 20.0$ m s^{-1}	1–2
Total	**4**

(d) Calculate the maximum speed at which the ball can be moving at point C for the string not to break at point A. (3 marks)

Description	Marks
At C: $E_{total} = 0.5mv_C^2 + mg \times 2.4 = m20^2/2$	1
$v_C = \sqrt{2(200 - 23.5)}$	1
$= 18.8 \text{ m s}^{-1}$	1
Total	**3**

2022 Section 3 Question 19

Gravity and motion

Kepler's three laws of planetary motion can be stated as follows:

1. All planets move about the Sun in elliptical orbits, having the Sun as one of the foci.
2. A radius vector joining any planet to the Sun sweeps out equal areas in equal lengths of time.
3. The squares of the periods (of revolution) of the planets are directly proportional to the cubes of their mean distances from the Sun.

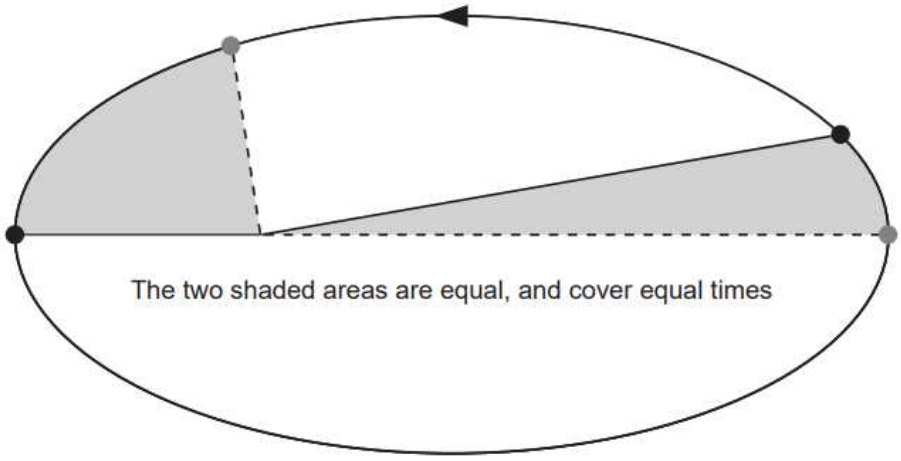


Figure 1: Kepler's 2nd Law

Kepler's 3rd Law, which appears on the Formulae and Data booklet, can be derived for a circular orbit from first principles: the centripetal force between the planet and the Sun is provided by Newton's Law of Gravitation, and $S = vT$, where S is the orbiting circumference and T is the period.

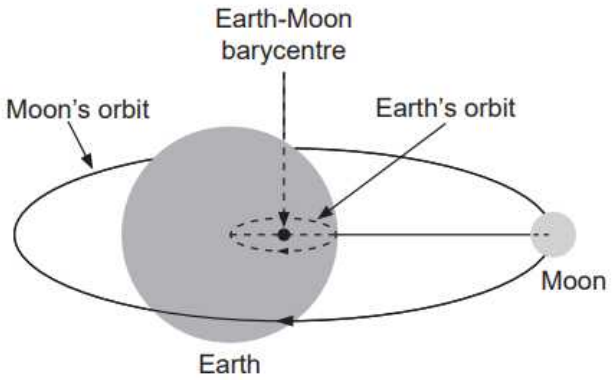


Figure 2: Location of Earth-Moon barycentre

The system of any large celestial body, and its satellite, orbits around a 'barycentre'. This represents the centre of mass of the system. The barycentre of the Earth–Moon system is shown in Figure 2. The system could be seen as a balance beam, with the barycentre located where the fulcrum would be placed to achieve equilibrium. The gravitational field strength due to the Sun is identical for both the Earth and Moon and therefore cancels out when calculating moments around the barycentre.

When the mass of the satellite represents a significant percentage of the system, the barycentre is outside either body. When its mass is significantly less, the barycentre is usually found within the more massive body which appears to 'wobble'. When the mass of the orbiting satellite is insignificant compared to the mass of the body it is orbiting, the barycentre can be assumed to be the centre of mass of the larger body.

(a) (i) Using Kepler's 2nd Law, describe the relationship between the distance a planet is from the Sun it orbits and its orbiting speed by filling in the blank below. (1 mark)

As the distance from the planet increases, the orbiting speed _____.

Description	Marks
decreases	1
Total	**1**

(ii) Without completing a calculation, justify this relationship with reference to Figure 1. (3 marks)

Description	Marks
The shaded areas in the diagram show the same time interval.	1
The satellite further from the Sun travels less distance in the same time.	1
Therefore the further from the Sun, the lower the speed.	1
Total	**3**

(b) Using the instructions given in the article, derive Kepler's 3rd Law from first principles, showing each step of the derivation. The final expression must match the equation in the Formulae and Data booklet. Assume the orbit is perfectly circular and the mass of the satellite is insignificant compared to the mass of the body it is orbiting. (5 marks)

Element	Description	Marks
Equates gravitational force to centripetal force.	$mMG/r^2 = mv^2/r$	1
Cancels mass and r	$MG/r = v^2$	1
Substitutes $2\pi r/T$ for v	$MG/r = 4\pi^2r^2/T^2$	1
Simplifies by cross multiplying	$T^2MG = 4\pi^2r^3$	1
Rearranges to match formula on data sheet	$T^2/r^3 = 4\pi^2/GM$	1
Total		**5**

(c) Using moments, estimate how far the barycentre of the Earth–Moon system is from the centre of the Earth. (4 marks)

Element	Description	Marks
Uses moments around barycentre to solve problem	$\Sigma cm = \Sigma acm$	1
Uses d and $(3.84 \times 10^8 - d)$ as distances	$5.97 \times 10^{24} \times g \times d$ $= 7.35 \times 10^{22} \times g \times (3.84 \times 10^8 - d)$	1
Solves for d	$d = 4.7 \times 10^6$ m	1
2 significant figures		1
Total		**4**

Alternate solution:

Element	Description	Marks
Uses moments around centre of Earth to solve problem	$\Sigma cm = \Sigma acm$	1
Uses $\Sigma m \times g \times d$ as acm	$(5.97 \times 10^{24} + 7.35 \times 10^{22}) \times g \times d$ $= 7.35 \times 10^{22} \times g \times 3.84 \times 10^8$	1
Solves for d	$d = 4.7 \times 10^6$ m	1
2 significant figures		1
Total		**4**

(d) With the use of a calculation and your answer to part (c), show that the Moon is travelling roughly 81 times faster than Earth as they orbit the barycentre. If you could not get an answer to part (c), use 4.81×10^6 m and show that the ratio of the Moon's orbiting velocity to that of the Earth is roughly 80. (4 marks)

Element	Description	Marks
Realises the period for both Earth and Moon are identical	T = 28 days (± 1 day only)	1
Uses $T = 2\pi r/v$	$2\pi r_m/v_m = 2\pi r_E/v_E$	1
Simplifies and uses correct radii	v_m/v_E $= (3.84 \times 10^8 - 4.670 \times 10^6)/4.670 \times 10^6$	1
Calculates correct answer	$v_m/v_E = 81.2$	1
	Total	**4**
Note: If used 4.81×10^6, $v_m/v_E = 78.8$, therefore roughly 80 times.		

2020 Section 3 Question 21

Gravity and motion

Wind turbines

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How do wind turbines work?

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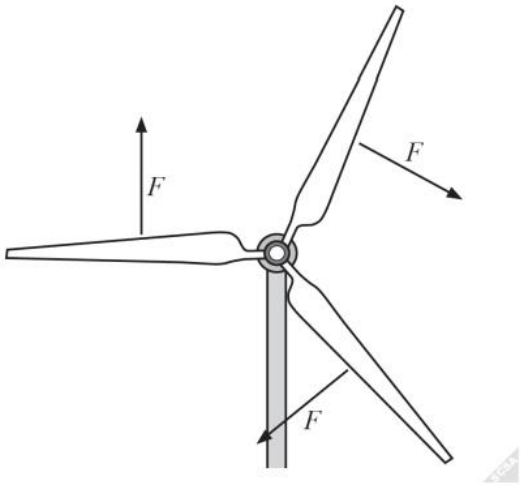

Wind turbine blades vary in length between 40 and 80 m.

A major problem with wind turbines is varying wind speed. The input power must match the output power. The output power depends entirely on rotational speed and torque so how do we keep rotational frequency constant when wind speed keeps changing? The solution is mechanical. The operators use blade pitch control which changes the angle of the blades and reduces the surface area facing the wind. This reduces the amount of energy collected by the turbine and controls the force applied to each blade.

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How the pitch is altered to control the rotational speed.

Each blade experiences a gravitational torque. If the clockwise and anticlockwise gravitational torques add up to zero, the turbine is considered balanced. A symmetrical three-blade turbine is considered balanced at all times.

(a) (i) Explain why a step-up transformer is used to increase the voltage before transporting the electricity into the National Grid. Use specific equations in your answer. (4 marks)

Description	Marks
It is more efficient to step-up the voltage.	1
$P = VI$ so if we increase V we have less current for the same power.	1
$P_{lost} = I^2R$ power is lost as heat	1
The lower the current, the lower the power lost due to heat.	1
Total	**4**

(ii) Calculate the output voltage of the transformer if the turbine produces 690 V and the ratio of turns is 100 in the primary coil to 2500 in the secondary coil. (2 marks)

Element	Description	Marks
uses ratio of coils = ratio of voltages correctly	$V_S = N_S V_P / N_P$	1
correct answer	= 2500 × 690/100 = 17.2 kV	1
	Total	**2**

(b) With specific reference to the text, explain why the pitch of the rotor blades is changed by the operators of the turbine. (4 marks)

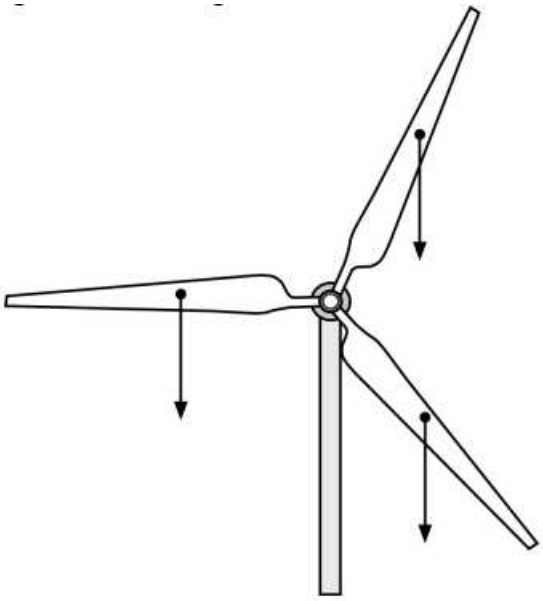
Description	Marks
The power input (wind energy) must match the power output (voltage produced).	1
The power output depends on rotational speed which must be kept constant.	1
The operators use pitch control which changes the angle of the blades.	1
This reduces or increases the amount of energy collected by the turbine and controls the force applied.	1
Total	**4**

(c) If the 60 m long blades on an average-sized turbine are rotating at 0.20 Hz, estimate the speed of the centre of mass of one of the blades. (4 marks)

Element	Description	Marks
Takes average length of 60 m and estimates the distance of COM from pivot as less than half of the length.	Take COM as 20 m from pivot	1
converts f to T	0.2 Hz = 5 s period	1
uses v = circ/T	$v = 2\pi \times 20/5 = 25$ m s^{-1}	1
two significant figures		1
	Total	**4**

Consider the three-blade turbine in the diagram to be rotating clockwise. The blade on the left hand side is parallel to the ground. The blades are identical in size and mass.

(d) (i) Draw the weight forces acting on the blades. (2 marks)



Description	Marks
all three mg drawn equal distance from axle along blade	1
all same size	1
Total	**2**

(ii) Show mathematically that the turbine is balanced in this position. (4 marks)

Element	Description	Marks
calculates angles correctly	Angle between blades is 120° therefore angle to calculate r is 60°	1
identifies acm and cm correctly in equation and	$(mg \times r\cos60) + (mg \times r\cos60) = mg \times r\cos0$	1
derives the correct moment equation		1
solves equation to show LHS = RHS	cos60 + cos60 = cos0 0.5 + 0.5 = 1.0	1
	Total	**4**

Unit 3 – Electromagnetism

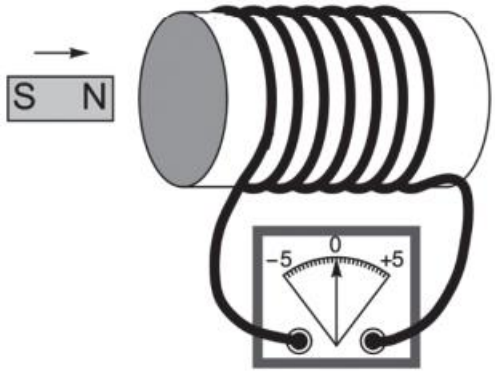
Section 1

2023 Section 1 Question 1 **Electro-magnetism**	A DC motor is attached to a 6.00 V supply, as shown in the diagram on the right. The square coil has a side length of 8.60 cm and contains 50 turns. The total resistance of the circuit is 3.00 Ω and it sits in a 3.70×10^{-3} T magnetic field. ***Copyright restrictions prohibit the release of this SCSA exam material.*** (a) Which way will the coil rotate when observed from X? Circle your answer. (1 mark) A. Clockwise B. Anticlockwise. (b) Calculate the magnitude of the initial torque on the coil in the position shown in the diagram. (4 marks) Answer _____ N m

2023 Section 1 Question 7

Electro-magnetism

The north pole of a bar magnet is moved at a constant speed of 0.370 m s^{-1} towards a coil of wire. The coil has seven turns and a cross sectional area of 0.0240 m^2 . The ends of the wire are connected to a galvanometer (which measures very small currents).



(a) State Lenz's law. (2 marks)

(b) With reference to Lenz's law, explain why the needle in the galvanometer moves to the left, i.e. the current in the galvanometer flows right to left. (3 marks)

(c) Explain why the emf induced in the coil is not constant, even though the speed of the magnet remains constant. (2 marks)

2023 Section 1 Question 12

Electro-magnetism

A metal bar of mass m is falling through a uniform horizontal magnetic field of strength B. The effective length of the bar in the field is ℓ. The bar, which maintains contact with the frictionless wire, completes an external circuit with a resistance of R. Derive an expression for the velocity of the bar in terms of m, g, R, B and ℓ given the velocity is constant.

Answer: v = _____

2022 Section 1 Question 3 **Electro-magnetism**	A simple AC generator is shown in the diagram below. A coil is manually rotated in a fixed magnetic field, producing an alternating current in the external circuit. Explain how the alternating current is produced, making specific reference to the labelled parts in the diagram. (4 marks) ***Copyright restrictions prohibit the release of this SCSA exam material.***

2022 Section 1 Question 7 **Electro-magnetism**	A group of students place a metal bar in a DC circuit, as shown in the diagram below. The bar is arranged horizontally between the poles of a horseshoe magnet. When they turn on the switch (K), they notice that the bar moves. ***Copyright restrictions prohibit the release of this SCSA exam material.*** (a) In which direction is the initial movement of the bar? Circle your answer. (1 mark) Left Right (b) Explain why the bar moved when the circuit was turned on. (3 marks)

2021 Section 1 Question 3

Electro-magnetism

A DC electric motor is shown in the diagram below. A current of 3.50 A is running through the single rectangular loop, which is pictured at 45.0° to a uniform 1.52 mT horizontal magnetic field.

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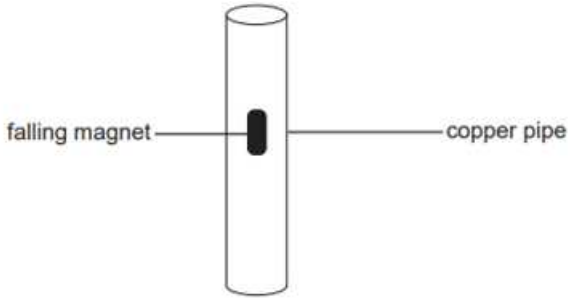
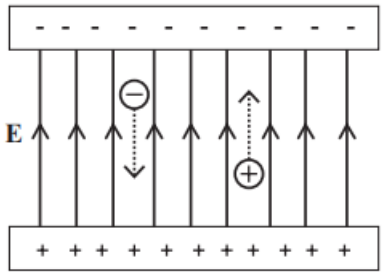
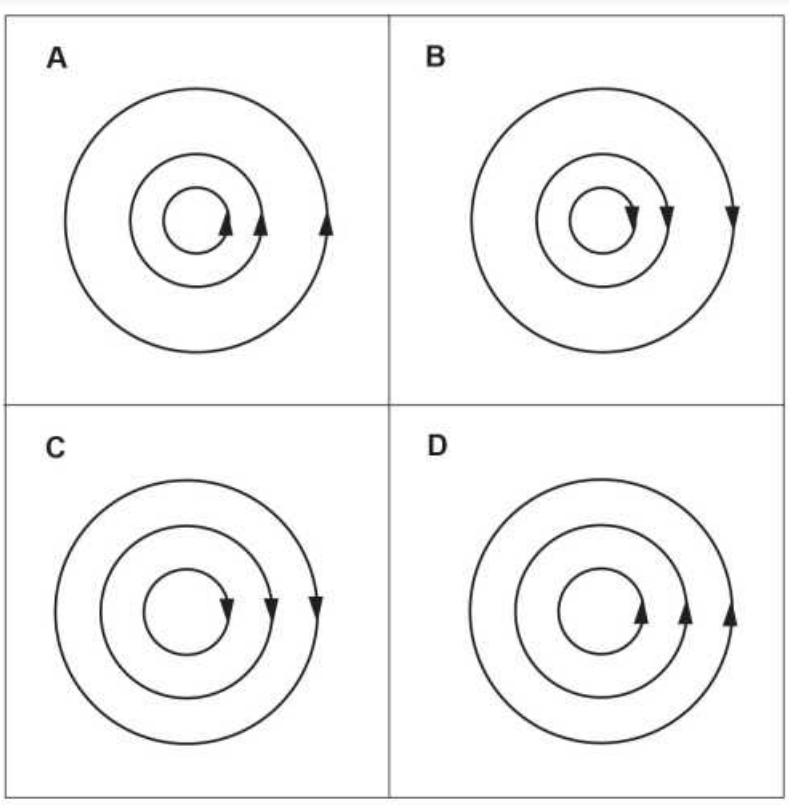
Calculate the magnitude and give the direction of the forces on sides AB and CD of the loop, using the directions provided in the table below. Write your answers in the table below. (4 marks)

Side	Force (N)	Direction (up, down, left, right, into the page, out of the page, no force)
AB		
CD		

2021 Section 1 Question 10 **Electro-magnetism**	A very strong 55.0 g neodymium magnet is dropped vertically down a hollow copper pipe. The eddy currents induced in the copper provide an upwards force which enables the magnet to reach a terminal velocity of 8.51 cm s^{-1}.  (a) Calculate the power supplied as heat to the pipe as the magnet falls at this velocity. (3 marks) Answer _____ W (b) Silver has a higher electrical conductivity than copper. How would your answer to part (a) change if the pipe was now made of silver? Circle your answer. (1 mark) (i) Increase (ii) Decrease (iii) No change

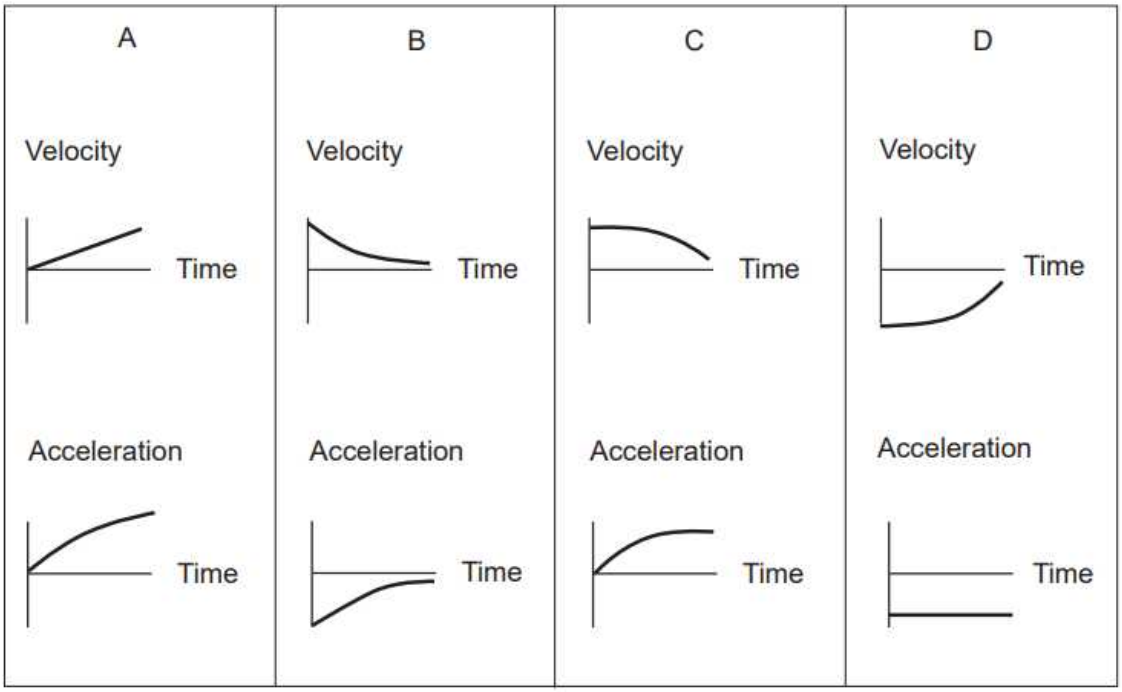
2021 Section 1 Question 11 **Electro-magnetism**	High-speed charged particles have many technological and scientific applications. One way of accelerating these particles to high speeds is by using strong electric fields.  (a) Through what potential difference would a proton at rest need to be accelerated for it to achieve a speed of 6.00 × 105 m s-1? (3 marks) Answer _____ V (b) What would be the final velocity of an electron accelerated from rest across the same potential difference? If you could not obtain an answer to part (a), use 2.00 kV as the potential difference. (3 marks) Answer _____ m s^{-1} (c) What is the ratio of the kinetic energies between the proton and electron once they cross the same potential difference? (1 mark) Answer _____

2020 **Section 1** **Question 4** **Electro-magnetism**	In a Physics experiment, a group of students run a DC current upwards through a 3.5 m long vertical wire. (a) Calculate the magnetic field strength 25.1 cm from the vertical wire carrying a current of 2.78 A. (3 marks) _____T (b) Looking from above, which of the following diagrams shows the magnetic field around the wire correctly? (1 mark)  Answer: _____

2020 Section 1 Question 6 **Electro-magnetism**	Calculate the electric field strength 2.25×10^{-3} m from a point charge of 4.00×10^{-18} C. _____ N C^{-1}

2020 Section 1 Question 7 **Electro-magnetism**	Students in a physics laboratory launch plastic discs across an aluminium air table. Air is blown vertically through small holes in the surface of the table, allowing the discs to float above the surface as they move. This is a nearly frictionless environment and the discs barely slow down as they cross the table. The students then attach a small but strong magnet on top of a disc and repeat the experiment. The disc slows down quite quickly, even though there is still no contact between it and the table. (a) Explain why the disc with the magnet slows down quickly. (4 marks)

(b) The students deduce that the retarding force on the disc with the magnet is proportional to the speed of the disc. Which set of velocity and acceleration versus time graphs below best describe the motion of the disk with the magnet? (1 mark)



Answer _____

2019 Section 1 Question 1

Electro-magnetism

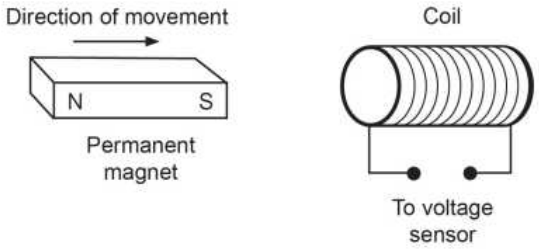
A straight conducting rod is placed in contact with, and at right angles to, two conducting rails 30 cm apart. A magnetic field of 0.4 T is perpendicular to both the rails and the rod, as shown in the diagram below. A current of 1.5 A flows from the supply through both the rails and the rod.

(a) (i) Draw an arrow showing the direction of the flow of conventional current in the circuit. (1 mark)

(ii) Draw an arrow on the conducting rod to show the direction of the force acting on it. (1 mark)

(b) Calculate the magnitude of the force referred to in part (a) (ii). (2 marks)

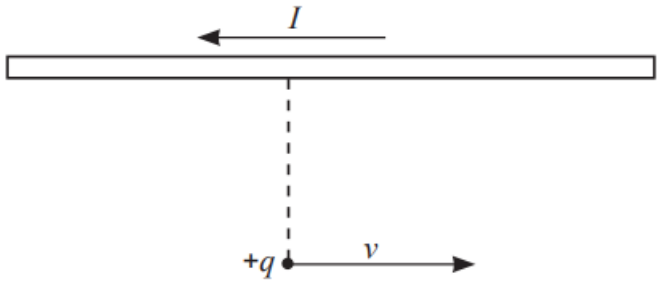
_____ N

2019 **Section 1** **Question 3** **Electro-magnetism**	A permanent magnet is moved toward a coil at a constant velocity causing an emf to be induced across the ends of the coil.  Using an appropriate equation from the Formulae and Data booklet, explain why a larger emf would be detected if the magnet was moved at a greater velocity toward the coil.

Section 2

2023 Section 2 Question 13

Electro-magnetism



A positive charge of 4.80×10^{-19} C is 35.0 cm below an extremely long straight wire carrying a current of 2.51 A to the left. The positive charge is moving parallel to the wire with a velocity of 1.57×10^{4} m s^{-1} to the right, at the instant shown in the diagram above.

(a) Calculate the strength of the magnetic field 35.0 cm from the wire. (3 marks)

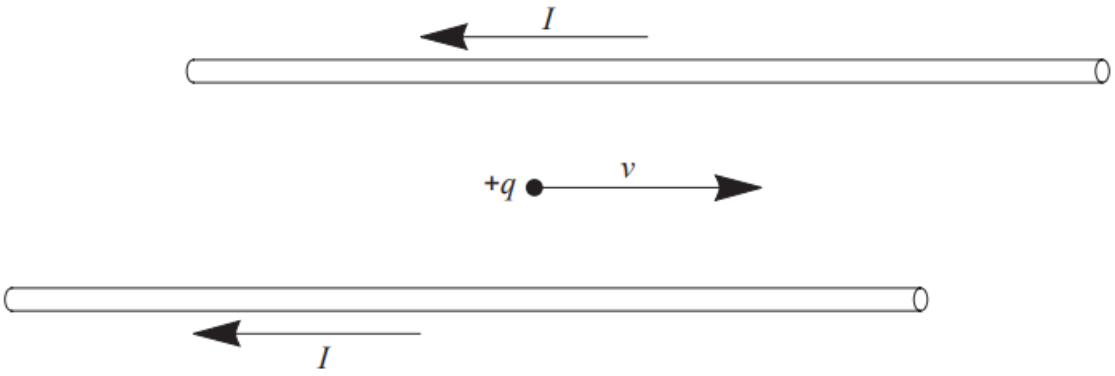
Answer: _____ T

(b) Calculate the force experienced by the particle as it moves through this magnetic field. Include the direction of the force in your answer. If you could not obtain an answer to part (a), use 2.51×10^{-6} T. (3 marks)

Answer: _____ N Direction: _____

(c) With reference to **two** relevant equations on the data sheet, discuss why the path the particle takes is not circular. (5 marks)

(d) The particle is now moving midway between two wires with equal currents flowing in the same direction. In this position, the particle experiences no net force.

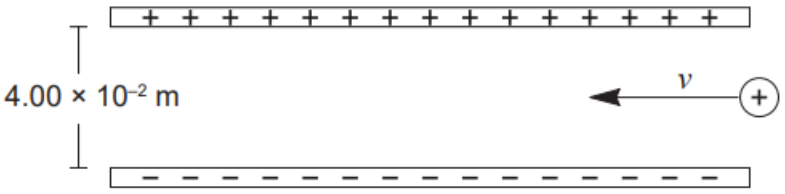


(i) The diagram below shows the view of the wires from the front left. The current is flowing out of the page. Draw the composite magnetic field generated by the two current-carrying wires. Indicate clearly the location of the charge *q* on your diagram. (4 marks)

(ii) Describe why the charge q experiences no net force in this position. (Ignore any gravitational effects.) (2 marks)

2023 Section 2 Question 18

Electro-magnetism



In an evacuated chamber, a proton enters an electric field at a speed of 1.79×10^6 m s^{-1} midway between two charged parallel plates and is initially moving parallel to them. The plates are 4.00×10^{-2} m apart and there is a potential difference of 4.80×10^3 V between them.

(a) (i) Calculate the downward force exerted on the proton by the electric field. (3 marks)

Answer: _____ N

(ii) Choose which mathematical relationship (A, B, C or D) describes the path taken by the proton when it enters the field. Circle your answer. (1 mark)

A. $y \propto x$ B. $y \propto \frac{1}{x}$ C. $y \propto \sqrt{x}$ D. $y \propto x^2$

(b) Given that the proton does not exit the field before hitting the bottom plate, how far from the right hand end of the bottom plate does the proton land? Ignore any effects due to gravity. (7 marks)

Answer: _____ m

	(c) Calculate the velocity of the proton just before it strikes the bottom plate. Include an angle in your answer. (6 marks) Answer: _____ m s^{-1} at _____ ° to the horizontal

2022 Section 2 Question 16

Electro-magnetism

Figure 1 shows a power station that supplies electricity to a small community. The owners decided to switch from DC generation to AC (Figure 2) to save costs and reduce greenhouse gas emissions.

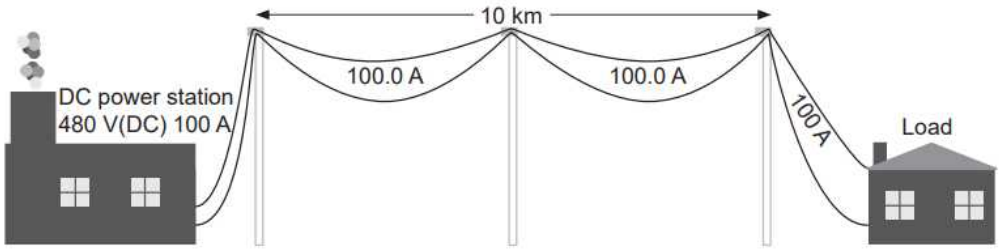


Figure 1: A DC power station

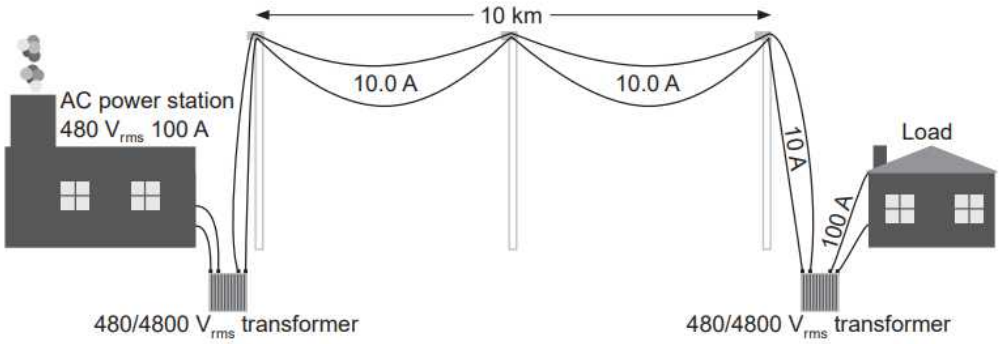


Figure 2: An AC power station

(a) Calculate the power output of both stations in kW. (2 marks)

DC power station

Answer: _____ kW

AC power station

Answer: _____ kW

(b) If the resistance of the transmission lines between the pylons is $2.19 \times 10^{-4}\ \Omega\ m^{-1}$, estimate the efficiencies of both systems by calculating power loss in the wires. Assume negligible power losses in the lines to the pylons from the station, and from the pylons to the houses. (6 marks)

DC power station: _____ % AC power station: _____ %

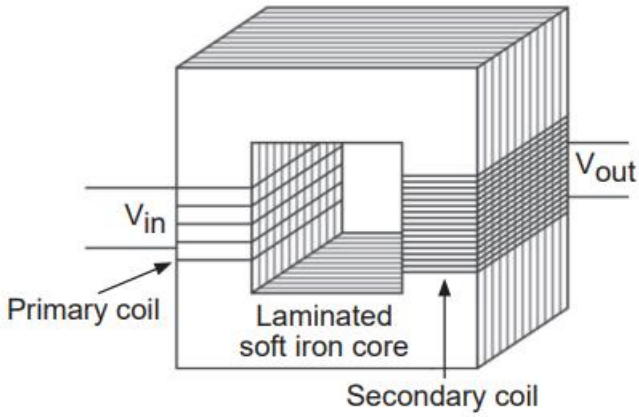


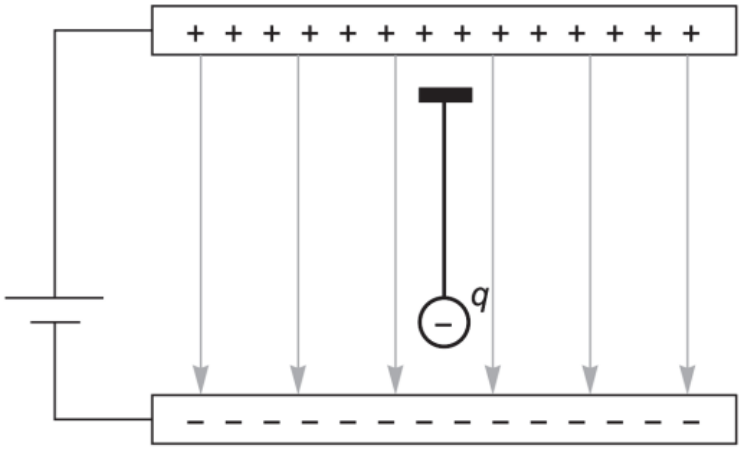
Figure 3: A step-up transformer with a laminated core

(c) Figure 3 shows a step-up transformer. One of the features that increases efficiency is the laminated soft iron core. Explain why laminating the core increases the transformer's efficiency. (3 marks)

(d) Explain why transformers require AC current to function in electricity transmission. (4 marks)

2021 Section 2 Question 14

Electro-magnetism



A 0.200 kg metal sphere with a net negative charge of 2.72 mC is suspended by a 0.800 m long almost massless string in a uniform electric field. The plates of the field are 1.20 m apart and the potential difference between the positive top and the negative bottom plate is 1.80×10^2 V.

(a) Calculate the strength of the electric field. (1 mark)

Answer _____ V m^{-1}

(b) Calculate the tension in the string. (4 marks)

Answer _____ N

(c) The sphere is pulled to one side and released. At the bottom of the swing, the sphere is travelling at 2.80 m s^{-1}.

(i) Draw a free body diagram of the forces acting on the sphere in this position. Label all forces. Do not show the net force acting on the sphere. (3 marks)

(ii) Derive an expression for the net force acting on the sphere in terms of the forces in your diagram. (1 mark)

F_{net} =

(iii) Calculate the tension in the string at the bottom of its swing. (4 marks)

Answer _____ N

2021 Section 2 Question 19

Electro-magnetism

A group of students wanted to calculate the strength of the Earth's magnetic field in Perth. They set up a DC circuit with a section of the wire placed 50.0 mm above a compass.

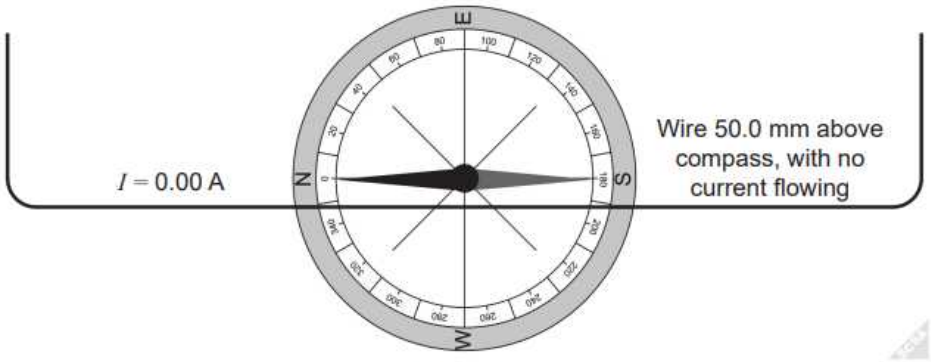


Figure 1

With no current running through the circuit, the compass lined up with the Earth's magnetic field as shown in Figure 1.

Figure 2

When they closed the switch, they saw the compass needle deflect at an angle of 80.0° to the wire as shown in Figure 2. The needle now pointed in the direction of the net magnetic field. The reading on the ammeter at this time was 3.70 A.

(a) Calculate the strength of the wire's magnetic field felt by the compass in the position described in Figure 2. (3 marks)

Answer _____ T

(b) Calculate the strength of the horizontal component of the Earth's magnetic field. (4 marks)

Answer _____ T

(c) The Earth's magnetic field is at an angle of 66.0° to its surface in Perth. This is called the 'angle of dip'. Use this information to calculate the overall strength of the Earth's magnetic field in Perth. (3 marks)

Answer _____ T

2020 Section 2 Question 16

Electro-magnetism

A group of physics students made a simple AC generator in class. It had 150 turns of wire in the 6.00 cm wide square coil and was placed in a magnetic field of strength 1.85×10^2 mT. They connected the handle to a motor which rotated it at 240 rpm and used the electricity produced to power a light globe.

(a) Calculate the maximum EMF produced by the generator. (5 marks)

_____ V

(b) Calculate the RMS voltage produced. (1 mark)

_____ V

The students removed the motor and turned the handle themselves, maintaining a constant speed of rotation. They noticed that the force required to turn it varied as the coil rotated. They also noticed that the light bulb glowed brightest when the force required was greatest and went out when the force required was virtually zero.

(c) (i) Explain why the force required varied as the handle went through one rotation. (3 marks)

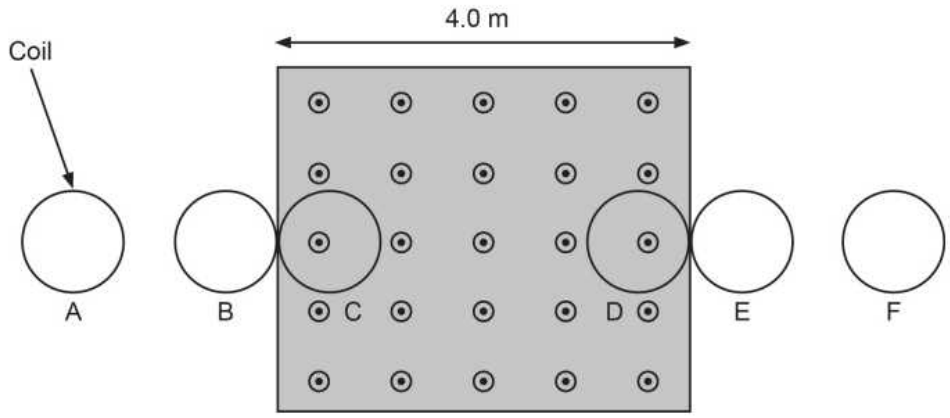
(ii) In what position was the plane of the rotating coil relative to the field when the light bulb went out? Explain why it went out. (3 marks)

2019 Section 2 Question 18

Electro-magnetism

A coil with a radius of 50.0 cm and 25 turns is moved at a constant velocity of 0.80 m s^{-1} to the right of the page into, through and out of a uniform magnetic field of strength 0.28 T.

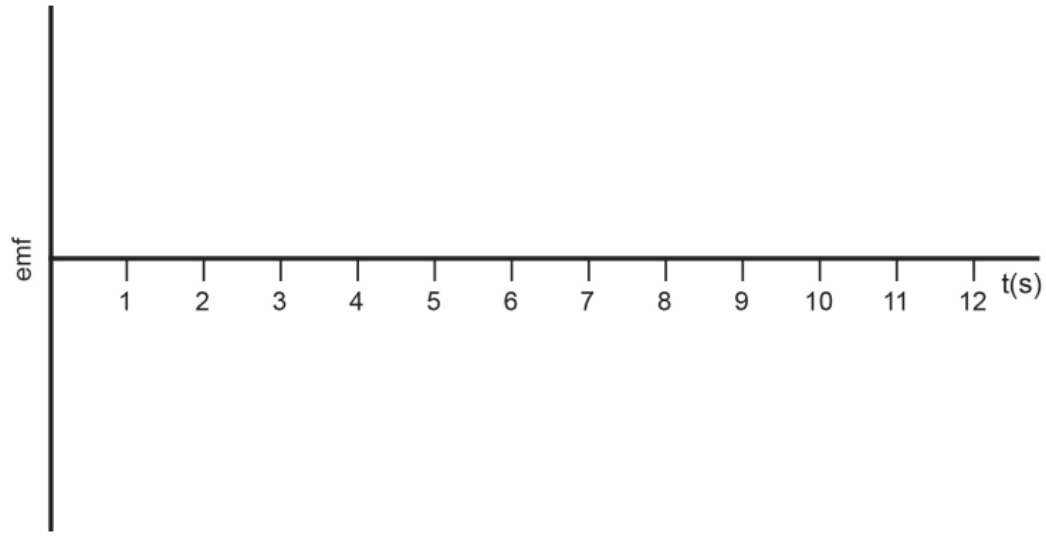
The total distance from the centre of the coil at A to the centre of the coil at F is 8.00 m and the distance from A to B is the same as E to F.

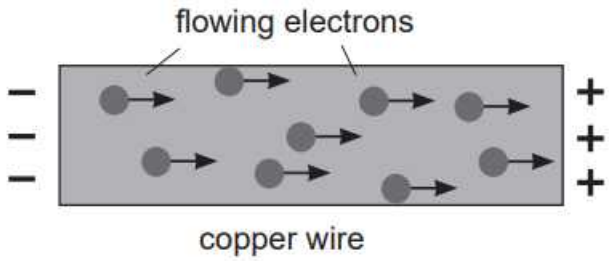


(a) Calculate the average emf induced as the coil moves from B to C. (4 marks)

_____ V

(b) On the axes below, show the induced emf versus time as the coil moves from A to F. (Note: only include specific values on the time axis.) (8 marks)



2021 Section 3 Question 21 Electro-magnetism	**Drift velocity** When you turn on a light, it comes on as soon as the circuit is complete. The energy flowing in the circuit is transferred almost instantly. But how fast do the charged particles, which carry that energy, move? It turns out that they move extremely slowly. This velocity is called the drift velocity and it depends on several factors. The equation is given below: $$v_D = \frac{I}{nAq}$$ where, • I is the current flowing through the conductor, measured in amperes • n is the electron density in m^{-3} • A is the area of the cross-section of the conductor, measured in m^2 • v_D is the drift velocity of the electrons, measured in m s^{-1} • q is the charge of an electron, measured in coulombs.  (a) Calculate the drift velocity of electrons if a current of 3.00 A is flowing in a copper wire with a cross-sectional area of 1.00 mm^2. (3 marks) For copper, n = 8.50 × 1028 m^{-3}. Answer _____ m s^{-1}

Another way of measuring drift velocity uses what is called the Hall Effect. This occurs when a current flows through a flat piece of metal placed in an external magnetic field. This is shown in the diagram below.

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The negatively charged particles experience a force due to the magnetic field and move to one side of the metal strip. This sets up a potential difference, and therefore an electric field, between the sides of the strip. This potential difference can be measured by a voltmeter (V_H). Dividing V_H by the width of the strip (w) will give us the strength of the electric field created:

$$E = \frac{V_H}{w}$$

If the strip is moved with the same velocity as the charge carriers but in the opposite direction, their relative velocity in the field is now zero; and therefore, there is no force placed upon them by the magnetic field. At this stage, the voltmeter would read 0 V. By measuring how fast the strip is moving, we can calculate drift velocity

The magnetic force on the charged particles is:

$$F_M = qv_D B$$

where v_D is the drift velocity of the charge.

When the strip is not moving and the system reaches equilibrium, V_H remains constant and the force exerted on the charge carriers by the magnetic field (F_M) is equal to the force due to the electric field between the edges of the strip (F_E). By substitution, it can be shown that:

$$F_E = \frac{V_H q}{w}$$

(b) With reference to the text, explain why V_H reduces to zero when the strip is moved in the correct direction at the correct speed. (4 marks)

(c) Explain why increasing the magnitude of the magnetic field will increase V_H for a stationary strip when equilibrium is restored. (3 marks)

(d) The article says: '*By substitution, it can be shown that:* $F_E = \frac{V_H q}{w}$ '. Derive this equation from information supplied in the article. (2 marks)

(e) Calculate V_H if the dimensions of the copper strip are w = 3.00 cm and d = 0.100 cm, B = 3.50 T and I = 26.0 A. Use electrons as the charge carriers in your calculation. (6 marks)

For copper, $n = 8.50 \times 10^{28}$ m^{-3}.

Answer _____ V

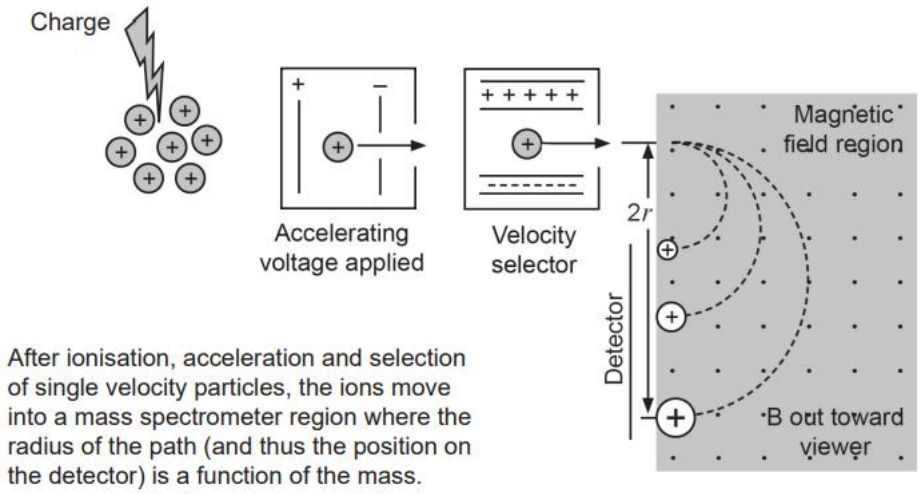
2019 Section 3 Question 19

Electro-magnetism

Mass spectrometer

The mass spectrometer is an instrument that can measure the masses and relative concentrations of atoms in a mixed sample. It makes use of the magnetic force on a moving charged particle.

Different elements are ionised so they all have a charge of +1. They are then accelerated across a potential difference that increases their velocities. They move through a velocity selector and are then fired into a magnetic field where they undergo circular motion and land on a detector. The different masses of the elements will determine where they land on the detector. The concentration of each element can be determined by how many ions land in the one place.



After ionisation, acceleration and selection of single velocity particles, the ions move into a mass spectrometer region where the radius of the path (and thus the position on the detector) is a function of the mass.

Velocity selector

In many experiments involving moving charged particles, it is important that the particles all move with essentially the same velocity. This can be achieved by applying a combination of an electric field and a magnetic field oriented as shown in the diagram above. A uniform electric field is directed vertically downward, and a uniform magnetic field is applied in the direction perpendicular to the electric field and into the page. For positive particles, the magnetic force is equal to qvB upward and the electric force (qE) is downward.

(a) Give an expression for the radius of a charged particle's path when fired into a uniform magnetic field. (1 mark)

$r =$

(b) Explain why it is important to make sure that all the ions that enter the detector have the same velocity. (3 marks)

(c) Below is a table of ions and their masses in kg.

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An unknown ion enters the detector at 9.24 × 104 m s^{-1}. It strikes the detector plate 12.38 cm from the entrance point. If the magnetic field strength is 3.50 T, calculate the mass of the unknown particle and identify it from the table above. (5 marks)

_____ kg Particle: _____

(d) Calculate the accelerating voltage needed for the ion to attain a velocity of 9.24 × 10^4 m s^{-1} when entering the velocity selector. If you could not obtain an answer to part (c), use 3.11 × 10^{-25} kg. (4 marks)

_____ V

(e) The velocity selector shown on page 29 *(above)* uses a combination of electric and magnetic fields to select only ions with a specific velocity to enter the detector. These ions travel directly across the selector parallel to the charged plates. Derive an expression for the selected velocity in terms of *B* and *E*. (3 marks)

	(f) Explain in detail why an ion travelling at a velocity greater than the selected velocity would not enter the detector. Use the diagram below to show the path the ion would take. (4 marks) ***Copyright restrictions prohibit the release of this SCSA exam material.***

2023 Section 1 Question 1

Electro-magnetism

A DC motor is attached to a 6.00 V supply, as shown in the diagram on the right. The square coil has a side length of 8.60 cm and contains 50 turns. The total resistance of the circuit is 3.00 Ω and it sits in a 3.70×10^{-3} T magnetic field.

(a) Which way will the coil rotate when observed from X? Circle your answer. (1 mark)

A. Clockwise
B. Anticlockwise.

Description	Marks
clockwise	1
Total	**1**

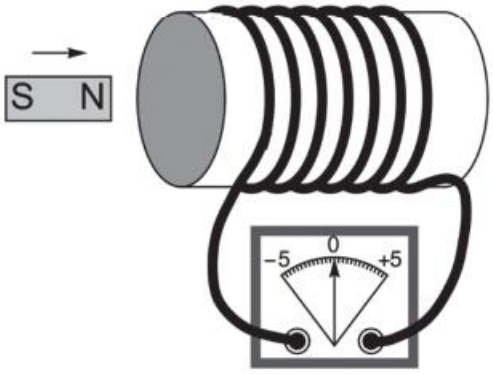
(b) Calculate the magnitude of the initial torque on the coil in the position shown in the diagram. (4 marks)

Element	Description	Marks
Calculates current	$I = \frac{V}{R} = \frac{6.00}{3.00} = 2.00$ A	1
Substitutes $BI\ell$ for F	Torque = $2rBI\ell N$	1
Substitutes values	Torque = $50 \times 3.70 \times 10^{-3} \times 2.00 \times (0.0860)^2$	1
Calculates answer	Torque = 2.74×10^{-3} N m	1
	Total	**4**

2023 Section 1 Question 7

Electro-magnetism

The north pole of a bar magnet is moved at a constant speed of 0.370 m s^{-1} towards a coil of wire. The coil has seven turns and a cross sectional area of 0.0240 m^2 . The ends of the wire are connected to a galvanometer (which measures very small currents).



(a) State Lenz's law. (2 marks)

Description	Marks
the direction of the induced current by a changing magnetic field is such that the magnetic field created opposes the changes in the initial magnetic field	1–2
Total	**2**
Note: must have all components of the Law to achieve full marks	

(b) With reference to Lenz's law, explain why the needle in the galvanometer moves to the left, i.e. the current in the galvanometer flows right to left. (3 marks)

Description	Marks
as the north pole of the magnet approaches, the area in the solenoid experiences a change in flux	1
this induces a north pole at the left end of the solenoid	1
current flows from right to left in the galvanometer in order to achieve this	1
Total	**3**

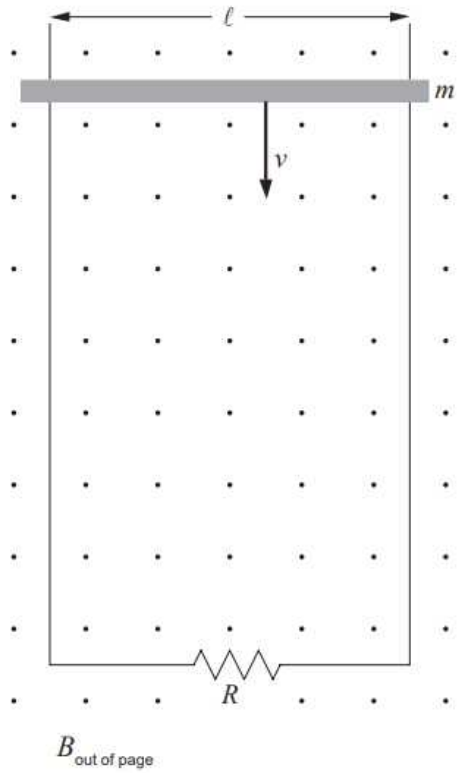
(c) Explain why the emf induced in the coil is not constant, even though the speed of the magnet remains constant. (2 marks)

Description	Marks
the magnetic field around the magnet is not uniform	1
therefore the rate of change of flux is not constant so neither is the induced emf in the solenoid	1
Total	**2**

2023 Section 1 Question 12

Electro-magnetism

A metal bar of mass m is falling through a uniform horizontal magnetic field of strength B. The effective length of the bar in the field is ℓ. The bar, which maintains contact with the frictionless wire, completes an external circuit with a resistance of R. Derive an expression for the velocity of the bar in terms of m, g, R, B and ℓ given the velocity is constant.



Element	Description	Marks
Equates F_{up} to F_{down}		1
Substitutes correct expressions for forces	$BI\ell = mg$	1
Uses Ohm's Law to get expression for current	$I = \frac{\text{emf}}{R}$	1
Substitutes $Bv\ell$ for emf		1
Combines equations	$B \times Bv\ell \times \frac{\ell}{R} = mg$	1
Simplifies and isolates v	$v = \frac{mgR}{B^2\ell^2}$	1
	Total	**6**

2022 Section 1 Question 3

Electro-magnetism

A simple AC generator is shown in the diagram below. A coil is manually rotated in a fixed magnetic field, producing an alternating current in the external circuit. Explain how the alternating current is produced, making specific reference to the labelled parts in the diagram. (4 marks)

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Description	Marks
As the coil rotates, each side travels up or down, cutting across the magnetic flux present.	1
The current induced in each side of the coil changes direction every half turn of the coil.	1
Each side of the coil is attached to the external circuit by a slip ring.	1
The slip ring maintains sliding contact with the carbon brushes so the current in each ring changes direction every half turn, which produces an AC current.	1
Total	**4**

2022 Section 1 Question 7

Electro-magnetism

A group of students place a metal bar in a DC circuit, as shown in the diagram below. The bar is arranged horizontally between the poles of a horseshoe magnet. When they turn on the switch (K), they notice that the bar moves.

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(a) In which direction is the initial movement of the bar? Circle your answer. (1 mark)

Description	Marks
Left	1
Total	**1**

(b) Explain why the bar moved when the circuit was turned on. (3 marks)

Description	Marks
There is a magnetic field between the poles of the magnet.	1
Moving charged particles generate a magnetic field.	1
The two magnetic fields interact, producing a force to the left.	1
Total	**3**

Alternate solution:

Description	Marks
The bar has a flow of current which is moving through the magnetic field between the poles of the magnet.	1
Charges moving through a magnetic field experience a force given by $F = qvB$ ($F = BIL$ on the rod)	1
The force on the charges (rod) will be perpendicular to their motion and the external magnetic field.	1
Total	**3**

2021 Section 1 Question 3

Electro-magnetism

A DC electric motor is shown in the diagram below. A current of 3.50 A is running through the single rectangular loop, which is pictured at 45.0° to a uniform 1.52 mT horizontal magnetic field.

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Calculate the magnitude and give the direction of the forces on sides AB and CD of the loop, using the directions provided in the table below. Write your answers in the table below. (4 marks)

1 mark for each correct box.

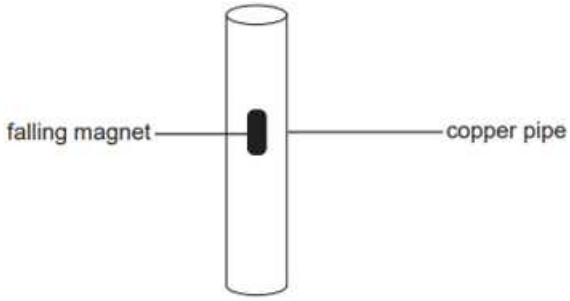
Description	Marks
Directions correct	1–2
Forces correctly calculated	1–2
Total	**4**

Side	Force (N)	Direction (up, down, left, right, into the page, out of the page, no force)
AB	$F = BIl = 1.52 \times 10^{-3} \times 3.50 \times 5.00 \times 10^{-2} = 2.66 \times 10^{-4}$ N	down
CD	2.66×10^{-4} N	up
Note: 1 mark if AB = CD but value incorrect. 1 mark for direction of AB opposite to CD if AB is incorrect.		

2021 Section 1 Question 10

Electro-magnetism

A very strong 55.0 g neodymium magnet is dropped vertically down a hollow copper pipe. The eddy currents induced in the copper provide an upwards force which enables the magnet to reach a terminal velocity of 8.51 cm s^{-1}.



(a) Calculate the power supplied as heat to the pipe as the magnet falls at this velocity. (3 marks)

Element	Description	Marks
Power = change in potential energy per second. $h/t = v$	$P = \Delta mgh/t = mgv$	1
	$P = 0.0550 \times 9.80 \times 0.0851$	1
Correctly calculates answer	$P = 4.59 \times 10^{-2}$ W	1
	Total	**3**

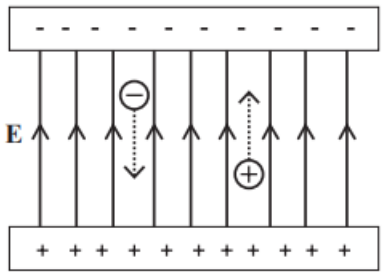
(b) Silver has a higher electrical conductivity than copper. How would your answer to part (a) change if the pipe was now made of silver? Circle your answer. (1 mark)

Description	Marks
(ii) Decrease	1
Total	**1**

2021 Section 1 Question 11

Electro-magnetism

High-speed charged particles have many technological and scientific applications. One way of accelerating these particles to high speeds is by using strong electric fields.



(a) Through what potential difference would a proton at rest need to be accelerated for it to achieve a speed of 6.00 × 105 m s-1? (3 marks)

Element	Description	Marks
Kinetic energy gained = potential energy lost	$Vq = mv^2/2$	1
Correctly rearranges formula for V	$V = 1.67 \times 10^{-27} \times (6.00 \times 10^5)^2 / 2 \times 1.60 \times 10^{-19}$	1
Correctly calculates answer	1.88×10^3 V	1
	Total	**3**

(b) What would be the final velocity of an electron accelerated from rest across the same potential difference? If you could not obtain an answer to part (a), use 2.00 kV as the potential difference. (3 marks)

Element	Description	Marks
Same as part a only rearranges for v	$v = \sqrt{2\,V\,q/m}$	1
Uses m(e)	$v = \sqrt{\frac{2 \times 1.88 \times 10^{3} \times 1.60 \times 10^{-19}}{9.11 \times 10^{-31}}}$	1
	$v = 2.57 \times 10^{7}$ m s^{-1}	1
If uses 2.00 kV	$v = 2.65 \times 10^{7}$ m s^{-1}	
	Total	**3**

(c) What is the ratio of the kinetic energies between the proton and electron once they cross the same potential difference? (1 mark)

Description	Marks
1:1	1
Total	**1**

2020 Section 1 Question 4

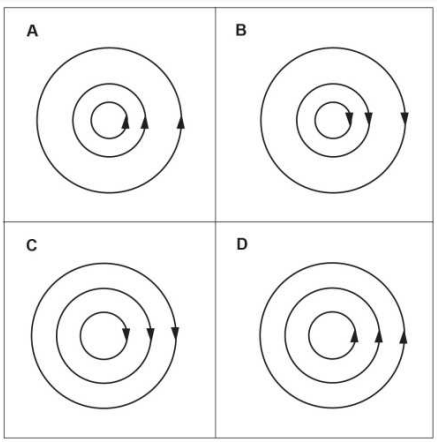
Electro-magnetism

In a Physics experiment, a group of students run a DC current upwards through a 3.5 m long vertical wire.

(a) Calculate the magnetic field strength 25.1 cm from the vertical wire carrying a current of 2.78 A. (3 marks)

Element	Description	Marks
correct constant and conversion from cm to m	$B = (1.26 \times 10^{-6}) \times 2.78/(2\pi \times 0.251)$	1–2
correct answer	2.22×10^{-6} T	1
	Total	**3**

(b) Looking from above, which of the following diagrams shows the magnetic field around the wire correctly? (1 mark)



Description	Marks
A	1
Total	**1**

2020 Section 1 Question 6

Electro-magnetism

Calculate the electric field strength 2.25×10^{-3} m from a point charge of 4.00×10^{-18} C.

Element	Description	Marks
uses Coulomb's Law	$F = qq/4\pi\varepsilon r^2$	1
divides both sides by q to get E on LHS and eliminate q on RHS	$E = q/4\pi\varepsilon r^2$	1
uses correct constant and squares r	$E = (4.00 \times 10^{-18})/(4\pi \times 8.85 \times 10^{-12}) \times (2.25 \times 10^{-3})^2$	1
correct/consistent numerical answer	7.11×10^{-3} N C^{-1}	1
	Total	**4**

2020 Section 1 Question 7

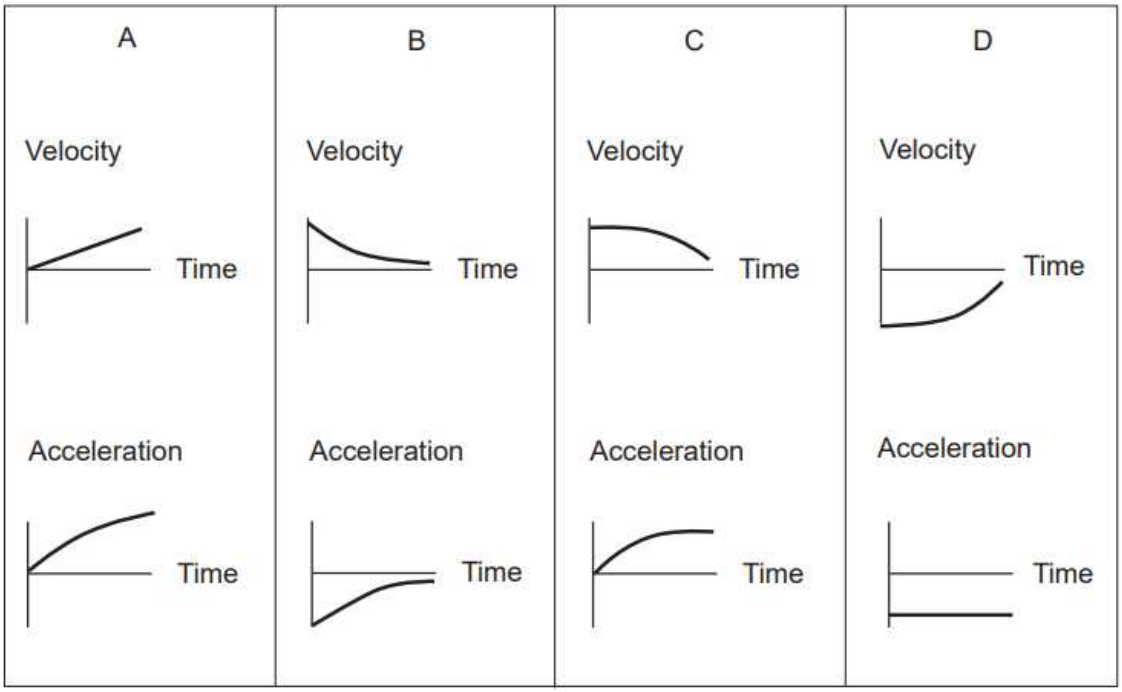
Electro-magnetism

Students in a physics laboratory launch plastic discs across an aluminium air table. Air is blown vertically through small holes in the surface of the table, allowing the discs to float above the surface as they move. This is a nearly frictionless environment and the discs barely slow down as they cross the table. The students then attach a small but strong magnet on top of a disc and repeat the experiment. The disc slows down quite quickly, even though there is still no contact between it and the table.

(a) Explain why the disc with the magnet slows down quickly. (4 marks)

Description	Marks
aluminium is a conductor	1
The changing magnetic field due to the magnet moving induces eddy currents in the aluminium.	1
Lenz's Law states that an induced current will flow in a way to oppose the change producing it.	1
The disc experiences a retarding force so it slows down.	1
Total	**4**

(b) The students deduce that the retarding force on the disc with the magnet is proportional to the speed of the disc. Which set of velocity and acceleration versus time graphs below best describe the motion of the disk with the magnet? (1 mark)



Answer _____

Description	Marks
B	1
Total	**1**

2019 Section 1 Question 1

Electro-magnetism

A straight conducting rod is placed in contact with, and at right angles to, two conducting rails 30 cm apart. A magnetic field of 0.4 T is perpendicular to both the rails and the rod, as shown in the diagram below. A current of 1.5 A flows from the supply through both the rails and the rod.

(a) (i) Draw an arrow showing the direction of the flow of conventional current in the circuit. (1 mark)

Description	Marks
draws one arrow away from positive **or** draws one arrow towards the negative.	1
Total	**1**

(ii) Draw an arrow on the conducting rod to show the direction of the force acting on it. (1 mark)

Description	Marks
arrow pointing to the right	1
Total	**1**

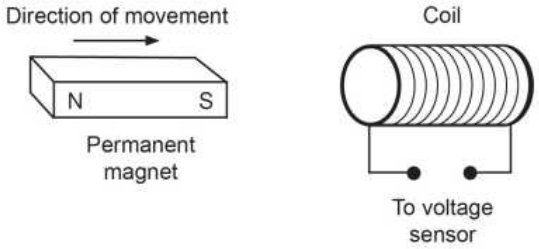
(b) Calculate the magnitude of the force referred to in part (a) (ii). (2 marks)

Description	Marks
$F = BIl$	
= 0.4 × 1.5 x 0.3	1
= 0.18N	1
Total	**2**

2019 Section 1 Question 3

Electro-magnetism

A permanent magnet is moved toward a coil at a constant velocity causing an emf to be induced across the ends of the coil.

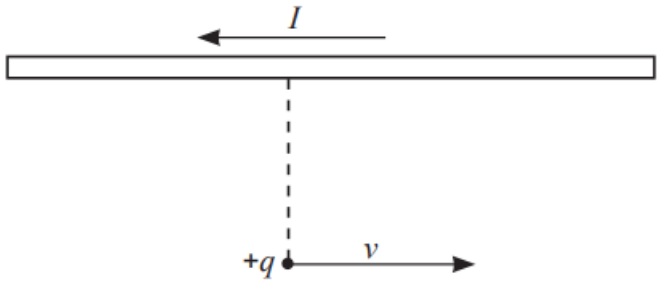


Using an appropriate equation from the Formulae and Data booklet, explain why a larger emf would be detected if the magnet was moved at a greater velocity toward the coil.

Description	Marks
$EMF = -N(\Delta BA/\Delta t)$	1
EMF is proportional to rate of change of flux. N, B and A remain constant. As velocity increases, Δt decreases therefore EMF increases	1–3
Total	**4**

2023 Section 2 Question 13

Electro-magnetism



A positive charge of 4.80×10^{-19} C is 35.0 cm below an extremely long straight wire carrying a current of 2.51 A to the left. The positive charge is moving parallel to the wire with a velocity of 1.57×10^{4} m s^{-1} to the right, at the instant shown in the diagram above.

(a) Calculate the strength of the magnetic field 35.0 cm from the wire. (3 marks)

Element	Description	Marks
Uses correct equation	$B = \frac{u_0 I}{2\pi r}$	1
Substitutes correct constant and simplifies	$B = \frac{4\pi \times 10^{-7} \times 2.51}{2\pi \times 0.350}$ $= \frac{2 \times 10^{-7} \times 2.51}{0.350}$	1
Calculates answer	1.43×10^{-6} T	1
	Total	**3**

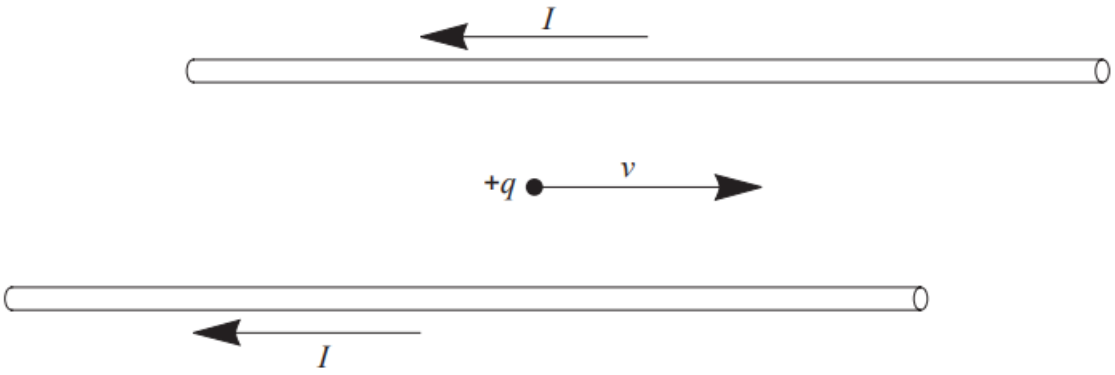
(b) Calculate the force experienced by the particle as it moves through this magnetic field. Include the direction of the force in your answer. If you could not obtain an answer to part (a), use 2.51×10^{-6} T. (3 marks)

Element	Description	Marks
Substitutes correct values into $F = Bvq$	$F = 4.80 \times 10^{-19} \times 1.57 \times 10^{4} \times 1.43 \times 10^{-6}$	1
Calculates answer	$F = 1.08 \times 10^{-20}$ N	1
Includes direction	down	1
	Total	**3**
Note: if uses 2.51×10^{-6} T, $F = 1.89 \times 10^{-20}$ N		

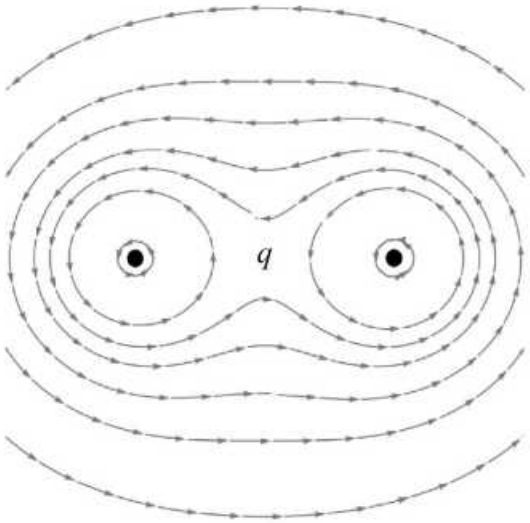
(c) With reference to **two** relevant equations on the data sheet, discuss why the path the particle takes is not circular. (5 marks)

Description	Marks
$B = \frac{u_0 I}{2\pi r}$ and $r = \frac{mv}{Bq}$	1
B is inversely proportional to r so as r increases, B decreases	1
B is not constant as particle moves away from the wire	1
$r = \frac{mv}{Bq}$ assumes B, q and m are constant	1
B is not constant therefore motion is not circular	1
Total	**5**

(d) The particle is now moving midway between two wires with equal currents flowing in the same direction. In this position, the particle experiences no net force.



(i) The diagram below shows the view of the wires from the front left. The current is flowing out of the page. Draw the composite magnetic field generated by the two current-carrying wires. Indicate clearly the location of the charge *q* on your diagram. (4 marks)



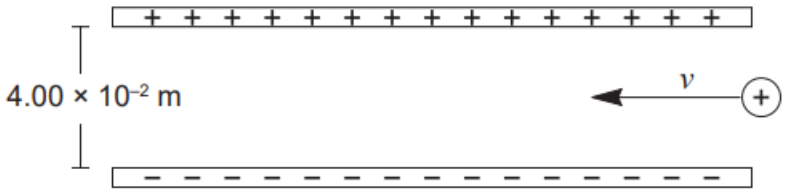
Description	Marks
Fields must be anti-clockwise shown with arrows	1
Must show composite field lines around each wire	1
At least two composite field lines must be shown that do not touch or cross	1
Drawing must show *q* equidistant from each wire	1
Total	**4**

(ii) Describe why the charge q experiences no net force in this position. (Ignore any gravitational effects.) (2 marks)

Description	Marks
at the location of the charge, the two fields cancel each other out (neutral point)	1
therefore the charge experiences no net force	1
Total	**2**

2023 Section 2 Question 18

Electro-magnetism



In an evacuated chamber, a proton enters an electric field at a speed of 1.79×10^6 m s^{-1} midway between two charged parallel plates and is initially moving parallel to them. The plates are 4.00×10^{-2} m apart and there is a potential difference of 4.80×10^3 V between them.

(a) (i) Calculate the downward force exerted on the proton by the electric field. (3 marks)

Element	Description	Marks
Uses $E = \frac{V}{d} = \frac{F}{q}$ to get expression for F	$F = \frac{Vq}{d}$	1
Substitutes correct values into equation	$F = \frac{4.80 \times 10^3 \times 1.60 \times 10^{-19}}{4.00 \times 10^{-2}}$	1
Calculates correct answer	$F = 1.92 \times 10^{-14}$ N	1
	Total	**3**

(ii) Choose which mathematical relationship (A, B, C or D) describes the path taken by the proton when it enters the field. Circle your answer. (1 mark)

A. $y \propto x$ B. $y \propto \frac{1}{x}$ C. $y \propto \sqrt{x}$ D. $y \propto x^2$

Description	Marks
D. $y \propto x^2$	1
Total	**1**

(b) Given that the proton does not exit the field before hitting the bottom plate, how far from the right hand end of the bottom plate does the proton land? Ignore any effects due to gravity. (7 marks)

Element	Description	Marks
Uses $s = ut + 0.5at^2$ to calculate time to hit plate		1
Uses $u = 0$		1
Uses $a = F/m$		1
Uses $s = 2.00 \times 10^{-2}$ m	$0.02 = 0 + 0.5\left(\frac{1.92 \times 10^{-14}}{1.67 \times 10^{-27}}\right)t^2$	1
Isolates t correctly	$t = \sqrt{\frac{0.04}{1.15 \times 10^{13}}}$	1
Calculates t correctly	$t = 5.90 \times 10^{-8}$ s	1
Calculates distance using $s = vt$	$s = 1.79 \times 10^6 \times 5.90 \times 10^{-8} = 0.106$ m	1
	Total	**7**

(c) Calculate the velocity of the proton just before it strikes the bottom plate. Include an angle in your answer. (6 marks)

Element	Description	Marks
Calculates v_v using $v = u + at$ where $u = 0$		1
Uses t from part (b)	$v_v = 0 + (1.15 \times 10^{13}) \times 5.90 \times 10^{-8}$ $= 6.78 \times 10^5$ m s^{-1}	1
Uses Pythagoras to calculate v_{net}	$v_{net}^2 = (6.78 \times 10^5)^2 + (1.79 \times 10^6)^2$	1
Calculates correct answer	$v_{net} = 1.91 \times 10^6$ m s^{-1}	1
Uses a correct trig function	e.g. $\tan\theta = \frac{6.78\times10^5}{1.79\times10^6}$	1
Calculates angle correctly	$\theta = 20.7°$	1
	Total	**6**

2022 Section 2 Question 16

Electro-magnetism

Figure 1 shows a power station that supplies electricity to a small community. The owners decided to switch from DC generation to AC (Figure 2) to save costs and reduce greenhouse gas emissions.

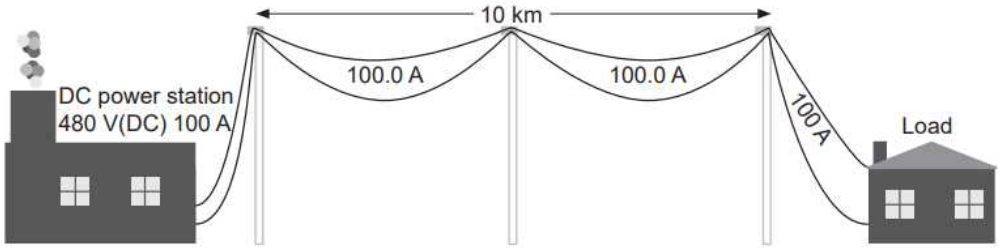


Figure 1: A DC power station

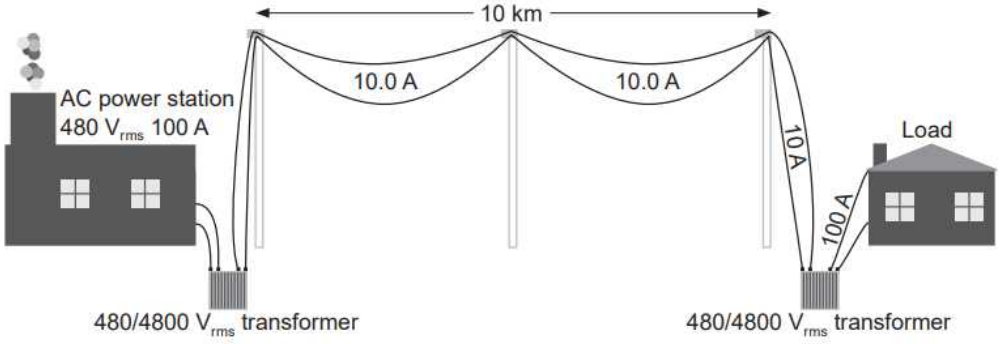


Figure 2: An AC power station

(a) Calculate the power output of both stations in kW. (2 marks)

Element	Description	Marks
Uses $P = VI$	$P = 480 \times 100 = 48\,000$ W	1
Converts to kW	48.0 kW	1
	Total	**2**

(b) If the resistance of the transmission lines between the pylons is $2.19 \times 10^{-4}\ \Omega\ m^{-1}$, estimate the efficiencies of both systems by calculating power loss in the wires. Assume negligible power losses in the lines to the pylons from the station, and from the pylons to the houses. (6 marks)

Element	Description	Marks
Calculates total resistance of 20.0 km of line	$2.19 \times 10^{-4} \times 10\,000 \times 2 = 4.38\ \Omega$	1
$P_{lost} = I^2R$ for DC	$P = 100.0^2 \times 4.38$ $P = 4.38 \times 10^4$ W	1
Efficiency for DC	$100 - (4.38 \times 10^4 / 4.80 \times 10^4) \times 100$ $= 8.8\%$	1
$P_{lost} = I^2R$ for AC	$P = 10.0^2 \times 4.38 = 438$ W	1
Efficiency for AC	$100 - (438 / 4.80 \times 10^4) \times 100 = 99\%$	1
2 significant figures		1
	Total	**6**

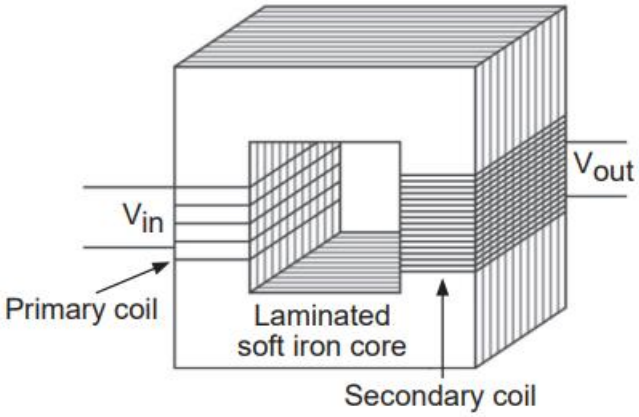


Figure 3: A step-up transformer with a laminated core

(c) Figure 3 shows a step-up transformer. One of the features that increases efficiency is the laminated soft iron core. Explain why laminating the core increases the transformer's efficiency. (3 marks)

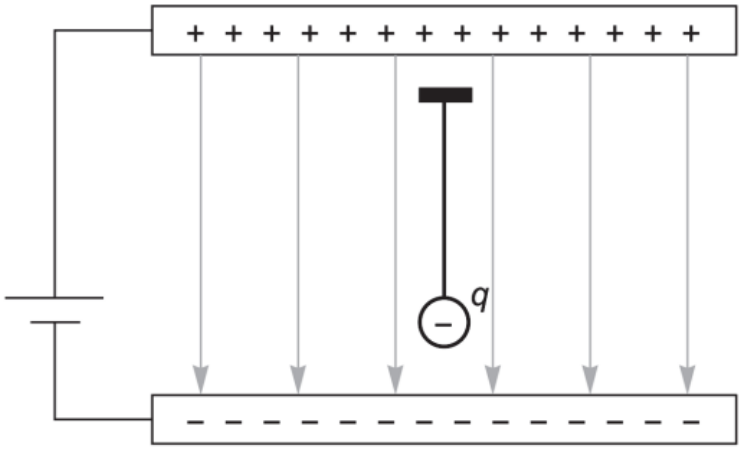
Description	Marks
Changing magnetic fields induce eddy currents in the metal.	1
This heats up the metal and power is lost.	1
A laminated core reduces the magnitude of the eddy currents and therefore reduces power lost as heat.	1
Total	**3**

(d) Explain why transformers require AC current to function in electricity transmission. (4 marks)

Description	Marks
A current-carrying conductor has a magnetic field around it.	1
An alternating current produces an alternating magnetic field.	1
This changing magnetic field induces an EMF in the secondary coil.	1
The EMF allows current to flow in the transmission lines.	1
Total	**4**

2021 Section 2 Question 14

Electro-magnetism



A 0.200 kg metal sphere with a net negative charge of 2.72 mC is suspended by a 0.800 m long almost massless string in a uniform electric field. The plates of the field are 1.20 m apart and the potential difference between the positive top and the negative bottom plate is 1.80×10^2 V.

(a) Calculate the strength of the electric field. (1 mark)

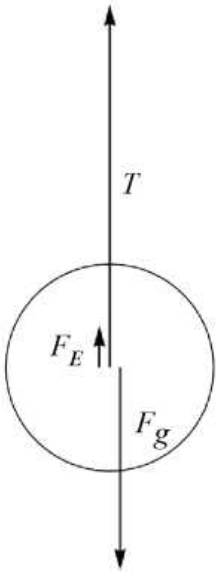
Description	Marks
$E = V/d = 180/1.20 = 1.50 \times 10^2$ V m^{-1} or N C^{-1}	1
Total	**1**

(b) Calculate the tension in the string. (4 marks)

Element	Description	Marks
Derives correct expression for T using F_E in opposite direction to mg	$T = mg - Eq$	1–2
Uses correct values	$T = (0.200 \times 9.80) - (1.50 \times 10^2 \times 2.72 \times 10^{-3})$	1
Correctly calculates answer	1.55 N	1
Total		**4**

(c) The sphere is pulled to one side and released. At the bottom of the swing, the sphere is travelling at 2.80 m s^{-1}.

(i) Draw a free body diagram of the forces acting on the sphere in this position. Label all forces. Do not show the net force acting on the sphere. (3 marks)



Description	Marks
Each force labelled correctly and in correct direction	1–3
Total	**3**
Note: If more than three forces provided, award a maximum of 2 marks.	

(ii) Derive an expression for the net force acting on the sphere in terms of the forces in your diagram. (1 mark)

Description	Marks
$F_N = T + Eq - mg$ (follow through marks for consistency with diagram as long as there are 3 forces)	1
Total	**1**

(iii) Calculate the tension in the string at the bottom of its swing. (4 marks)

Element	Description	Marks
Rearranges equation correctly for T	$T = mv^2/r - Eq + mg$	1
Correct substitution of values	$T = (0.200 \times 2.80^2 / 0.800) - (1.50 \times 10^2 \times 2.72 \times 10^{-3}) + (0.200 \times 9.80)$	1–2
Correctly calculates answer	3.51 N	1
Total		**4**

2021 Section 2 Question 19

Electro-magnetism

A group of students wanted to calculate the strength of the Earth's magnetic field in Perth. They set up a DC circuit with a section of the wire placed 50.0 mm above a compass.

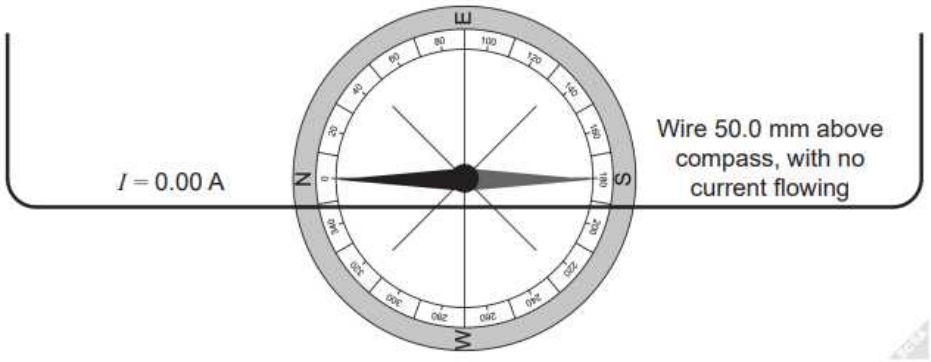


Figure 1

With no current running through the circuit, the compass lined up with the Earth's magnetic field as shown in Figure 1.

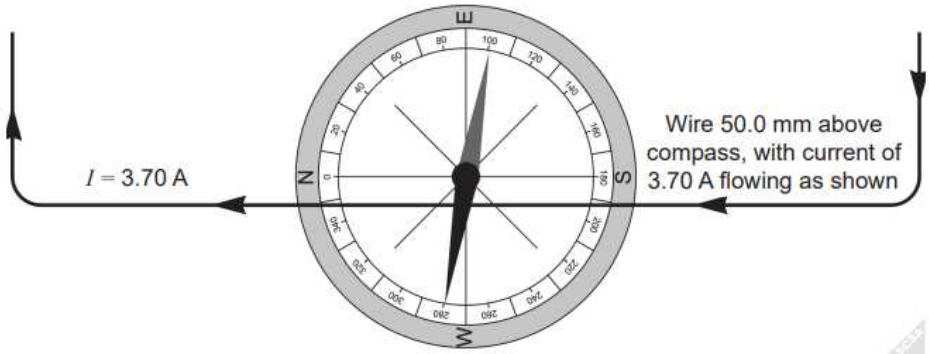


Figure 2

When they closed the switch, they saw the compass needle deflect at an angle of 80.0° to the wire as shown in Figure 2. The needle now pointed in the direction of the net magnetic field. The reading on the ammeter at this time was 3.70 A.

(a) Calculate the strength of the wire's magnetic field felt by the compass in the position described in Figure 2. (3 marks)

Element	Description	Marks
Uses correct equation, constants	$B = 1.26 \times 10^{-6} \times 3.70/6.28 \times 5.00 \times 10^{-2}$	1
Converts mm to m		1
Correctly calculates answer	$B = 1.48 \times 10^{-5}$ T	1
	Total	**3**

(b) Calculate the strength of the horizontal component of the Earth's magnetic field. (4 marks)

Element	Description	Marks
Uses 80.0° as angle of resultant B of Earth and wire		1
Uses correct trigonometric function	$\tan 80.0° = 1.48 \times 10^{-5} / B_{EH}$	1
Rearranges expression correctly for B of Earth	$B_{EH} = 1.48 \times 10^{-5} / \tan 80.0°$	1
Correctly calculates answer	$B_{EH} = 2.62 \times 10^{-6}$ T	1
	Total	**4**

(c) The Earth's magnetic field is at an angle of 66.0° to its surface in Perth. This is called the 'angle of dip'. Use this information to calculate the overall strength of the Earth's magnetic field in Perth. (3 marks)

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Element	Description	Marks
Uses B_{EH} and 66.0° to calculate B		1
Uses correct trigonometric function	$B \cos 66.0° = 2.62 \times 10^{-6}$	1
Correctly calculates answer	6.44×10^{-6} T	1
	Total	**3**

2020 Section 2 Question 16

Electro-magnetism

A group of physics students made a simple AC generator in class. It had 150 turns of wire in the 6.00 cm wide square coil and was placed in a magnetic field of strength 1.85×10^2 mT. They connected the handle to a motor which rotated it at 240 rpm and used the electricity produced to power a light globe.

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(a) Calculate the maximum EMF produced by the generator. (5 marks)

Element	Description	Marks
uses correct equation	$EMF_{max} = 2\pi NBAf$	1
converts rpm to Hz	240 rpm = 4 Hz	1
converts cm to m	6.0 cm = 0.06 m	1
converts mT to T	1.85×10^2 mT = 0.185 T	1
correct answer	2.51 V	1
	Total	**5**

(b) Calculate the RMS voltage produced. (1 mark)

Description	Marks
$emf_{rms} = 2.51/\sqrt{2} = 1.78$ V	1
Total	**1**

The students removed the motor and turned the handle themselves, maintaining a constant speed of rotation. They noticed that the force required to turn it varied as the coil rotated. They also noticed that the light bulb glowed brightest when the force required was greatest and went out when the force required was virtually zero.

(c) (i) Explain why the force required varied as the handle went through one rotation. (3 marks)

Element	Description	Description	Marks
Recognises that emf varies as rate of change of flux varies as coil rotates.	The amount of flux through the coil varies with $\sin\theta$. As rotational speed is constant, rate of change of flux also varies.	Conservation of energy. As electrical energy is produced, mechanical energy must be consumed.	1
Links light produced with greater emf.	The light is brighter when the emf is greatest.	When the light is brightest, maximum work must be done by the student turning the handle.	1
Recognises that force required will increase as greater emf is produced.	The induced emf is trying to stop the coil rotating therefore the greater the emf the greater the force required to maintain constant speed.	As the speed of rotation is kept constant, the force required to turn the handle is greatest when the most electrical energy is produced.	1
		Total	**3**

(ii) In what position was the plane of the rotating coil relative to the field when the light bulb went out? Explain why it went out. (3 marks)

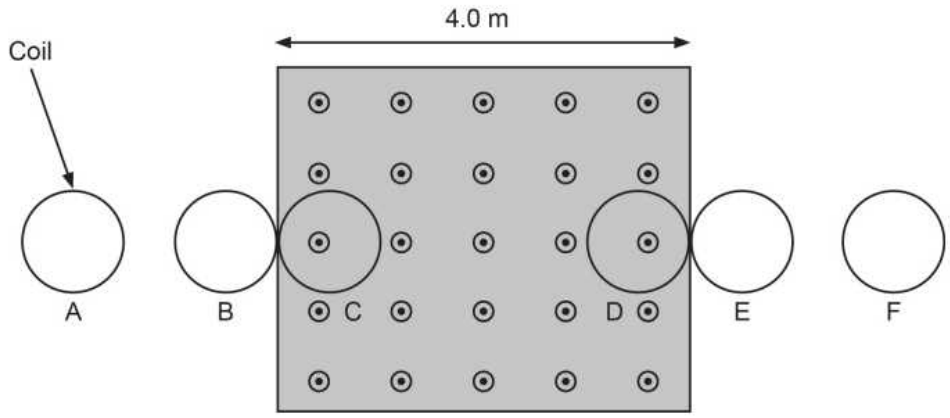
Description	Marks
perpendicular	1
when perpendicular to the field, rate of change of flux = 0	1
therefore emf = 0 so no current produced	1
Total	**3**

2019 Section 2 Question 18

Electro-magnetism

A coil with a radius of 50.0 cm and 25 turns is moved at a constant velocity of 0.80 m s^{-1} to the right of the page into, through and out of a uniform magnetic field of strength 0.28 T.

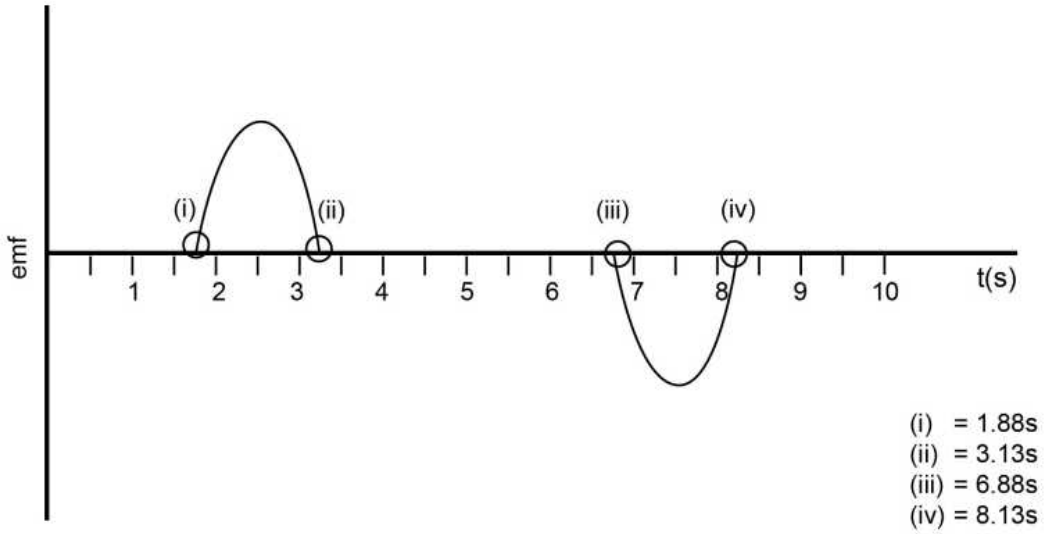
The total distance from the centre of the coil at A to the centre of the coil at F is 8.00 m and the distance from A to B is the same as E to F.



(a) Calculate the average emf induced as the coil moves from B to C. (4 marks)

Description	Marks
Area of coil = $\pi r^2 = \pi (0.5)^2 = 0.785$ m^2	1
$\Delta t = 1.0/0.8 = 1.25$ s	1
Average emf = 25 × 0.28 × 0.785/1.25	1
= 4.40 V	1
Total	**4**

(b) On the axes below, show the induced emf versus time as the coil moves from A to F. (Note: only include specific values on the time axis.) (8 marks)



Description	Marks
one mark per correct time i, ii, iii and iv	1–4
graph: same size curves	1
curves not straight lines	1
opposite sides of x-axis	1
flat line between at zero	1
Total	**8**

2021 Section 3 Question 21

Electro-magnetism

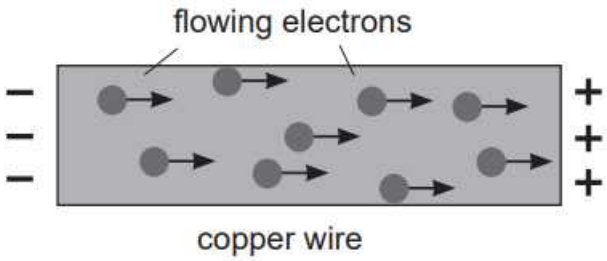
Drift velocity

When you turn on a light, it comes on as soon as the circuit is complete. The energy flowing in the circuit is transferred almost instantly. But how fast do the charged particles, which carry that energy, move? It turns out that they move extremely slowly. This velocity is called the drift velocity and it depends on several factors. The equation is given below:

$$v_D = \frac{I}{nAq}$$

where,

- I is the current flowing through the conductor, measured in amperes
- n is the electron density in m^{-3}
- A is the area of the cross-section of the conductor, measured in m^2
- v_D is the drift velocity of the electrons, measured in m s^{-1}
- q is the charge of an electron, measured in coulombs.



(a) Calculate the drift velocity of electrons if a current of 3.00 A is flowing in a copper wire with a cross-sectional area of 1.00 mm^2. (3 marks)

For copper, n = 8.50 × 1028 m^{-3}.

Element	Description	Marks
Converts mm^2 to m^2	1.00 x 10^{-6} m^2	1
Substitutes correct values	v_D= 3.00/ 8.50 x10^{28} x 1.60 x 10^{-19} x 1.00 x 10^{-6}	1
Correctly calculates answer	2.21 x 10^{-4} m s^{-1}	1
	Total	**3**

Another way of measuring drift velocity uses what is called the Hall Effect. This occurs when a current flows through a flat piece of metal placed in an external magnetic field. This is shown in the diagram below.

The negatively charged particles experience a force due to the magnetic field and move to one side of the metal strip. This sets up a potential difference, and therefore an electric field, between the sides of the strip. This potential difference can be measured by a voltmeter (V_H). Dividing V_H by the width of the strip (w) will give us the strength of the electric field created:

$$E = \frac{V_H}{w}$$

If the strip is moved with the same velocity as the charge carriers but in the opposite direction, their relative velocity in the field is now zero; and therefore, there is no force placed upon them by the magnetic field. At this stage, the voltmeter would read 0 V. By measuring how fast the strip is moving, we can calculate drift velocity

The magnetic force on the charged particles is:

$$F_M = qv_D B$$

where v_D is the drift velocity of the charge.

When the strip is not moving and the system reaches equilibrium, V_H remains constant and the force exerted on the charge carriers by the magnetic field (F_M) is equal to the force due to the electric field between the edges of the strip (F_E). By substitution, it can be shown that:

$$F_E = \frac{V_H q}{w}$$

(b) With reference to the text, explain why V_H reduces to zero when the strip is moved in the correct direction at the correct speed. (4 marks)

Description	Marks
$F_M = Bvq$	1
When $v = 0$ relative to magnetic field, no magnetic force is exerted on charges	1
No separation of charge means no electric field is established	1
No electric field between edges means no potential difference detected	1
Total	**4**

(c) Explain why increasing the magnitude of the magnetic field will increase V_H for a stationary strip when equilibrium is restored. (3 marks)

Description	Marks
$F_M = Bvq$. If B increases, so does F_M on charges	1
If F_M increases, more electrons will move further to one side of the strip/increased charge separation which increases the strength of the electric field produce	1
If electric field increases, V_H increases	1
Total	**3**

(d) The article says: '*By substitution, it can be shown that:* $F_E = \frac{V_H q}{w}$ '. Derive this equation from information supplied in the article. (2 marks)

Description	Marks
$E = F/q = V_H/d$ where $d = w$	1
$F = V_H q/w$	1
Total	**2**

(e) Calculate V_H if the dimensions of the copper strip are w = 3.00 cm and d = 0.100 cm, B = 3.50 T and I = 26.0 A. Use electrons as the charge carriers in your calculation. (6 marks)

For copper, $n = 8.50 \times 10^{28}$ m^{-3}.

Element	Description	Marks
At equilibrium, $F_M = F_E$		1
Substitutes expressions for field strengths	$Bv_Dq = V_Hq/w$	1
Isolates V_H correctly and simplifies	$V_H = Bwv_D$	1
Substitutes I/nAq for v_D	$V_H = BwI/nAq$	1
Uses correct values in calculation	$V_H = \frac{3.50 \times (3.00\times10^{-2}) \times 26.0}{(8.50\times10^{28}) \times (3.00\times10^{-2}) \times (1.00\times10^{-3}) \times (1.60\times10^{-19})}$	1
Correctly calculates answer	6.69×10^{-6} V	1
	Total	**6**

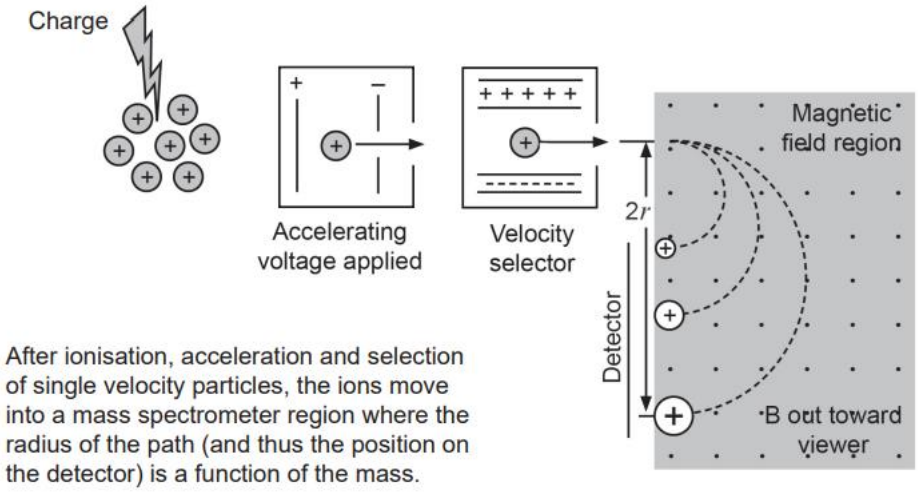
2019 Section 3 Question 19

Electro-magnetism

Mass spectrometer

The mass spectrometer is an instrument that can measure the masses and relative concentrations of atoms in a mixed sample. It makes use of the magnetic force on a moving charged particle.

Different elements are ionised so they all have a charge of +1. They are then accelerated across a potential difference that increases their velocities. They move through a velocity selector and are then fired into a magnetic field where they undergo circular motion and land on a detector. The different masses of the elements will determine where they land on the detector. The concentration of each element can be determined by how many ions land in the one place.



After ionisation, acceleration and selection of single velocity particles, the ions move into a mass spectrometer region where the radius of the path (and thus the position on the detector) is a function of the mass.

Velocity selector

In many experiments involving moving charged particles, it is important that the particles all move with essentially the same velocity. This can be achieved by applying a combination of an electric field and a magnetic field oriented as shown in the diagram above. A uniform electric field is directed vertically downward, and a uniform magnetic field is applied in the direction perpendicular to the electric field and into the page. For positive particles, the magnetic force is equal to qvB upward and the electric force (qE) is downward.

(a) Give an expression for the radius of a charged particle's path when fired into a uniform magnetic field. (1 mark)

Description	Marks
$r = mv/Bq$	1
Total	**1**

(b) Explain why it is important to make sure that all the ions that enter the detector have the same velocity. (3 marks)

Description	Marks
the purpose of the mass spectrometer is to identify particles by their mass	1
this is done by measuring r therefore all variables except m must be kept constant	1
q and B are constant therefore v must be also	1
Total	**3**

(c) Below is a table of ions and their masses in kg.

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An unknown ion enters the detector at 9.24 × 104 m s^{-1}. It strikes the detector plate 12.38 cm from the entrance point. If the magnetic field strength is 3.50 T, calculate the mass of the unknown particle and identify it from the table above. (5 marks)

Description	Marks
$m = rBq/v$	1
$= 0.1238 \times 3.5 \times 1.60 \times 10^{-19} / 2 \times 9.24 \times 10^{4}$	1–2
$= 3.75 \times 10^{-25}$ kg	1
Ra^{+}	1
Total	**5**

(d) Calculate the accelerating voltage needed for the ion to attain a velocity of 9.24 × 10^4 m s^{-1} when entering the velocity selector. If you could not obtain an answer to part (c), use 3.11 × 10^{-25} kg. (4 marks)

Description	Marks
$W = Vq = mv^2/2$	1
$V = mv^2/2q$	1
$= 3.75 \times 10^{-25} \times (9.24 \times 10^{4})^2 / 2 \times 1.60 \times 10^{-19}$	1
$= 1.0 \times 10^{4}$ V	1
Total	**4**

(e) The velocity selector shown on page 29 *(above)* uses a combination of electric and magnetic fields to select only ions with a specific velocity to enter the detector. These ions travel directly across the selector parallel to the charged plates. Derive an expression for the selected velocity in terms of *B* and *E*. (3 marks)

Description	Marks
$F_B = F_E$ $Bvq = Eq$	1
$Bv = E$	1
$v = E/B$	1
Total	**3**

(f) Explain in detail why an ion travelling at a velocity greater than the selected velocity would not enter the detector. Use the diagram below to show the path the ion would take. (4 marks)

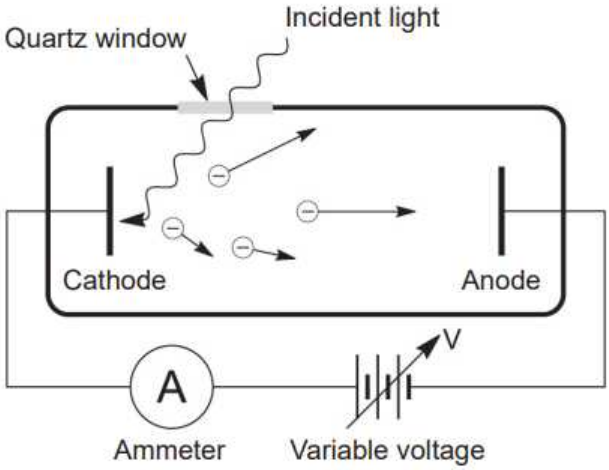
Description	Marks
if v is too great, F_B is too large	1
F_B exerts an upward force on the ion	1
particle will hit the barrier above the opening	1
path shown on diagram must be curved, not linear	1
Total	**4**

Unit 4 – Revolutions in modern physics

Unit 4 – Wave particle duality and the quantum theory

Section 1

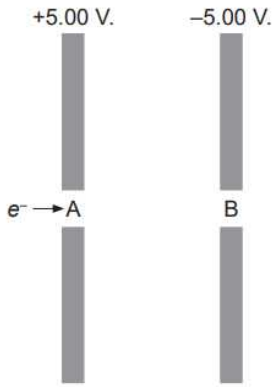
2023 Section 1 Question 4 **Wave particle duality and the quantum theory**	Calculate the wavelength of a photon with an energy of 1.81 keV. Answer: _____ m

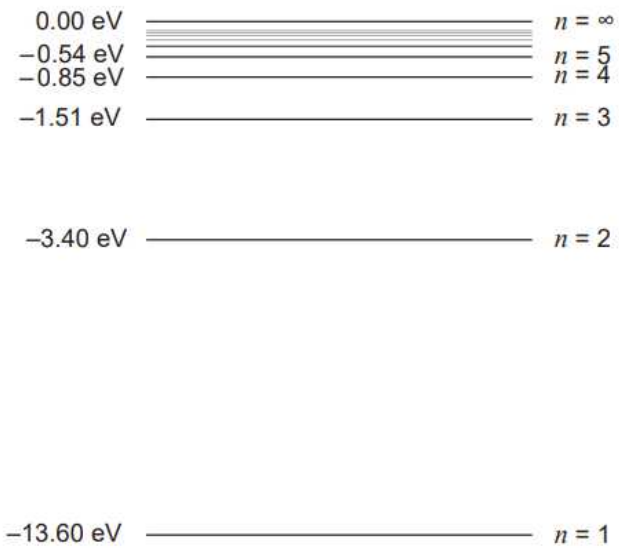
2023 Section 1 Question 6 **Wave particle duality and the quantum theory**	The photoelectric effect equation is $$\frac{1}{2}mv_{max}^2 = hf - W$$ The maximum kinetic energy of a liberated electron is equal to the difference between the energy of the incoming photon and the work function of the metal target.  Figure 1: Photoelectrons are released from a metal target in a vacuum tube (a) Describe how, and under what circumstances, electrons are liberated from the target by incoming photons. (2 marks) _____ _____ _____ _____

	(b) Discuss how the maximum kinetic energy of the liberated electrons is experimentally determined. (4 marks) _____ _____ _____ _____ _____ _____ _____ _____

2023 Section 1 Question 10 **Wave particle duality and the quantum theory**	Estimate the de Broglie wavelength for a standard men's basketball travelling at 10.0 m s^{-1}. Answer: _____ m

2022 Section 1 Question 1 **Wave particle duality and the quantum theory**	Light with a wavelength of 341 nm is shone onto a potassium metal plate in a photoelectric cell, causing a photocurrent to flow. The work function of potassium is 2.30 eV. Calculate the maximum speed of the electrons emitted by the plate. (5 marks) Answer: _____ m s^{-1}

2022 Section 1 Question 9 **Wave particle duality and the quantum theory**	Two parallel conducting metal plates are held at a potential difference of 10.0 V. An electron in a vacuum arrives at a small hole in the first plate at point A with 20.0 eV of kinetic energy, and travels through an electric field to B as shown in the diagram. Calculate the de Broglie wavelength of the electron as it exits at B. (5 marks) 

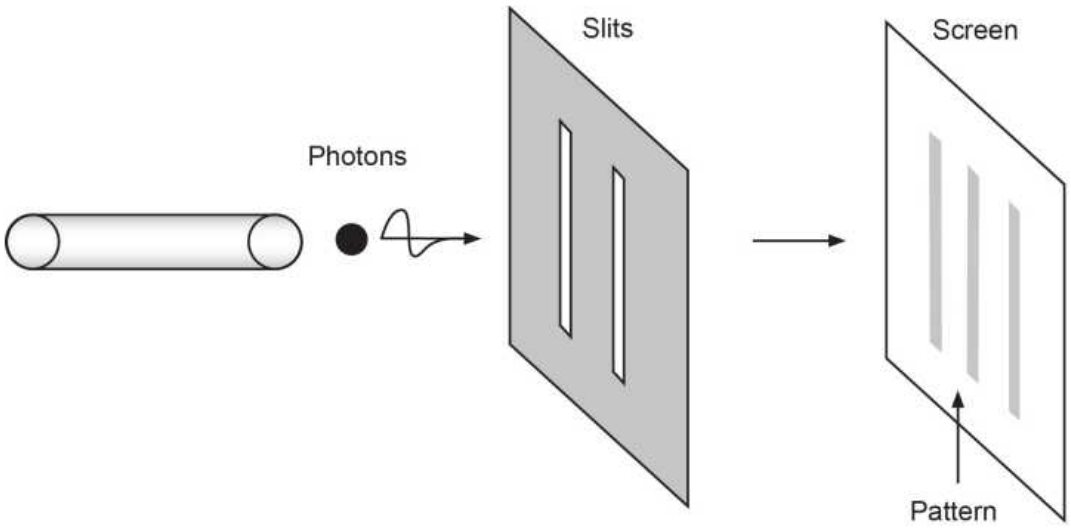
2021 Section 1 Question 1 **Wave particle duality and the quantum theory**	Some energy levels, n, for hydrogen atoms are shown in the diagram below.  Electrons with 12.2 eV of energy are incident on the hydrogen atoms. Calculate the energies of all scattered electrons in eV. (4 marks) Answer _____ eV

2020 Section 1 Question 2 **Wave particle duality and the quantum theory**	Calculate the speed of an electron with a de Broglie wavelength of 1.23 nm. _____ m s^{-1}

2020 Section 1 Question 3 **Wave particle duality and the quantum theory**	A 10.0 watt monochromatic LED radiates light with a wavelength of 525 nm. How many photons does it emit per second? Assume all the energy is converted to light. Answer: _____ photons per second

2020 Section 1 Question 8

Wave particle duality and the quantum theory



The diagram above shows that when monochromatic coherent light is shone through two narrow slits onto a screen, light and dark fringes appear on the screen.

(a) What property of light causes this to happen? Circle your answer. (1 mark)

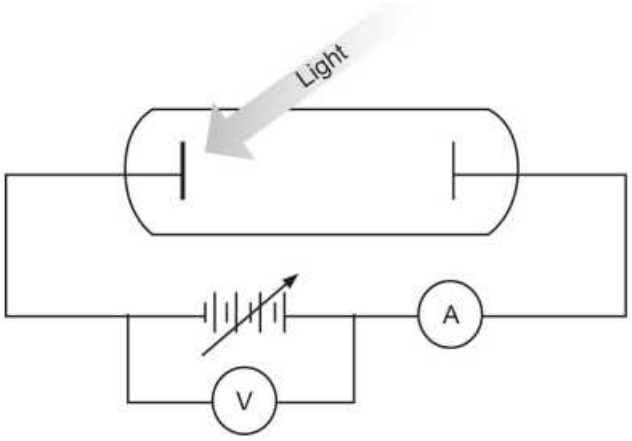
Wave Particle Massless

(b) Explain how **both** the light and dark fringes are formed. (4 marks)

2019 Section 1 Question 2

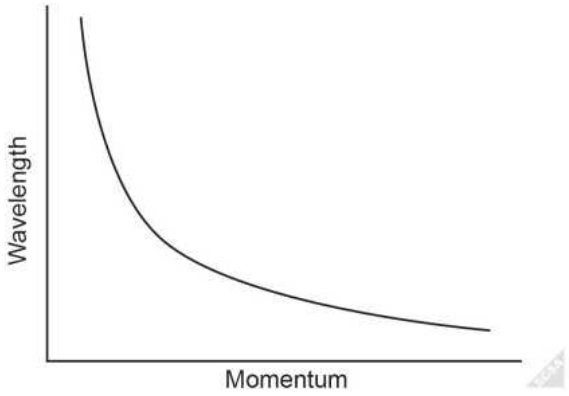
Wave particle duality and the quantum theory

When light is shone on a metal plate, electrons may be emitted from the plate. This is called the 'photoelectric effect'. The apparatus below shows incident light of wavelength 450 nm striking a metal plate. The number of photons striking the plate per second can also be controlled by varying the brightness of the incident light. The current produced by the light is initially measured by the ammeter (A). Initially, the ammeter (A) reads a current. The stopping potential (V) is then adjusted until the ammeter reads 0 A.



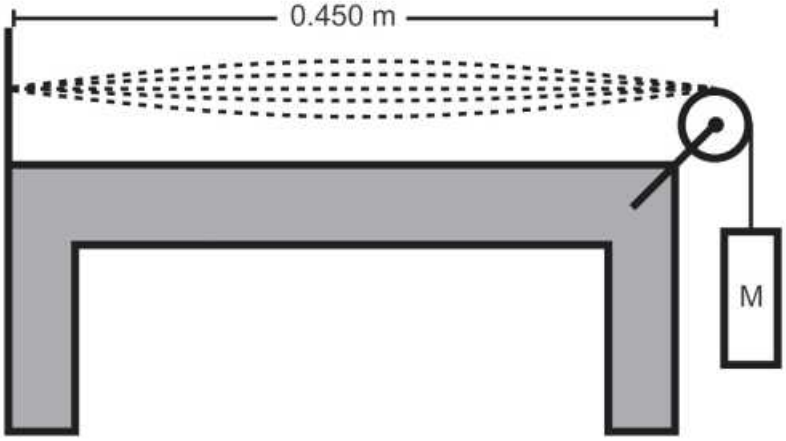
Assume the frequency of the light remains above the threshold frequency of the metal. In the table below, describe what would happen to the initial reading on A and the final reading on V, if the following changes were made. Use the terms 'increase', 'decrease' or 'unchanged'.

	Change 1: wavelength is changed to 490 nm. Photons/second remains unchanged.	Change 2: wavelength is changed to 400 nm. Photons/second is increased.
Initial A		
Final V		

2019 Section 1 Question 10 **Wave particle duality and the quantum theory**	If we plot the de Broglie wavelength of a subatomic particle against its momentum, we get the graph shown below. This applies to velocities less than 5% of the speed of light.  (a) Give a possible relationship between wavelength and momentum based upon the shape of the graph. (1 mark) (b) Describe how the data used to generate the graph could be reorganised to produce a straight-line graph. (2 marks) (c) What would the gradient of the straight-line from part (b) represent? (1 mark) (d) Ignoring relativistic effects, calculate the momentum of a particle with a wavelength of 2.50 × 102 nm. (4 marks) _____ Unit: _____

2023 Section 2 Question 16

Wave particle duality and the quantum theory



A group of students set up the apparatus shown in the diagram above to measure the mass per unit length of a thin and strong steel wire. On each successive trial, they increased the mass of the counterweight M, further stretching the wire. They then plucked the steel wire and measured the frequency of the vibrating wire using a strobe light. The length L of the vibrating portion of the wire, shown in the diagram above, was 0.450 m. Their results are given in the table below.

Mass (kg)	1.50	2.00	2.50	3.00	3.50	4.00
Frequency (Hz)	105	120	135	150	160	170

The students observed the wire vibrating in its fundamental mode, where wavelength $\lambda = 2L$, and substituted this into the wave equation $v = \lambda f$. They also used the following equation for the speed v of a wave along a wire under tension:

$v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the wire (in N) and μ is the mass per unit length (in kg m^{-1}).

Using these equations they derived the relationship below.

$$T = (4L^2 \mu) f^2$$

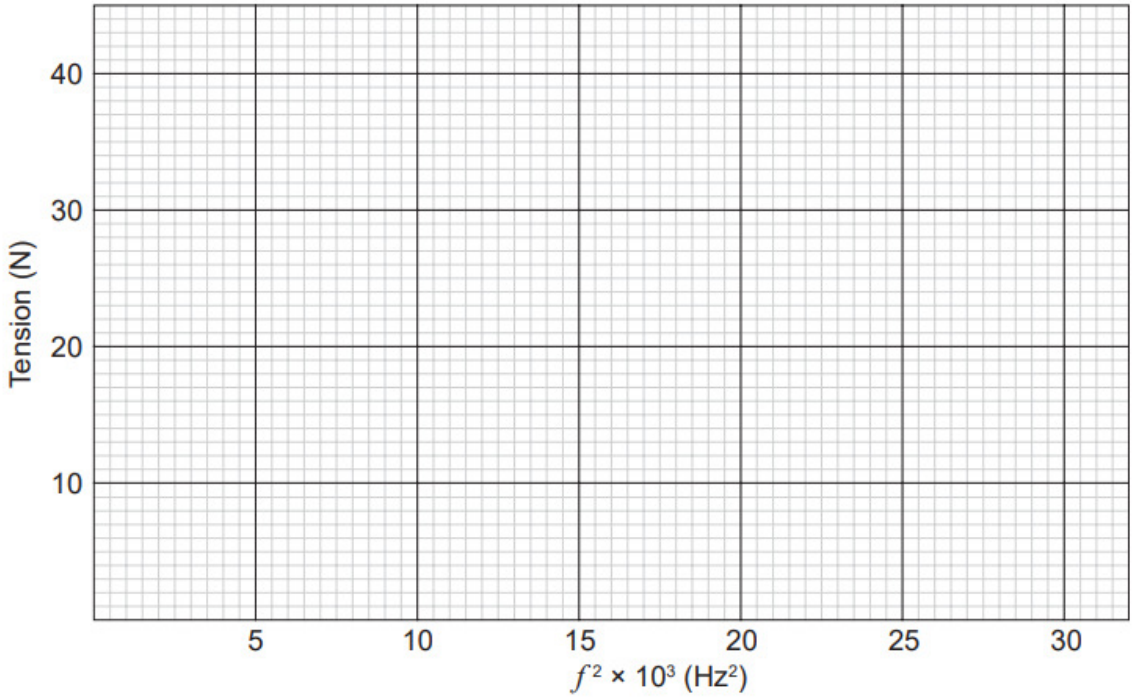
(a) Show how the students derived this relationship. (4 marks)

The students then manipulated their data so as to graph this relationship and produce a straight line.

(b) Make the adjustments to the data and place the results in the table below. Give your answers to **three** significant figures and express f 2 in scientific notation. (4 marks)

Mass (kg)	1.50	2.00	2.50	3.00	3.50	4.00
Tension (N)						
f^2 **(Hz²)**						

(c) Graph your data on the grid below. Include a line of best fit. (3 marks)



(d) Use the gradient of your line of best fit to calculate the mass per unit length in kg m^{-1} of the steel wire. Indicate clearly the two points used and express your answer to the appropriate number of significant figures. (5 marks)

Answer: _____ kg m^{-1}

(e) In the summary of their report, the students had to identify any variables that could affect the accuracy of their value. They identified correctly an important assumption they had made, which may have caused their value to be slightly different from the theoretical value. This had nothing to do with human error, inaccurate equipment, atmospheric conditions or calibration of instruments. Describe their assumption. (2 marks)

_____

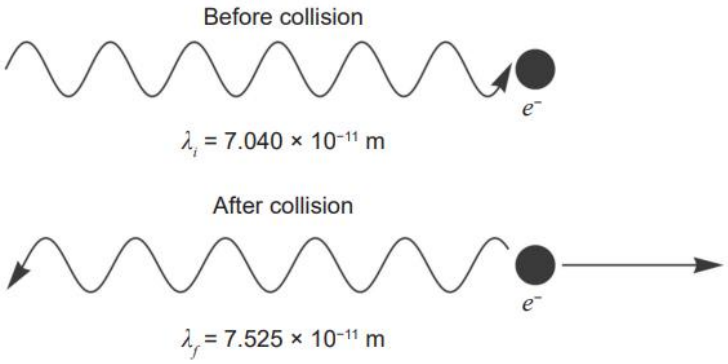
_____

_____

_____

2022 Section 2 Question 13

Wave particle duality and the quantum theory



A stationary free electron and a photon collide. In such collisions, both momentum and energy are conserved. In one such collision, a photon of wavelength 7.040×10^{-11} m is travelling in the direction shown in the diagram above. After the collision, the photon returns in the direction it came from (i.e. 180°) with a new wavelength of 7.525×10^{-11} m and the electron is no longer stationary. No other particles or photons are produced in the collision.

(a) What is the original energy of the photon in eV? (3 marks)

Answer: _____ eV

(b) What is the momentum of the photon before the collision? (2 marks)

Answer: _____ N s

(c) Explain why the wavelength of the photon is greater after the collision. (3 marks)

(d) Calculate the speed of the electron after the collision. (Hint: use the principles of conservation of energy.) (6 marks)

Answer: _____ m s^{-1}

2022 Section 2 Question 15

Wave particle duality and the quantum theory

In 1880, Johannes Rydberg established a mathematical relationship between the wavelengths of light and changes in the relevant energy levels of the hydrogen atom, which is observed in the emission spectrum.

$$\frac{1}{\lambda} = \frac{R}{hc}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

λ = wavelength of light emitted
R = Rydberg's constant
n = the number of the energy levels between which the electron falls (n_2 is always larger than n_1)

The wavelengths of the Lyman series of photons emitted for a hydrogen atom are shown in the diagram below. The Lyman series is made up of all electron transitions to $n = 1$ i.e. $n_1 = 1$.

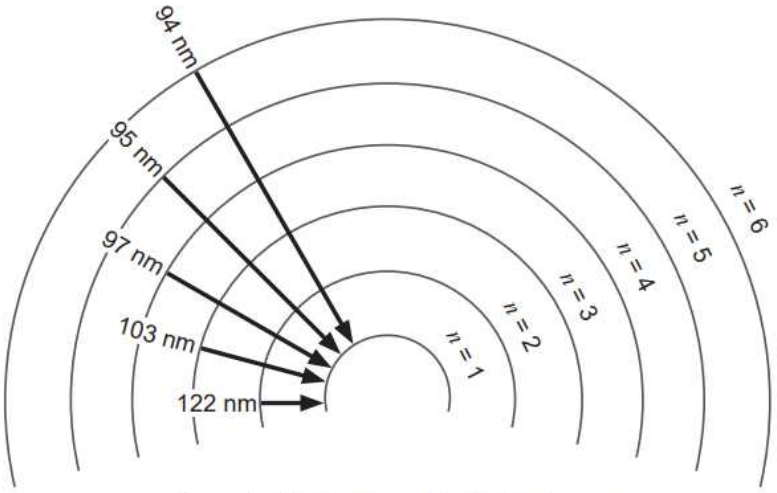
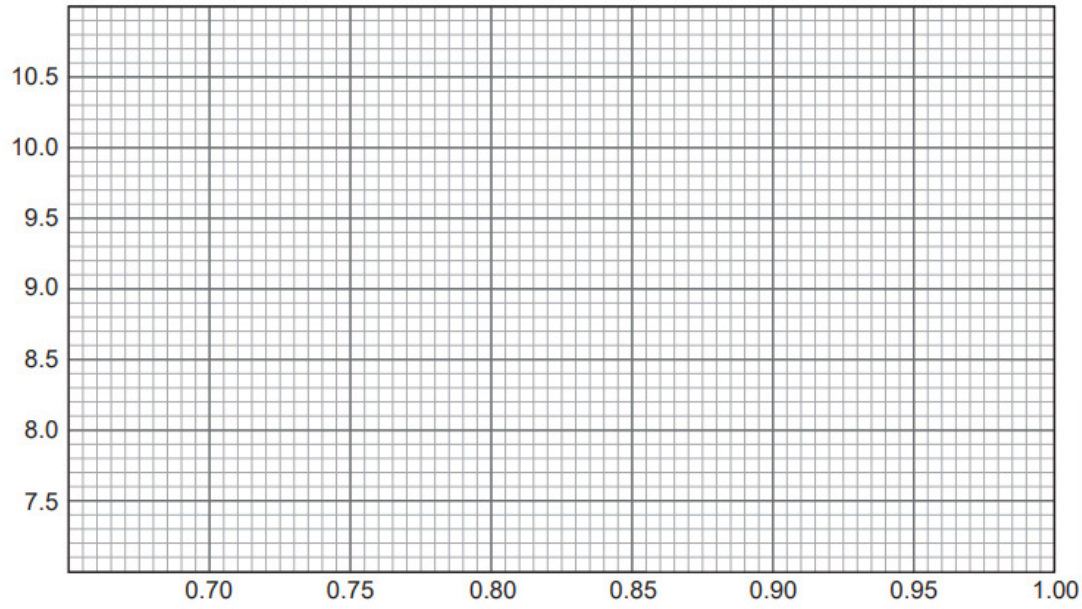


Figure 1: The Lyman series for hydrogen

(a) Fill in the table below using the values in Figure 1. Give your answers to **three** significant figures. (5 marks)

Δn	2 → 1	3 → 1	4 → 1	5 → 1	6 → 1
$\frac{1}{n_1^2} - \frac{1}{n_2^2}$					
$\frac{1}{\lambda}$ (10^6 m^{-1})					

(b) Graph $\frac{1}{\lambda}$ vs $\frac{1}{n_1^2} - \frac{1}{n_2^2}$ on the grid below. Label the axes clearly and draw a line of best fit. (5 marks)



(c) Use your line of best fit to calculate Rydberg's constant. Indicate clearly the points you have used. Give your answer to **two** significant figures. (5 marks)

Answer: _____ J

Rydberg's equation can also be applied to one-electron ions of different elements. The formula is modified to:

$$\frac{1}{\lambda} = Z^2 \frac{R}{hc}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

Z is the atomic number of the element. Figure 2 shows a selection of energy levels for a helium ion (Z = 2) and hydrogen atom (Z = 1).

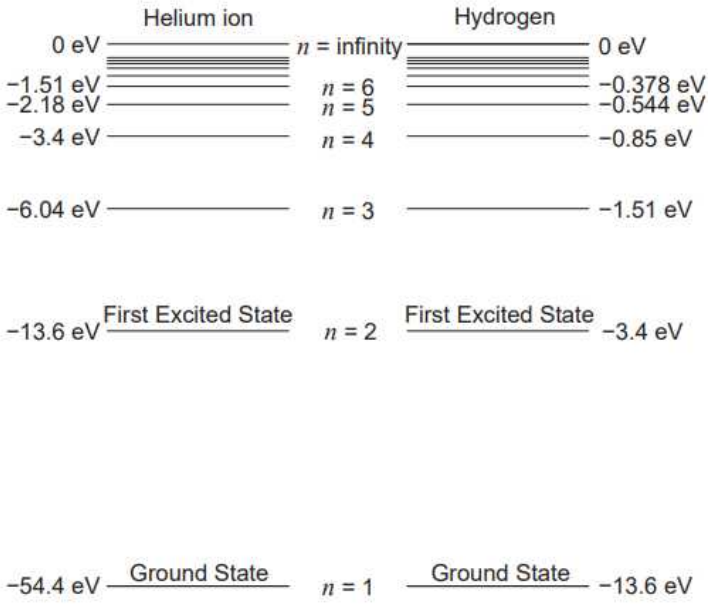


Figure 2: Energy levels for a helium ion and a hydrogen atom

(d) Identify and explain **two** differences you would see between the graph of $\frac{1}{\lambda}$ vs $\frac{1}{n_1^2} - \frac{1}{n_2^2}$ for hydrogen and the helium ion. (4 marks)

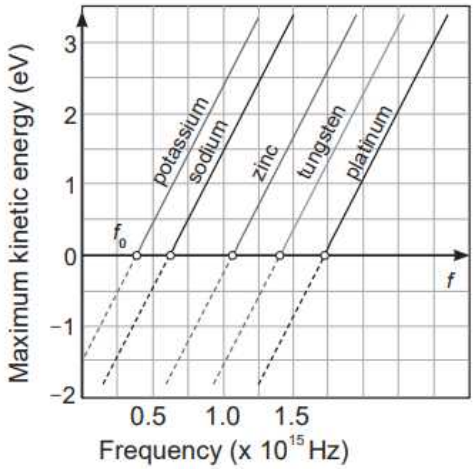
One:

Two:

2021 Section 2 Question 13

Wave particle duality and the quantum theory

The photoelectric effect uses light to liberate electrons from metals. The graph of the maximum kinetic energy of these liberated electrons from different metals plotted against the frequency of the incident light is shown below.



(a) Estimate the threshold frequency for potassium from the graph above. (2 marks)

Answer _____ Hz

Each metal has a work function that describes the minimum amount of energy required to liberate an electron from the surface of that metal.

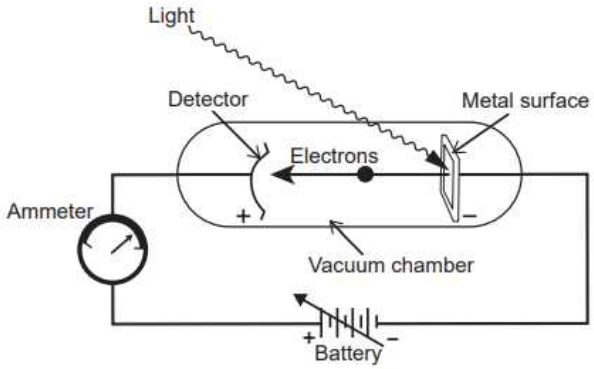
(b) Estimate the work function for potassium from the graph above. (2 marks)

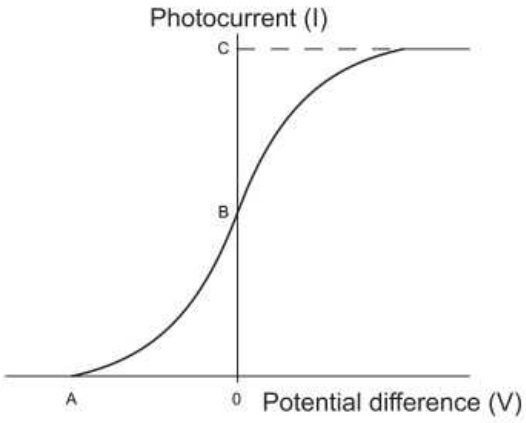
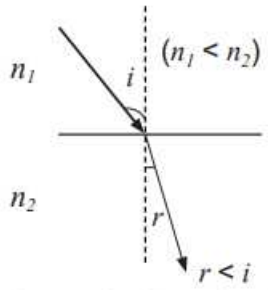
Answer _____ eV

(c) Using your value from part (b), estimate the maximum velocity of a liberated electron if light with a frequency of 1.20×10^{15} Hz shines on a potassium metal plate. Give your answer to two significant figures. (6 marks)

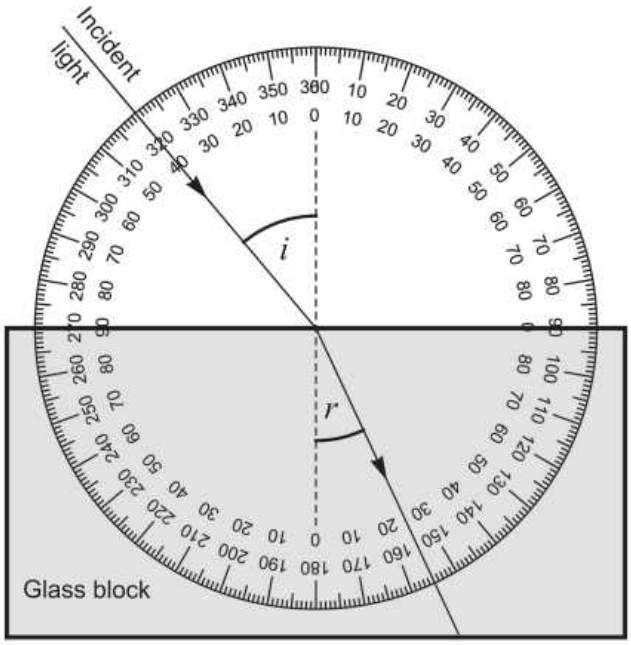
Answer _____ m s^{-1}

The diagram below shows how the kinetic energy of the liberated electrons is measured. The ammeter measures the photocurrent and the battery can reverse and vary the potential difference between the metal plate and the detector. The potential is increased until the ammeter reads zero.



	(d) Below is a graph of photocurrent versus potential difference. On this graph, draw the resulting curve when light of the same frequency but lower power is shone on the same metal. (3 marks) 
2021 Section 2 Question 16 **Wave particle duality and the quantum theory**	Light does not travel at the same speed in all materials. When travelling from air into a different material, light slows down and refracts. The amount of refraction is determined by the refractive index (n) of the material. It is calculated using the following equation: $$n = \frac{c}{v}$$ where v is the speed of light in the material and c is the speed of light in a vacuum.  Figure 1: Light refracting at the boundary between two media. From Figure 1, the following relationship can be demonstrated. This is known as Snell's Law. $$n_1 \sin i = n_2 \sin r$$

A group of students try to determine the refractive index of a glass block by measuring the refraction of light incident on the block. Below is a schematic of their experiment showing the angle of incidence *i* and the angle of refraction *r*.

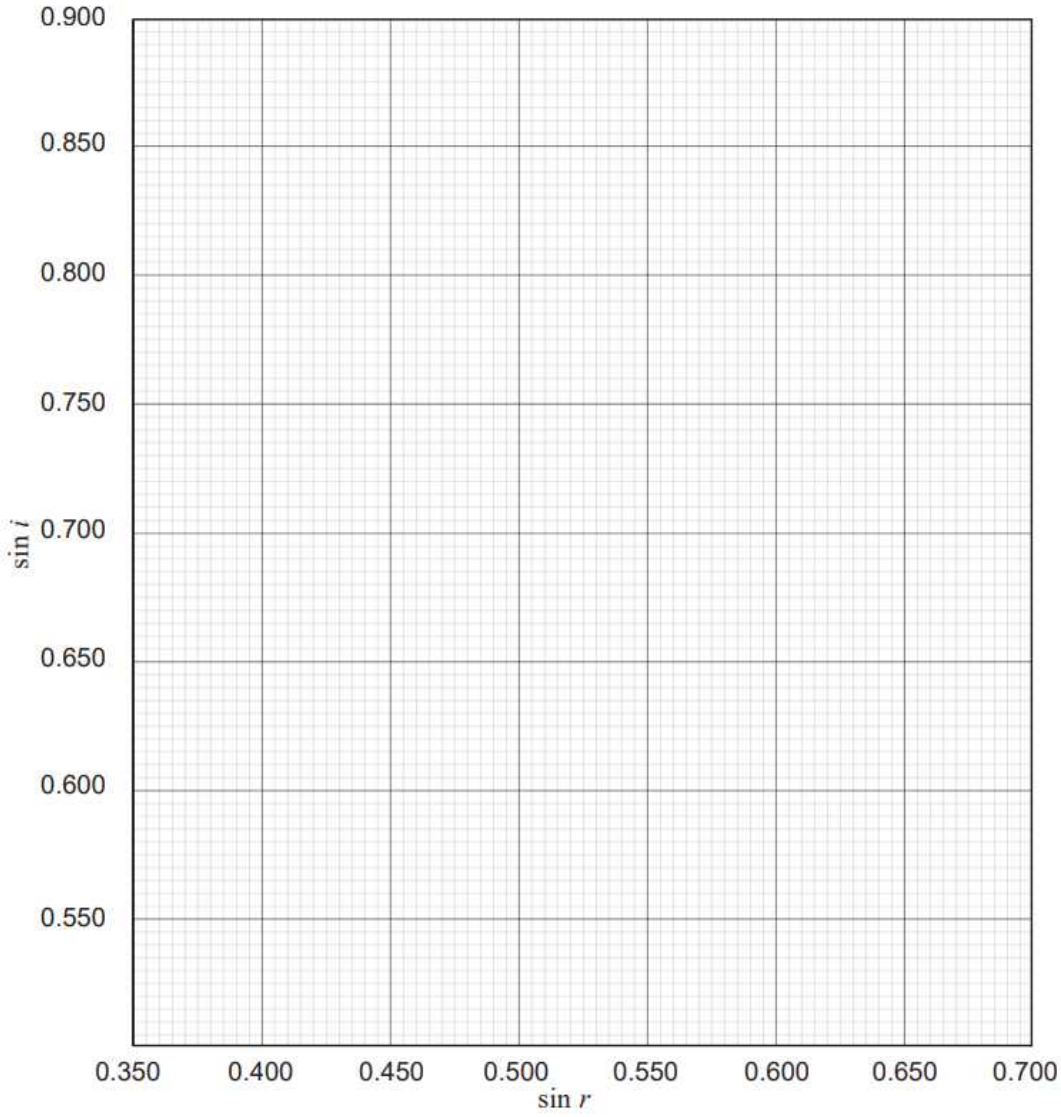


They varied the angle and found that white light produced a rainbow effect, which made measuring *r* very difficult. So they changed the light source to a monochromatic red light laser. They obtained the results in the table below.

Angle	$i \pm 1°$	35	40	45	50	55
	$\sin i$					
Angle	$r \pm 1°$	23	25	28	31	33
	$\sin r$					

(a) Complete the table, giving the values of sine to three significant figures. (2 marks)

(b) Graph sin *i* vs sin *r* on the graph below. Include a line of best fit. (3 marks)



(c) The refractive index of air (n_1) is 1.00. Using your line of best fit, determine the refractive index of the prism (n_2). Indicate clearly which two points on your line of best fit you used in your calculation. Give your answer to two significant figures. (4 marks)

Answer _____

(d) There are two phenomena described in this question that support the wave behaviour of light. List them below. (2 marks)

One: _____

Two: _____

(e) The tolerance for all angles was ± 1°. How does the percentage error change as the angle measured increases? Use calculations in your answer. (3 marks)

(f) Using the following trigonometric identity, calculate the percentage error of the sine of an angle of incidence of 50.0°. (4 marks)

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$$

Answer _____ %

2021 Section 2 Question 18

Wave particle duality and the quantum theory

In an experiment, two neutrally-charged subatomic particles, A and B, each of mass m, are fired directly toward each other. Both have a speed of 0.600 c, as seen by the observer O shown in Figure 1. The particles collide and become one particle, C, which O observes to be stationary. No energy is lost due to interactions with the environment and no other particles, e.g. photons, are emitted.

Figure 1: Two particles of equal mass and opposite velocities collide

(a) Using conservation of relativistic energy, calculate the mass of the combined particle m_C Give your answer in terms of m, the mass of each of the original particles. (4 marks)

Answer _____ m

(b) Explain why the velocity of the combined particle has to be 0 m s^{-1}. (2 marks)

For parts (c) and (d) consider the same collision viewed by an observer X, who is moving with a velocity of −0.600 *c* (i.e. the same velocity that Particle B had before the collision). X maintains this velocity after the collision.

Figure 2: Observer X is now shown.

(c) Using the formulas for relativistic velocity addition and relativistic momentum, determine the momentum of the system before the collision, as determined by X. Express your answer in terms of *m* and *c*, the speed of light. (5 marks)

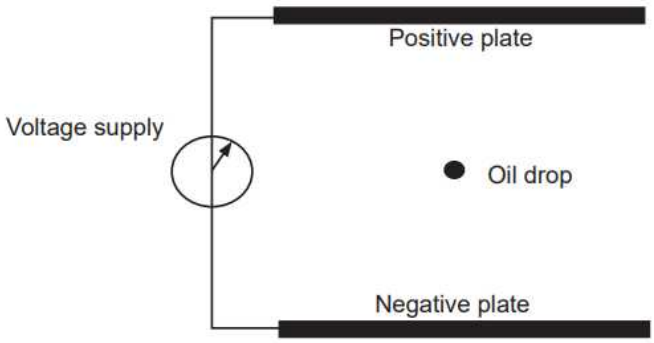
Answer _____ *mc*

(d) With the use of a calculation, show that your answer in part (c) is the same as the momentum of the system after the collision, as determined by X. (4 marks)

2020 Section 2 Question 13

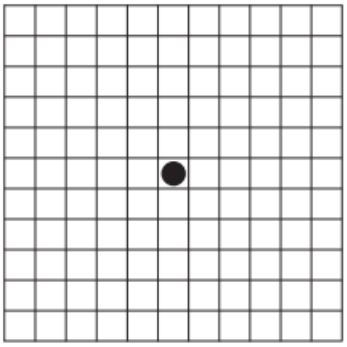
Wave particle duality and the quantum theory

In an experiment to measure the charge of an electron, a student creates many tiny oil drops and allows some to enter the space between two horizontal plates that are connected to a variable voltage supply. A diagram of the apparatus is shown below.



Initially there is no potential difference between the plates and the student chooses an oil drop and, using a microscope, watches as it slowly falls, measuring its speed. The student determines that the speed is constant at 0.0313 mm s^{-1}.

(a) On the grid below, draw a free body diagram showing all the forces acting on the oil drop as it falls. (2 marks)



Using the speed of the oil drop and other known quantities the student calculates the mass of the oil drop as 6.88 $\times 10^{-16}$ kg. The oil drop is exposed briefly to radiation and it captures one or more electrons and hence becomes negatively charged.

The student turns on the voltage supply and adjusts the potential difference between the upper and lower plates until the oil drop stops moving. The potential difference at this point is 346 V.

(b) Name the **two** forces now acting on the oil drop. (2 marks)

One: _____

Two: _____

(c) If the plate separation is 7.71 mm, what is the electric field strength experienced by the oil drop? (2 marks)

_____ V m^{-1}

(d) Calculate the electric charge of the oil drop. (3 marks)

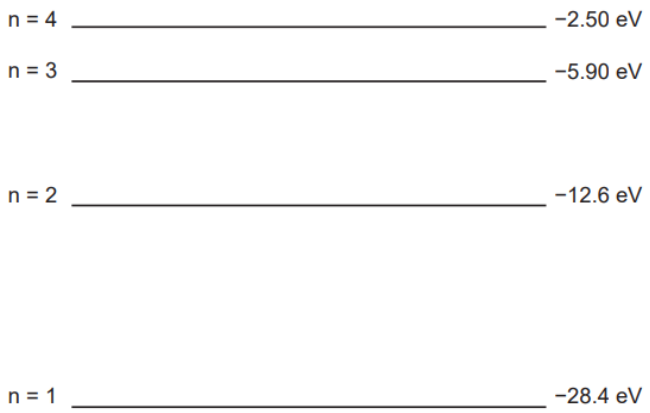
_____C

The student repeats this procedure several times for different oil drops (possibly carrying different numbers of electrons), and calculates the charge for each drop.

Trial number	Charge ($\times 10^{-19}$ C)
1	5.99
2	2.99
3	4.49
4	7.53
5	3.01
6	7.50

(e) Solely on the basis of this data, what does the student estimate the electron charge is most likely to be? (1 mark)

Answer: _____C

2019 Section 2 Question 14 **Wave particle duality and the quantum theory**	When gaseous mercury atoms are excited, they emit photons of varying wavelengths. Some of the energy levels in a mercury atom are shown in the diagram below.  A mercury lamp is used to produce light which is first fed through a filter that eliminates all wavelengths except those produced from the n = 2 to n = 1 transition. The resultant light is then shone onto a potassium metal plate whose work function is 2.00 eV. (a) On the diagram above, show all the possible downward electron transitions that can occur in a mercury atom after a successful collision with an incoming electron with an energy of 23.0 eV. (4 marks) (b) Calculate the wavelength of the photon from part (a) that strikes the potassium metal plate. (3 marks) _____ m

(c) Calculate the maximum velocity of any electrons liberated from the potassium metal plate. Ignore relativistic effects. (5 marks)

_____ m s^{-1}

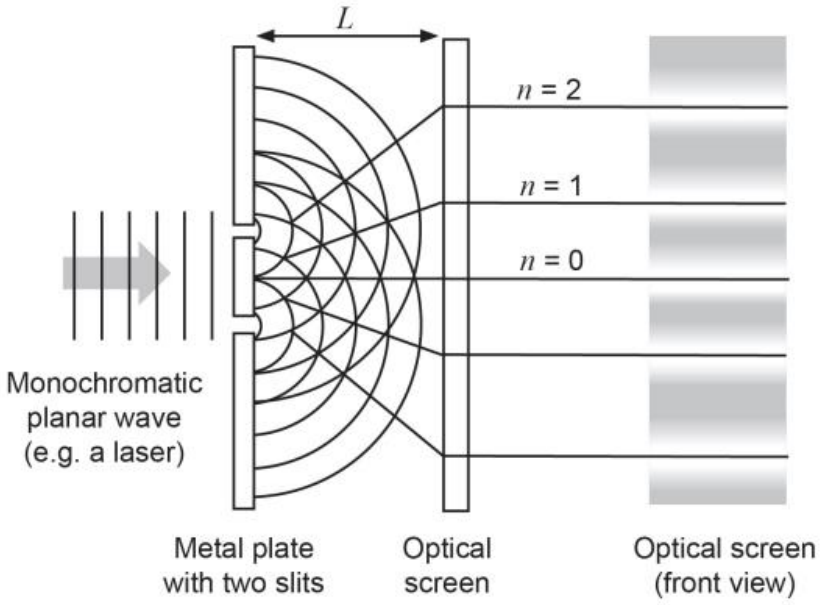
(d) State a formal definition of the term 'work function' and explain why part (c) refers to maximum velocity. (3 marks)

2019 Section 2 Question 17

Wave particle duality and the quantum theory

The first serious challenge to the particle theory of light was made by the English scientist Thomas Young in 1803. Young reasoned that if light were actually a wave phenomenon, as he suspected, then a similar interference effect observed with sound waves should occur for light. This line of reasoning led Young to perform an experiment which is nowadays referred to as 'Young's double-slit experiment'.

In Young's double-slit experiment, two very narrow parallel slits, separated by a distance *d*, are cut into a plate made of thin metal. Monochromatic light, from a distant light source, passes through the slits and eventually hits an optical screen a comparatively large distance *L* from the slits. The experimental setup is shown in the diagram below.



Young observed a series of alternating parallel light and dark bands on the screen, with the central band being bright.

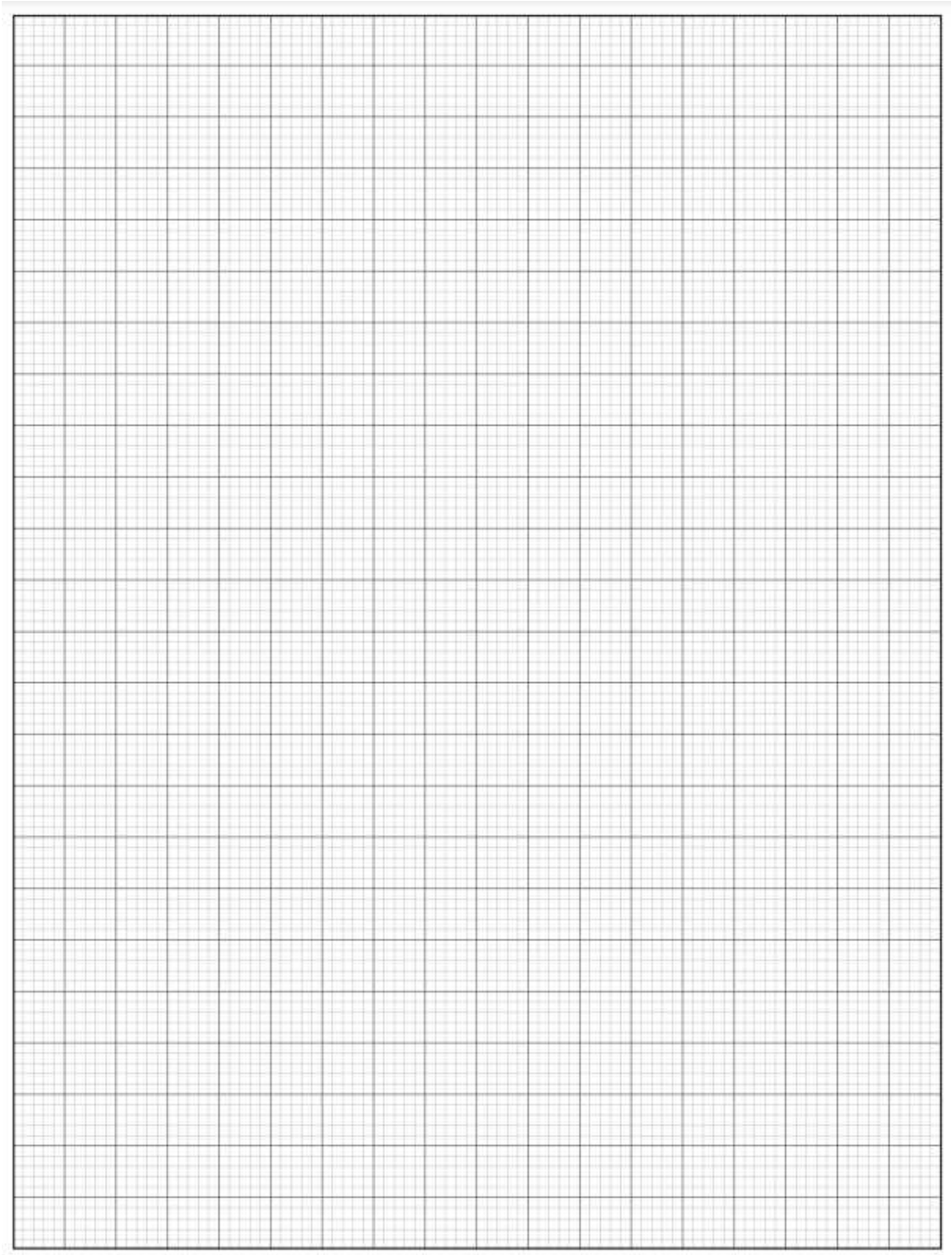
From his research, he established the following relationship between *L*, the distance between the slits and the screen; *d*, the distance between the two slits; λ, the wavelength of the monochromatic light and *x*, the distance between the centres of adjacent light bands in the interference patterns:

$$\frac{x}{L} = \frac{n\lambda}{d}$$

A group of students set up an experiment to measure the wavelength of light produced by a laser pointer. Using a commercially-produced metal plate where d = 2.19 × 10^{-5} m, they varied the distance from the slits to the optical screen (*L*) and measured the distance between the centre light band and the one closest to it (*n* = 1). Their results are shown in the table below.

L (m) ± 0.002 m	0.400	0.800	1.200	1.300	1.400	1.500
x (m × 10^{-2}) ± 0.002 m	1.12	2.21	3.06	3.76	4.28	4.38

(a) Graph x vs L on the grid paper provided on page 23 *(below)*. Include the line of best fit. Do **not** include uncertainties. (5 marks)



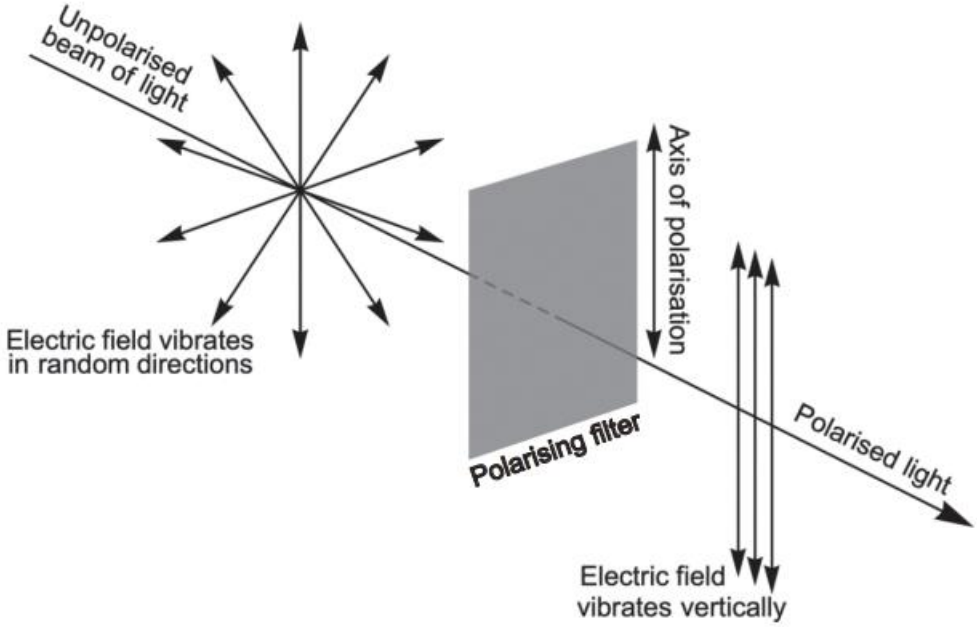
(b) From your graph, calculate the gradient of the line of best fit. Show construction lines on your graph. Use correct significant figures. (3 marks)

(c) Using the gradient from part (b), calculate the wavelength of the monochromatic light used. Use correct significant figures. (4 marks)

_____ nm

The students were disappointed when they found their answer was 10% different from the wavelength supplied by the manufacturers of the laser pointer. When the teacher helped them use the uncertainties associated with their experiment, they found the manufacture's value fell within the accepted range of uncertainty.

(d) Using the same values as in part (b), recalculate your gradient including uncertainties to show that a 10% difference falls within the accepted range. (5 marks)

2023 Section 3 Question 20 **Wave particle duality and the quantum theory**	**Polarisation of light**  Figure 1: Pair of polarised sunglasses When you buy a pair of polarised sunglasses, the main purpose they serve is to reduce the intensity of light hitting your eyes. How they achieve this is described below.  Figure 2: Randomly polarised light passing through a polarising filter Light waves are a combination of oscillating magnetic and electric fields. As the magnetic field changes, it induces a changing electric field, which in turn induces a magnetic field and so on. A beam of light consists of transverse waves oscillating in all directions around the line of propagation. A polarised filter can be thought of as a series of slits that only allows those waves to pass through with their electric fields oscillating in the same direction as the axis in the filter. But the filters do not have actual slits in them. The material consists of long chain polymers. Electrons in these chains are free to move along the chains but not between them. A light wave's electric field does work on these electrons and causes them to absorb the wave's energy. Therefore, light waves which are polarised parallel to the chains get absorbed and those travelling perpendicular pass through undisturbed. Those travelling at an angle to the chains are partially absorbed. The axis of the filter is perpendicular to the chains

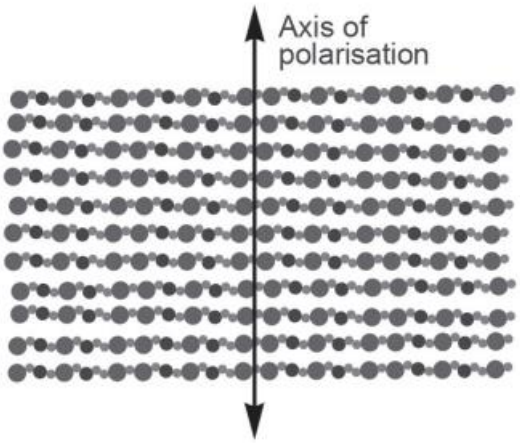


Figure 3: Axis of polarisation is perpendicular to the aligned long chain polymer molecules

Figure 4 illustrates this point. Only the component of the electric field parallel to the axis of a polarising filter is allowed to pass. In the diagram, angle θ represents the angle between the direction of polarisation of incident light and the axis of a polarising filter. After passing through the filter, the amplitude of the electric field has been reduced by a factor of $\cos\theta$.

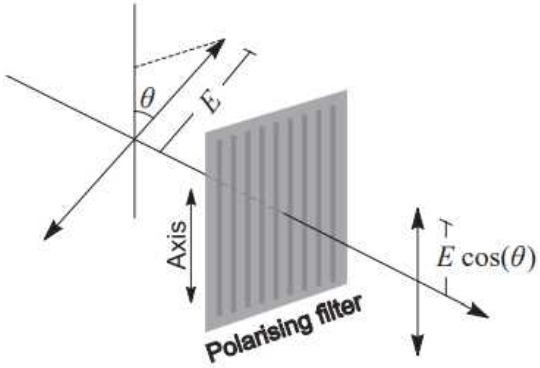


Figure 4: Polarising filter with angle θ shown

Since intensity of a wave is proportional to its amplitude squared, the intensity I of the transmitted wave is related to the initial intensity I_0 of the incident light by the following relationship, known as Malus' Law:

$$I = I_0 \cos^2\theta.$$

A single polarising filter reduces the wave's intensity by exactly 50.0%. Intensity is measured in watts per square metre (W m^{-2}).

(a) With reference to Figure 3 on page 35 *(above in question)*, discuss how unpolarised light can become polarised. (4 marks)

(b) Define the axis of a polarising filter and describe its function. (2 marks)

(c) According to Malus' Law, at what angle to the direction of polarisation of the incident light should the axis of a polarising filter be oriented in order to

(i) allow the light to pass without reduction in intensity? (1 mark)

Answer: _____ °

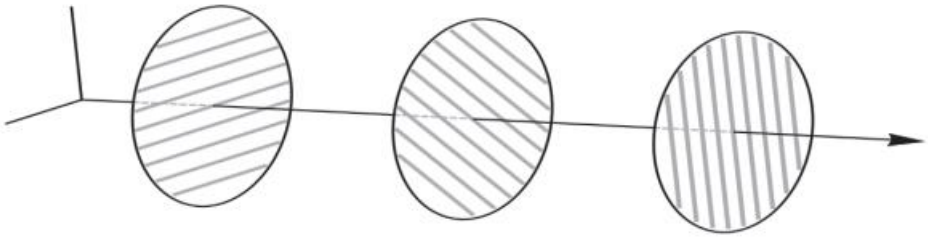
(ii) completely block the passage of the light? (1 mark)

Answer: _____ °

(d) Use Malus' Law to calculate the angle between the direction of polarisation of the incident light and the axis of a polarising filter if the incoming light has its intensity reduced by 75.0%. (4 marks)

Answer: _____ °

(e)



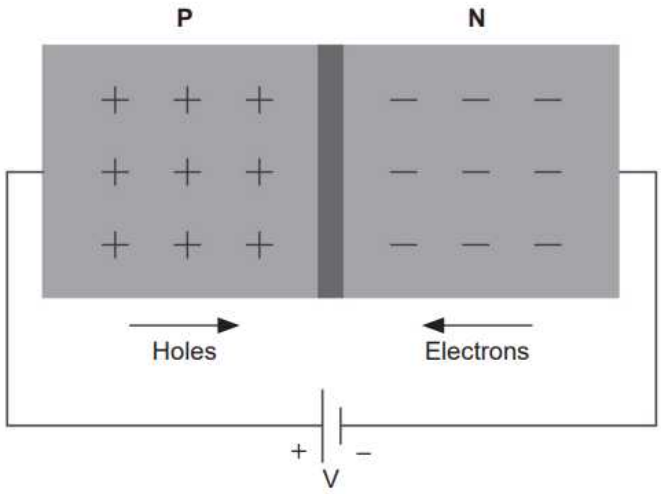
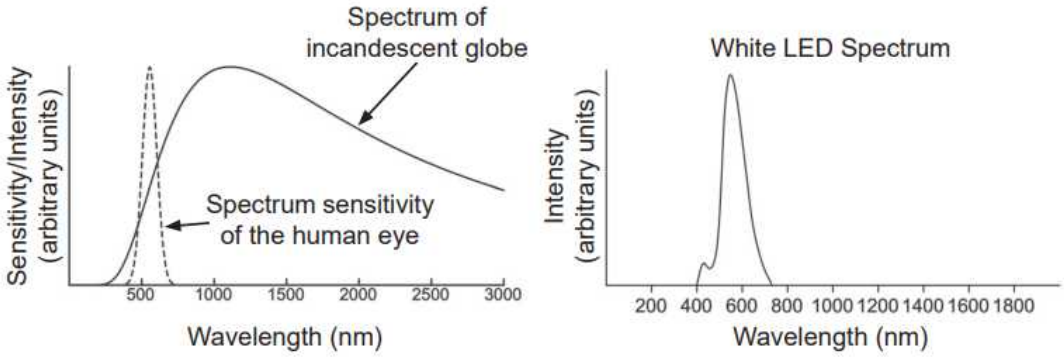
A group of students placed two polarising filters at right angles and saw no light being transmitted. They placed a third filter between the first two at 45.0° to each one and noticed light was transmitted.

(i) Explain how inserting the third filter allowed light to hit the screen when no light was hitting it before. (3 marks)

(ii) What percentage of the original light's intensity is hitting the screen with the third filter in place? (2 marks)

Answer: _____ %

(f) A photon's energy is given by $E = hf$. When light passes through a polarising filter, the total energy transmitted is reduced but the frequency of each photon remains the same. Using the particle model of light, account for the reduction in transmitted energy. (3 marks)

2022 Section 3 Question 18 **Wave particle duality and the quantum theory**	**Light-emitting diodes (LEDs)** ***Copyright restrictions prohibit the release of this SCSA exam material.***  ***Copyright restrictions prohibit the release of this SCSA exam material.***  ***Copyright restrictions prohibit the release of this SCSA exam material.*** **Efficacy** LEDs are also known for having the best 'efficacy' of all light sources. Efficacy is the measure of how well a light source produces visible light. It is measured in lumens per watt, or how much light is provided for every watt of power consumed. The power is calculated by multiplying the forward voltage (the lowest voltage at which current starts to flow in the normal conducting direction, V_F) by the operating current measured in amperes. In order to make sure that the correct voltage gets dropped across the LED, a voltage greater than the minimum required to produce the desired wavelength is used. A table of specific crystals, their forward voltages and the wavelengths they produce is given below. To increase brightness, the current is increased.

Typical LED characteristics			
Semiconductor material	**Wavelength (nm)**	**Colour**	**V_F**
GaAs	850–940	Infra-red	1.20 V
GaAsP	630–660	Red	1.80 V
GaAsP	605–620	Amber	2.00 V
GaAsP:N	585–595	Yellow	2.20 V
AlGaP	550–570	Green	3.50 V
SiC	430–505	Blue	3.60 V
GaInN	450–650	White	4.00 V

(a) Explain how a PN junction produces visible light. (4 marks)

The Law of Conservation of Energy states: 'Energy is neither created nor destroyed; it only moves from one place to another - from one type of energy to another.'

(b) LEDs and incandescent light bulbs are equally efficient at converting energy drawn from the mains into different types of energy. Why then does the passage on page 33 *(above)* state that LEDs are far more efficient than incandescent light bulbs? Reference must be made to the graphs of intensity versus wavelength. (4 marks)

(c) The efficacy of a particular LED is 120 lumens W^{-1}. Using information in the passage and table on page 33 *(above)*, calculate how much current would need to run through a blue SiC LED light bulb operating at minimum V_F to produce 840 lumens. (4 marks)

Answer: _____ A

(d) With the use of a calculation and data from the table on page 33 *(above)*, show how the minimum V_F for SiC crystals is large enough to produce photons with the lowest energy required for blue light. (4 marks)

(e) Lighting accounts for 15% of yearly global electricity consumption (194 EJ or 194×10^{18} J). Roughly 40% of this is supplied by LEDs. Each tonne of coal produces, on average, 21 GJ of energy. Eighty per cent of world energy consumption is derived from fossil fuels. Using the efficiencies stated in the passage, estimate the mass of coal the world could save per year if 100% of lighting was provided by LEDs. (5 marks)

Answer: _____ Tonnes

2021 Section 3 Question 20

Wave particle duality and the quantum theory

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Rembrandt's *The Night Watch* was painted in 1642. But there is something odd about the name 'The Night Watch': it was not the name of the original painting. After it was restored, it became obvious that it was a daytime scene.

By the end of the 18th century, the painting had accumulated so many layers of varnish and dirt that it looked like the scene took place at night – and hence, it was misnamed 'The Night Watch'. The Rijksmuseum in Amsterdam carried out the largest research and restoration project ever. With the aid of X-ray fluorescence spectrometry, expensive paintings can be investigated harmlessly before restoration. This ensures sophisticated preservation of valuable art objects. It also allows the paintings to be restored securely in the buildings where the public can still enjoy them.

Depending on its energy, the X-ray beam penetrates into different depths of the painting's surface. This allows us to examine different layers of paint and even detect corrections made by Rembrandt without having to remove any paint. It is already known today that Rembrandt lengthened lances (spears) and changed the positioning of the people in the picture.

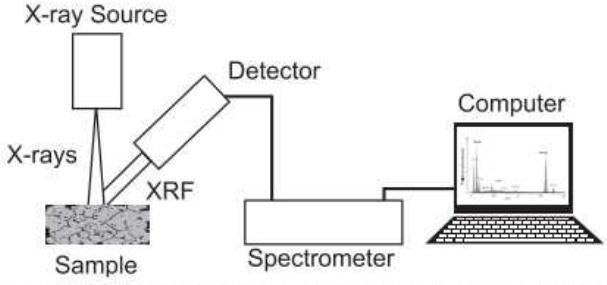

Figure 1: Schematic of process of X-ray fluorescence spectrometry

The spectrometer analyses the specific wavelengths of light given off by each sample of paint. It produces a printout similar to the one in Figure 2 showing the abundance of each wavelength emitted versus their energies.

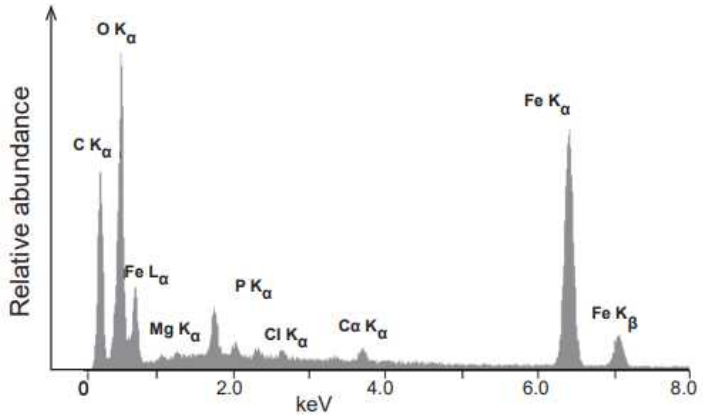

Figure 2: The relative abundance of energies of emitted photons

X-ray fluorescence analysis (XRF) is based on the detection of the fluorescence produced after the sample is bombarded with X-rays. Inner electrons are ejected by the incoming X-rays and then other electrons in higher energy shells cascade downward in smaller steps, emitting photons with specific wavelengths corresponding to the energy difference between shells. This fluorescence radiation is element-specific as the energy of each shell '*n*' is given by:

where *Z* is the charge on the nucleus, which is directly proportional to the number of protons in the nucleus. (For the K shell $n = 1$, for the L shell $n = 2$, and for the M shell $n = 3$.)

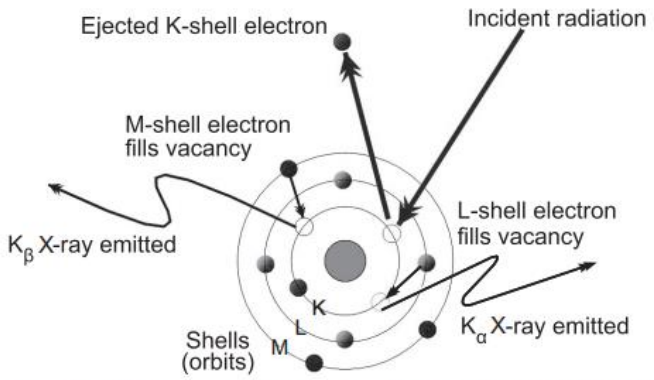

Figure 3: Electron transitions between K, L and M energy shells

The main spectral lines correspond to electron transitions to the K shell. Transitions from the L shell to K shell produce K*α* photons and those from the M shell to K shell produce K*β* photons. This process is described in Figure 3.

(a) List two properties of X-rays that make them suitable for X-ray fluorescence spectrometry. (2 marks)

One:

Two:

(b) Explain how we now know that Rembrandt's original painting had lances of different length and some of the people were in different positions. (2 marks)

(c) Give **two** advantages of using X-ray spectrometry to analyse old paintings. (2 marks)

One:

Two:

(d) Explain why the fluorescent radiation is element specific. (3 marks)

(e) (i) Estimate the values of the M and L energy shells relative to the K shell for iron (Fe) displayed in Figure 2 and place them in the corresponding spaces below. (3 marks)

M _____ eV

L _____ eV

K 0 eV

(ii) Estimate the wavelength of the photon given off when an electron falls from the M shell to the L shell in an iron atom. (4 marks)

Answer _____ m

(iii) To which part of the electromagnetic spectrum does this wavelength belong? (1 mark)

(f) How would the graph in Figure 2 change if the operators of the spectrometer increased the power of the X-ray beam while keeping the wavelength constant? Explain your answer.

(i) Change (1 mark)

(ii) Explanation (2 marks)

2020 Section 3 Question 20

Wave particle duality and the quantum theory

A cyclotron is a particle accelerator. It is an electrically-powered machine that produces a beam of charged particles that can be used for medical, industrial and research purposes. A cyclotron accelerates charged particles in a spiral path, which allows for a much longer path for acceleration than a straight-line accelerator.

A cyclotron consists of two semicircular charged plates in a flat vacuum chamber called 'dees' because of their shape. The chamber sits between the poles of a magnet that creates a strong and vertical magnetic field. A stream of charged particles is fed into the centre of the chamber and a high-frequency alternating voltage is applied across the plates. This voltage accelerates the charged particles across the gap every half turn. Combined with the magnetic field, this process causes the particles to spiral outwards until they exit the cyclotron.

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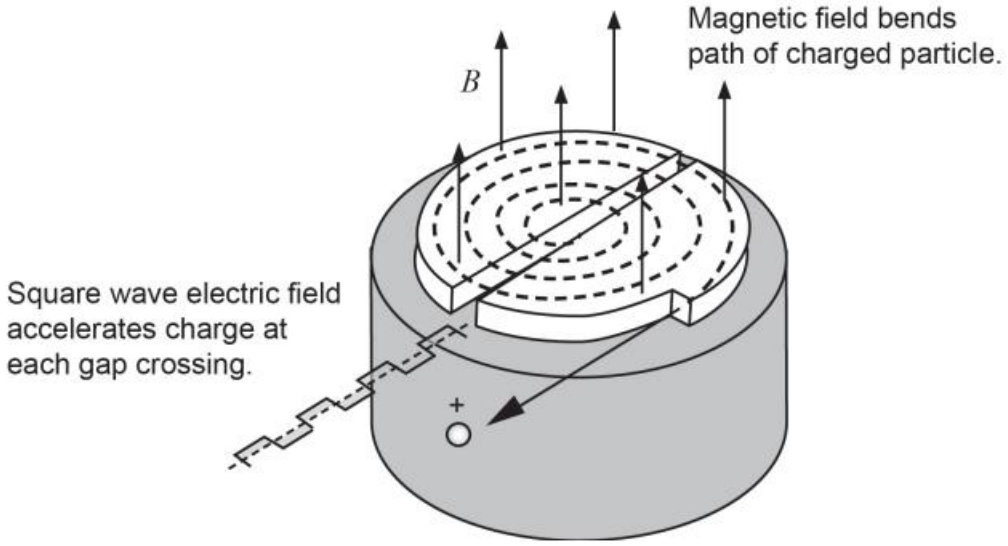


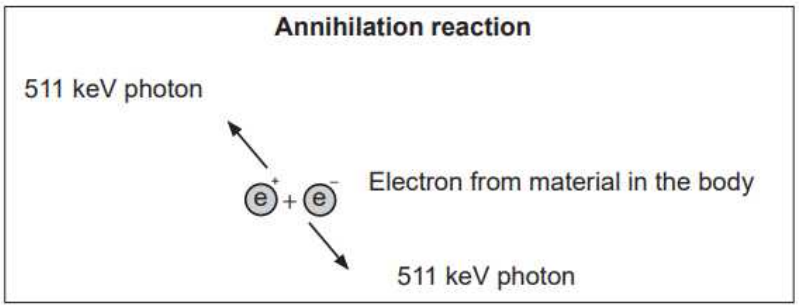
The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.

Medical cyclotrons

Medical cyclotrons produce proton beams that are used to manufacture radioisotopes used in medical diagnosis. Radioisotopes produced in a cyclotron decay by either positron emission or electron capture. Positron emission tomography (PET) and single photon emission computed tomography (SPECT), which utilises gamma ray emission, are two imaging techniques that rely on cyclotron-produced radioisotopes.

(a) The diagram above shows the acceleration of a positive particle in a cyclotron. Describe one change that would need to be made in order to use the same machine to produce a beam of negatively-charged particles exiting from the same place, and explain why. (3 marks)

Positrons (e^+) are examples of antimatter and have the same properties as electrons (e^-) except for having a positive charge. When they collide with an electron, the following process occurs.



(b) (i) Calculate the wavelength of the photons produced in the annihilation described in the diagram above. (3 marks)

_____ m

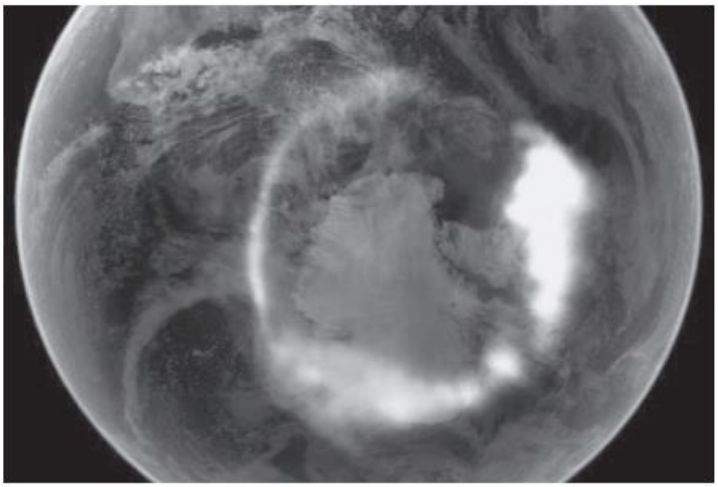
(ii) To which part of the electromagnetic spectrum does the photon belong? (1 mark)

(c) Explain why increasing the strength of the magnetic field would increase the velocity of the particles leaving the cyclotron. (4 marks)

(d) (i) Explain why the voltage across the dees must alternate. (2 marks)

On page 31 *(above)* the text states: 'The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.'

(ii) Derive an expression for the cyclotron frequency and use the expression to explain why this statement is correct. (Ignore relativistic effects.) (6 marks)

2019 Section 3 Question 20 **Wave particle duality and the quantum theory**	**Auroras: What are they and how are they created?**  The Aurora Australis, captured by NASA's IMAGE satellite and overlaid onto a photograph of the earth. (NASA: public domain) ***Copyright restrictions prohibit the release of this SCSA exam material.***

(a) (i) Estimate how much time it takes for the plasma from a typical CME to reach the earth's magnetic field. (2 marks)

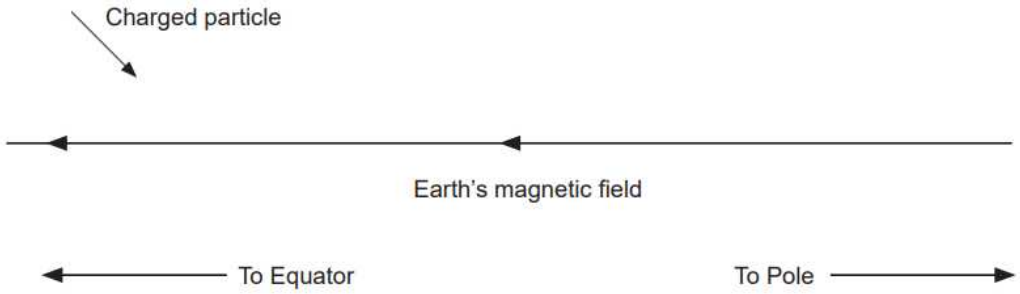
_____ hours

(ii) Give **two** reasons why your answer to part (a) (i) is only an estimate. (2 marks)

One:

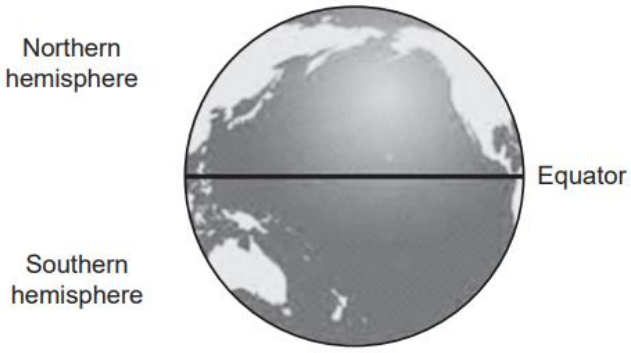
Two:

(b) Draw the possible path of a charged particle travelling along a magnetic field line after approaching it at an angle other than 90°. The field strength increases as the particle moves toward the pole. (3 marks)



A spare diagram is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and clearly indicate that you have redrawn it on the spare page.

(c) (i) Draw the magnetic field around the earth on the diagram below before any distortion occurs due to a CME. (3 marks)



(ii) Using information from the text, suggest a reason why auroras are usually seen at the north and south poles but not at the equator. (3 marks)

(d) Using specific information from the passage, explain why the same photon-producing electron transition produces red light in neutral molecular nitrogen and blue light in ionised molecular nitrogen. (5 marks)

2023 Section 1 Question 4

Wave particle duality and the quantum theory

Calculate the wavelength of a photon with an energy of 1.81 keV.

Element	Description	Marks
Converts to joules	$1810 \times 1.60 \times 10^{-19} = 2.896 \times 10^{-16}$ J	1
Substitutes $\frac{c}{\lambda}$ for f	$E = \frac{hc}{\lambda}$	1
Rearranges for λ	$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{2.896\times10^{-16}}$	1
Calculates answer	$\lambda = 6.87 \times 10^{-10}$ m	1
	Total	**4**

2023 Section 1 Question 6

Wave particle duality and the quantum theory

The photoelectric effect equation is

$$\frac{1}{2}mv_{max}^2 = hf - W$$

The maximum kinetic energy of a liberated electron is equal to the difference between the energy of the incoming photon and the work function of the metal target.

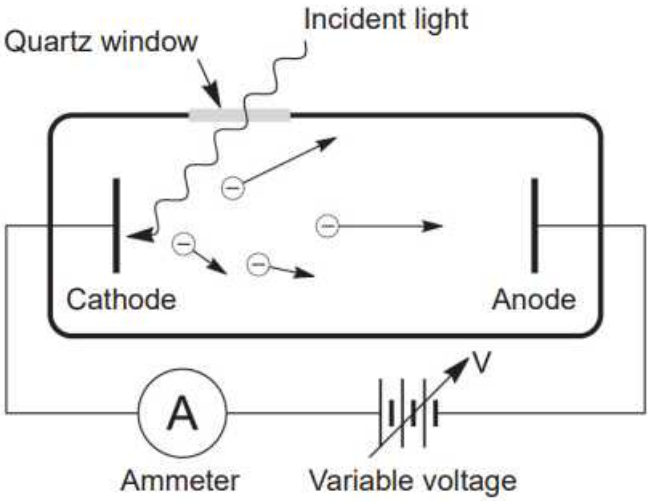


Figure 1: Photoelectrons are released from a metal target in a vacuum tube

(a) Describe how, and under what circumstances, electrons are liberated from the target by incoming photons. (2 marks)

Description	Marks
the incoming photons are completely absorbed by electrons in the target metal	1
if the photon energy is larger than the work function of the metal, an electron is released from the metal	1
Total	**2**

(b) Discuss how the maximum kinetic energy of the liberated electrons is experimentally determined. (4 marks)

Description	Marks
a reverse potential is applied which turns the anode into a negatively charged cathode	1
as the reverse potential increases, fewer electrons have the necessary kinetic energy (KE) to reach it	1
when KE = Vq, 0 current is recorded	1
this is the maximum KE of a liberated electron	1
Total	**4**

2023 Section 1 Question 10

Wave particle duality and the quantum theory

Estimate the de Broglie wavelength for a standard men's basketball travelling at 10.0 m s^{-1}.

Element	Description	Marks
Estimates mass of basketball	Range: 0.20 – 2.00 kg	1
Substitutes mv for p in equation (using 0.60 kg)	$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{0.60 \times 10.0}$	1
Calculates answer	$\lambda = 1.105 \times 10^{-34}$ m	1
2 significant figures	$\lambda = 1.1 \times 10^{-34}$ m	1
	Total	**4**
Note: If using 0.20 kg, $\lambda = 3.3 \times 10^{-34}$ m. If using 2.0 kg, $\lambda = 3.3 \times 10^{-35}$ m.,		

2022 Section 1 Question 1

Wave particle duality and the quantum theory

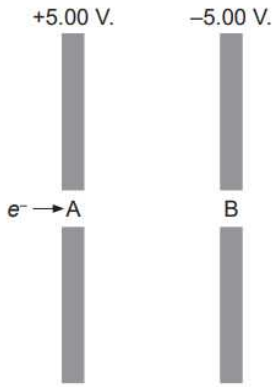
Light with a wavelength of 341 nm is shone onto a potassium metal plate in a photoelectric cell, causing a photocurrent to flow. The work function of potassium is 2.30 eV. Calculate the maximum speed of the electrons emitted by the plate. (5 marks)

Element	Description	Marks
Uses photoelectric effect equation	$E = hf - W$	1
Converts eV to Joules	$2.30 \times 1.60 \times 10^{-19} = 3.68 \times 10^{-19}$ J	1
Calculates the energy of incoming photon.	$E = \frac{hc}{\lambda} = 3.00 \times 10^{8} \times 6.63 \times 10^{-34} / 341 \times 10^{-9}$ $= 5.83 \times 10^{-19}$ J	1
Calculates kinetic energy of electron	$KE_e = (5.83 - 3.68) \times 10^{-19} = 2.15 \times 10^{-19}$ J	1
Calculates the velocity of the electron	$v = \sqrt{\frac{2 \times 2.15 \times 10^{-19}}{9.11 \times 10^{-31}}}$ $= 6.87 \times 10^{5}$ m s^{-1}	1
	Total	**5**

2022 Section 1 Question 9

Wave particle duality and the quantum theory

Two parallel conducting metal plates are held at a potential difference of 10.0 V. An electron in a vacuum arrives at a small hole in the first plate at point A with 20.0 eV of kinetic energy, and travels through an electric field to B as shown in the diagram. Calculate the de Broglie wavelength of the electron as it exits at B. (5 marks)

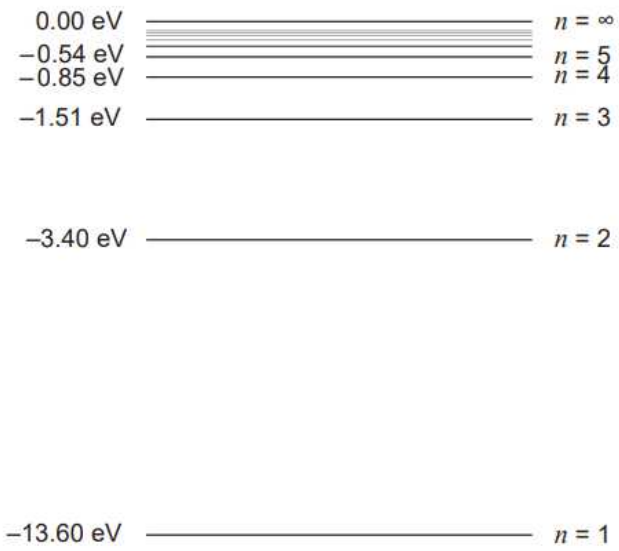


Element	Description	Marks
Reduces kinetic energy of electron by 10.0 eV	20.0 – 10.0 eV	1
Converts eV to Joules	$10.0 \times 1.60 \times 10^{-19} = 1.60 \times 10^{-18}$ J	1
Calculates exit velocity of electron	$v = \sqrt{\frac{2 \times 1.60 \times 10^{-18}}{9.11 \times 10^{-31}}}$ $= 1.87 \times 10^{6}$ m s^{-1}	1
Uses De Broglie equation and substitutes values correctly	$\lambda = 6.63 \times 10^{-34} / 9.11 \times 10^{-31} \times 1.87 \times 10^{6}$	1
Calculates correct answer	3.89×10^{-10} m	1
	Total	**5**
Note: If candidate adds 10 eV, $\lambda = 2.24 \times 10^{-10}$ m, award maximum 4 marks. If candidate uses 20 eV, award maximum 3 marks.		

2021 Section 1 Question 1

Wave particle duality and the quantum theory

Some energy levels, n, for hydrogen atoms are shown in the diagram below.



Electrons with 12.2 eV of energy are incident on the hydrogen atoms. Calculate the energies of all scattered electrons in eV. (4 marks)

Element	Description	Marks
Student calculates the maximum transition possible is from 1 to 3.	-13.60 + 12.2 = -1.40 eV	1
Calculates energies transferred to electrons in the atom	13.60 – 1.51 = 12.09 eV 13.60 – 3.40 = 10.2 eV	1
Calculates energies of scattered electrons	12.2 – 12.09 = 0.11 eV 12.2 – 10.2 = 2.00 eV	1
Student includes elastic collision where incident electrons retain all their energy	12.2 eV	1
	Total	**4**

2020 Section 1 Question 2

Wave particle duality and the quantum theory

Calculate the speed of an electron with a de Broglie wavelength of 1.23 nm.

Element	Description	Marks
substitutes mv for p and rearranges equation	$v = h/m\lambda$	1
uses m(e) and converts nm to m	$v = 6.63 \times 10^{-34} / 9.11 \times 10^{-31} \times 1.23 \times 10^{-9}$	1
performs calculation correctly	$= 5.91 \times 10^{5}$ m s^{-1}	1
	Total	**3**

2020 Section 1 Question 3

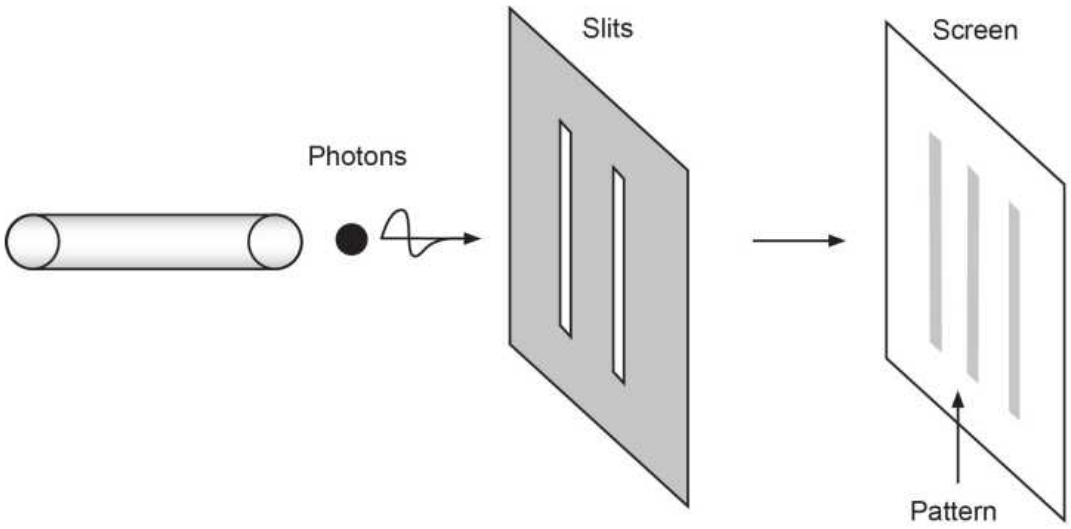
Wave particle duality and the quantum theory

A 10.0 watt monochromatic LED radiates light with a wavelength of 525 nm. How many photons does it emit per second? Assume all the energy is converted to light.

Element	Description	Marks
substitutes c/λ for f	$E = ch/\lambda$	1
converts nm to m and calculates energy of one photon	$E = (3.0 \times 10^{8} \times 6.63 \times 10^{-34})/(525 \times 10^{-9})$ $E = 3.79 \times 10^{-19}$J	1
divides 10.0 J by energy of one photon	$= 10.0/3.79 \times 10^{-19}$	1
correct/consistent numerical answer	$= 2.64 \times 10^{19}$	1
	Total	**4**

2020 Section 1 Question 8

Wave particle duality and the quantum theory



The diagram above shows that when monochromatic coherent light is shone through two narrow slits onto a screen, light and dark fringes appear on the screen.

(a) What property of light causes this to happen? Circle your answer. (1 mark)

Description	Marks
wave	1
Total	**1**

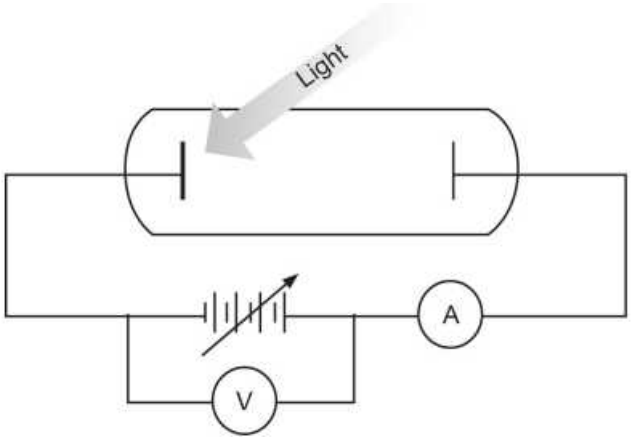
(b) Explain how **both** the light and dark fringes are formed. (4 marks)

Description	Marks
as light waves pass through narrow slits they spread out: diffraction	1
the two waves interfere with each other to form an interference pattern on the screen	1
when the two waves are in phase, constructive interference when the two waves meet 180 degrees out of phase, destructive interference	1
constructive interference occurs: bright fringe destructive interference occurs: dark fringe	1
Total	**4**

2019 Section 1 Question 2

Wave particle duality and the quantum theory

When light is shone on a metal plate, electrons may be emitted from the plate. This is called the 'photoelectric effect'. The apparatus below shows incident light of wavelength 450 nm striking a metal plate. The number of photons striking the plate per second can also be controlled by varying the brightness of the incident light. The current produced by the light is initially measured by the ammeter (A). Initially, the ammeter (A) reads a current. The stopping potential (V) is then adjusted until the ammeter reads 0 A.



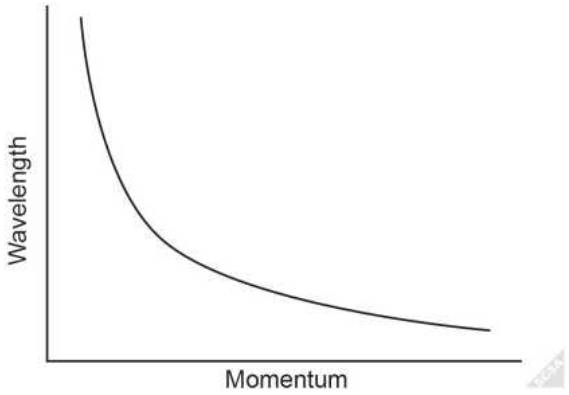
Assume the frequency of the light remains above the threshold frequency of the metal. In the table below, describe what would happen to the initial reading on A and the final reading on V, if the following changes were made. Use the terms 'increase', 'decrease' or 'unchanged'.

Description		Marks
unchanged	increases	1–2
decrease	increases	1–2
	Total	**4**

2019 Section 1 Question 10

Wave particle duality and the quantum theory

If we plot the de Broglie wavelength of a subatomic particle against its momentum, we get the graph shown below. This applies to velocities less than 5% of the speed of light.



(a) Give a possible relationship between wavelength and momentum based upon the shape of the graph. (1 mark)

Description	Marks
$\lambda \alpha \frac{1}{p}$ $\left(\text{not } \lambda = \frac{1}{p}\right)$ or inverse relationship	1
Total	**1**

(b) Describe how the data used to generate the graph could be reorganised to produce a straight-line graph. (2 marks)

Description	Marks
plot λ vs $1/p$ or p vs $1/\lambda$ (must mention both variables)	1–2
Total	**2**

(c) What would the gradient of the straight-line from part (b) represent? (1 mark)

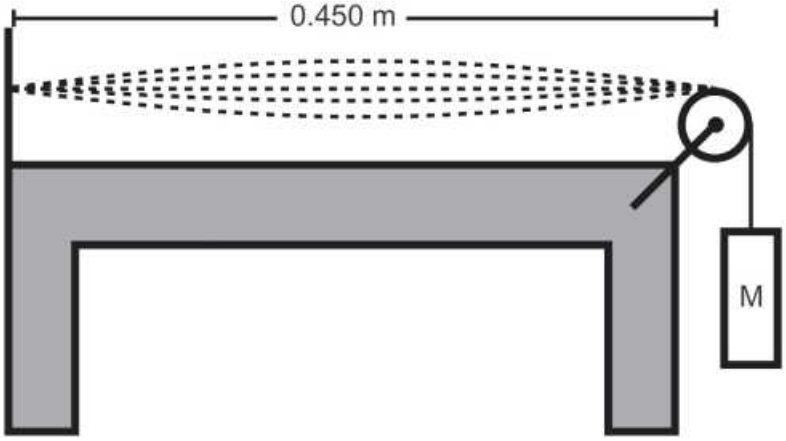
Description	Marks
Planck's constant for λ vs $1/p$	1
$1/h$ for p vs $1/\lambda$	
Total	**1**

(d) Ignoring relativistic effects, calculate the momentum of a particle with a wavelength of 2.50 × 102 nm. (4 marks)

Description	Marks
$p = h/\lambda$	1
$= 6.63 \times 10^{-34} / 2.5 \times 10^{-7}$	1
$= 2.65 \times 10^{-27}$	1
kg m s^{-1} or Ns or J s m^{-1}	1
Total	**4**

2023 Section 2 Question 16

Wave particle duality and the quantum theory



A group of students set up the apparatus shown in the diagram above to measure the mass per unit length of a thin and strong steel wire. On each successive trial, they increased the mass of the counterweight M, further stretching the wire. They then plucked the steel wire and measured the frequency of the vibrating wire using a strobe light. The length L of the vibrating portion of the wire, shown in the diagram above, was 0.450 m. Their results are given in the table below.

Mass (kg)	1.50	2.00	2.50	3.00	3.50	4.00
Frequency (Hz)	105	120	135	150	160	170

The students observed the wire vibrating in its fundamental mode, where wavelength $\lambda = 2L$, and substituted this into the wave equation $v = \lambda f$. They also used the following equation for the speed v of a wave along a wire under tension:

$v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the wire (in N) and μ is the mass per unit length (in kg m^{-1}).

Using these equations they derived the relationship below.

$$T = (4L^2 \mu) f^2$$

(a) Show how the students derived this relationship. (4 marks)

Element	Description	Marks
Substitutes $f\lambda$ for v	$f\lambda = \sqrt{\frac{T}{\mu}}$	1
Substitutes $2L$ for λ	$f2L = \sqrt{\frac{T}{\mu}}$	1
Squares both sides	$f^2 4L^2 = \frac{T}{\mu}$	1
Isolates T correctly	$T = (4L^2\mu) f^2$	1
	Total	**4**

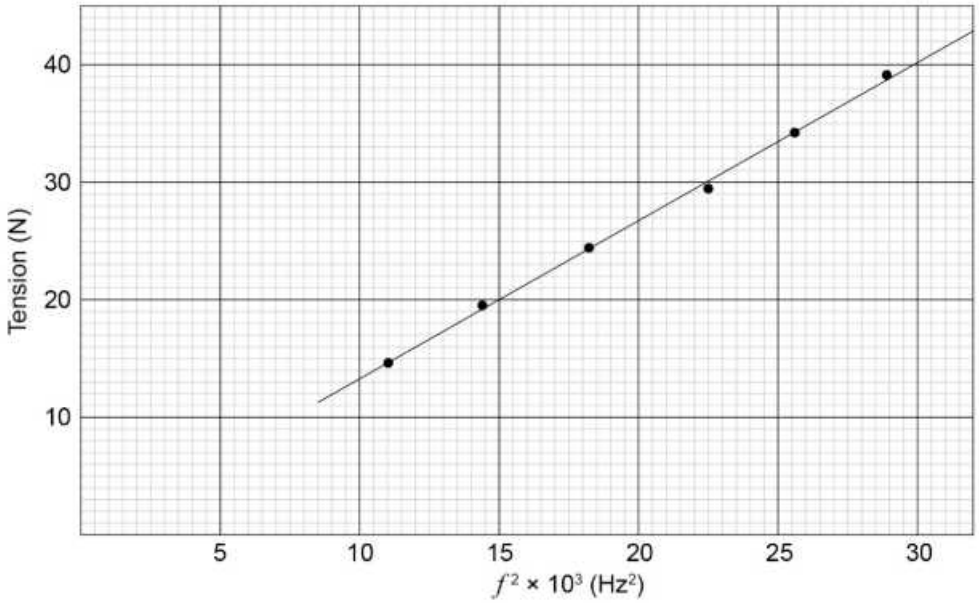
The students then manipulated their data so as to graph this relationship and produce a straight line.

(b) Make the adjustments to the data and place the results in the table below. Give your answers to **three** significant figures and express f 2 in scientific notation. (4 marks)

Mass (kg)	1.50	2.00	2.50	3.00	3.50	4.00
Tension (N)	14.7	19.6	24.5	29.4	34.3	39.2
f^2 (Hz^2)	1.10×10^4	1.44×10^4	1.82×10^4	2.25×10^4	2.56×10^4	2.89×10^4

Description	Marks
Converts mass to tension (× 9.80)	1
Squares frequencies	1
Scientific notation	1
3 significant figures	1
Total	**4**

(c) Graph your data on the grid below. Include a line of best fit. (3 marks)



Description	Marks
Plots all points	1
Plots accurately	1
Accurate line of best fit	1
Total	**3**

(d) Use the gradient of your line of best fit to calculate the mass per unit length in kg m^{-1} of the steel wire. Indicate clearly the two points used and express your answer to the appropriate number of significant figures. (5 marks)

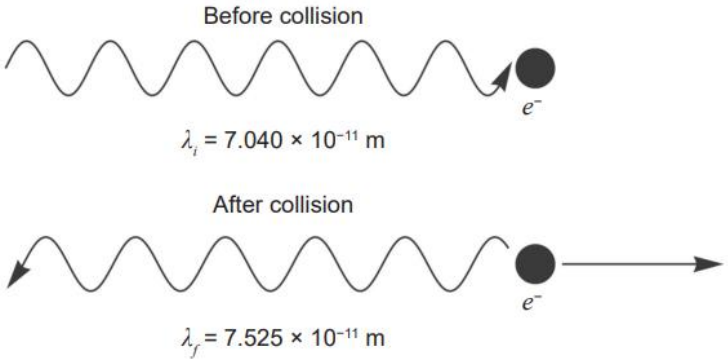
Element	Description	Marks
Indicates clearly two points used (not data points)		1
Calculates gradient of line of best fit	$\Delta y/\Delta x = (1.30 - 1.40) \times 10^{-3}$ N Hz^{-2}	1
Calculates μ using the gradient	$\mu = m/(4 \times 0.450^2) = 1.69 \times 10^{-3}$	1
Answer within range	$(1.60 - 1.73) \times 10^{-3}$ kg m^{-1}	1
2 or 3 significant figures only (must be consistent with values read from graph)		1
	Total	**5**

(e) In the summary of their report, the students had to identify any variables that could affect the accuracy of their value. They identified correctly an important assumption they had made, which may have caused their value to be slightly different from the theoretical value. This had nothing to do with human error, inaccurate equipment, atmospheric conditions or calibration of instruments. Describe their assumption. (2 marks)

Description	Marks
the wire stretches when increased weight is added	1
the mass per unit length will also change as it stretches	1
Total	**2**

2022 Section 2 Question 13

Wave particle duality and the quantum theory



A stationary free electron and a photon collide. In such collisions, both momentum and energy are conserved. In one such collision, a photon of wavelength 7.040×10^{-11} m is travelling in the direction shown in the diagram above. After the collision, the photon returns in the direction it came from (i.e. 180°) with a new wavelength of 7.525×10^{-11} m and the electron is no longer stationary. No other particles or photons are produced in the collision.

(a) What is the original energy of the photon in eV? (3 marks)

Element	Description	Marks
Substitutes $\frac{c}{\lambda}$ for f in $E = hf$	$E = \frac{hc}{\lambda}$	1
Calculates correct answer in Joules	$E = 3.00 \times 10^8 \times 6.63 \times 10^{-34}/7.040 \times 10^{-11}$ $= 2.82 \times 10^{-15}$ J	1
Converts to eV	$E = 1.77 \times 10^4$ eV	1
	Total	**3**

(b) What is the momentum of the photon before the collision? (2 marks)

Element	Description	Marks
Uses de Broglie and isolates p	$p = \frac{h}{\lambda}$	1
Calculates correct answer	$p = 6.63 \times 10^{-34} / 7.040 \times 10^{-11}$ $= 9.42 \times 10^{-24}$ N s	1
	Total	**2**

(c) Explain why the wavelength of the photon is greater after the collision. (3 marks)

Description	Marks
Conservation of Energy means the energy gained by the electron comes from the photon.	1
$E = \frac{hc}{\lambda}$	1
As energy has decreased, wavelength must increase.	1
Total	**3**

Alternate solution:

Description	Marks
Photon transfers momentum to the electron.	1
Conservation of Momentum means photon rebounds with less momentum.	1
From $\lambda = \frac{h}{p}$, λ must increase.	1
Total	**3**

(d) Calculate the speed of the electron after the collision. (Hint: use the principles of conservation of energy.) (6 marks)

Element	Description	Marks
Energy lost by the photon is gained by the electron		1
Correct formula	$E_e = \frac{hc}{\lambda_1} - \frac{hc}{\lambda_2}$	1
Uses correct wavelengths	$3.00 \times 10^8 \times 6.63 \times 10^{-34} \times (1/7.040 \times 10^{-11} - 1/7.525 \times 10^{-11})$	1
Calculates correct energy	$E = 1.82 \times 10^{-16}$ J	1
Isolates v from KE equation	$v = \sqrt{\frac{2 \times 1.82 \times 10^{-16}}{9.11 \times 10^{-31}}}$	1
Calculates correct answer	$v = 2.00 \times 10^7$ m s^{-1}	1
	Total	**6**

2022 Section 2 Question 15

Wave particle duality and the quantum theory

In 1880, Johannes Rydberg established a mathematical relationship between the wavelengths of light and changes in the relevant energy levels of the hydrogen atom, which is observed in the emission spectrum.

$$\frac{1}{\lambda} = \frac{R}{hc}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

λ = wavelength of light emitted
R = Rydberg's constant
n = the number of the energy levels between which the electron falls (n_2 is always larger than n_1)

The wavelengths of the Lyman series of photons emitted for a hydrogen atom are shown in the diagram below. The Lyman series is made up of all electron transitions to $n = 1$ i.e. $n_1 = 1$.

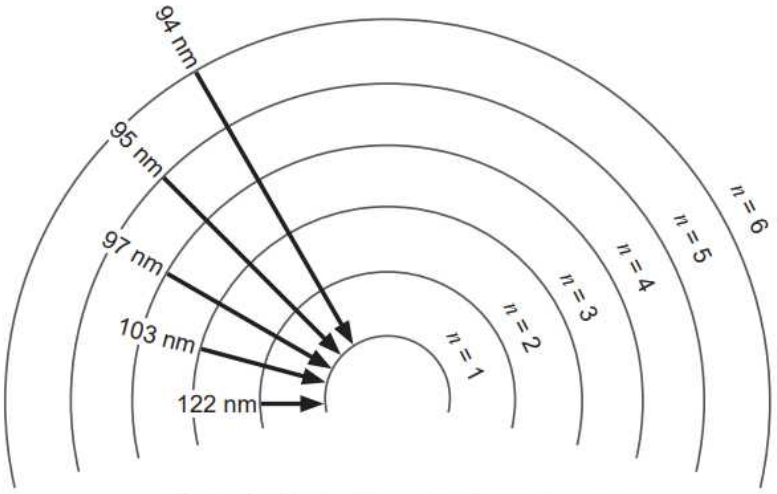


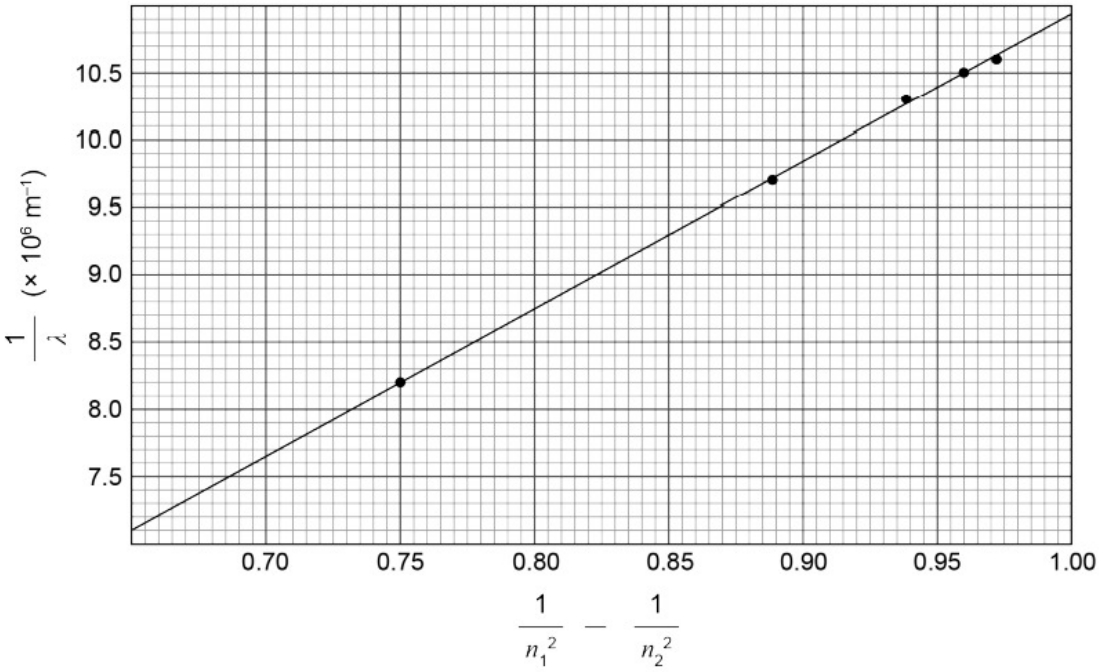
Figure 1: The Lyman series for hydrogen

(a) Fill in the table below using the values in Figure 1. Give your answers to **three** significant figures. (5 marks)

Δn	2→1	3→1	4→1	5→1	6→1
$\frac{1}{n_1^2} - \frac{1}{n_2^2}$	0.750	0.889	0.938	0.960	0.972
$\frac{1}{\lambda}$ (10^6 m^{-1})	8.20	9.71	10.3	10.5	10.6

Description	Marks
first row correct (1 mark off for each incorrect answer, maximum 2)	1–2
second row correct (1 mark off for each incorrect answer, maximum 2)	1–2
3 significant figures	1
Total	**5**

(b) Graph $\frac{1}{\lambda}$ vs $\frac{1}{n_1^2} - \frac{1}{n_2^2}$ on the grid below. Label the axes clearly and draw a line of best fit. (5 marks)



Description	Marks
y–axis labelled correctly with correct units	1
x–axis labelled correctly with no units	1
all points plotted	1
points plotted accurately	1
line of best fit	1
Total	**5**

(c) Use your line of best fit to calculate Rydberg's constant. Indicate clearly the points you have used. Give your answer to **two** significant figures. (5 marks)

Description	Marks
clearly indicates the 2 points used (must not be data points).	1
uses correct formula for gradient ($\Delta y/\Delta x$)	1
calculates gradient. ($1.1 \pm 0.1 \times 10^7$ m^{-1})	1
multiplies gradient by ch. $1.1 \times 10^7 \times 3.00 \times 10^8 \times 6.63 \times 10^{-34} = 2.2 \times 10^{-18}$ J	1
2 significant figures	1
Total	**5**

Rydberg's equation can also be applied to one-electron ions of different elements. The formula is modified to:

$$\frac{1}{\lambda} = Z^2 \frac{R}{hc}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

Z is the atomic number of the element. Figure 2 shows a selection of energy levels for a helium ion (Z = 2) and hydrogen atom (Z = 1).

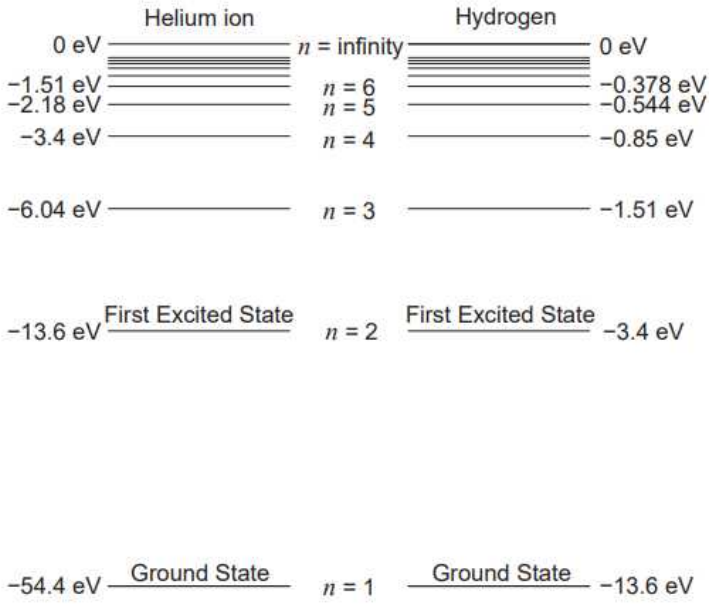


Figure 2: Energy levels for a helium ion and a hydrogen atom

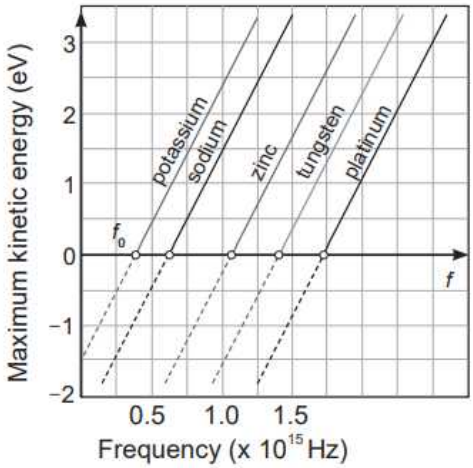
(d) Identify and explain **two** differences you would see between the graph of $\frac{1}{\lambda}$ vs $\frac{1}{n_1^2} - \frac{1}{n_2^2}$ for hydrogen and the helium ion. (4 marks)

Description	Marks
One	
The gradient will be 4 times greater for He^+ than hydrogen.	1
Therefore Z for He^+ is 2 therefore coefficient of x variable is × 4.	1
Two	
The wavelengths will be shorter and the range of values on the y-axis will be greater.	1
Therefore the energy differences between levels for He^+ are greater than for hydrogen.	1
Total	**4**

2021 Section 2 Question 13

Wave particle duality and the quantum theory

The photoelectric effect uses light to liberate electrons from metals. The graph of the maximum kinetic energy of these liberated electrons from different metals plotted against the frequency of the incident light is shown below.



(a) Estimate the threshold frequency for potassium from the graph above. (2 marks)

Description	Marks
0.37 – 0.38 x 10^{15} Hz	1
Max 2 significant figures	1
Total	**2**

Each metal has a work function that describes the minimum amount of energy required to liberate an electron from the surface of that metal.

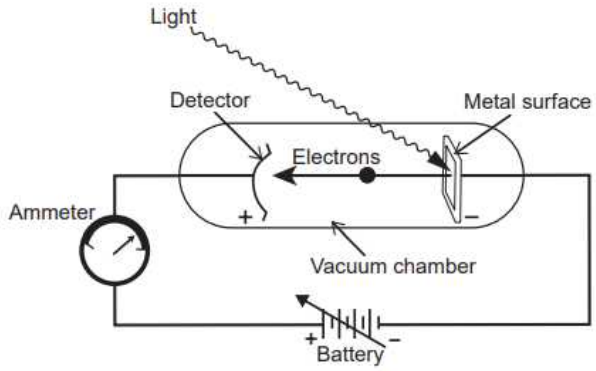
(b) Estimate the work function for potassium from the graph above. (2 marks)

Description	Marks
1.4 – 1.5 eV	1
Max 2 significant figures	1
Total	**2**

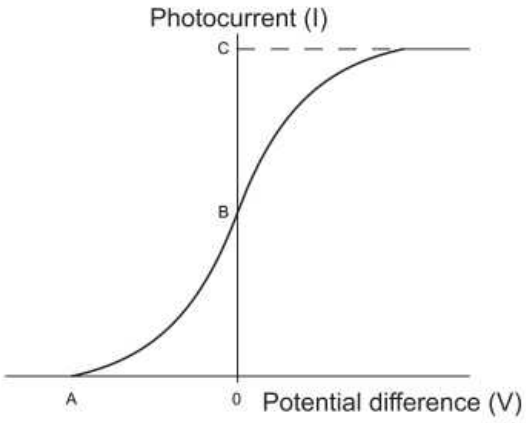
(c) Using your value from part (b), estimate the maximum velocity of a liberated electron if light with a frequency of 1.20 × 10^{15} Hz shines on a potassium metal plate. Give your answer to two significant figures. (6 marks)

Element	Description	Marks
Converts eV to Joules	2.24 x 10^{-19} – 2.40 x 10^{-19} J	1
Uses correct equation	$mv^2/2 = hf - W$	1
Rearranges for v	$v = \sqrt{2(hf - W)/m}$	1
Correct substitution	$v = \sqrt{\frac{2\,(6.63 \times 10^{-34} \times 1.20 \times 10^{15} - 2.40 \times 10^{-19})}{9.11 \times 10^{-31}}}$	1
Correctly calculates answer	1.1 x 10^{6} m s^{-1} (same for all values)	1
2 significant figures		1
	Total	**6**

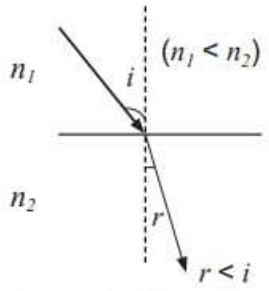
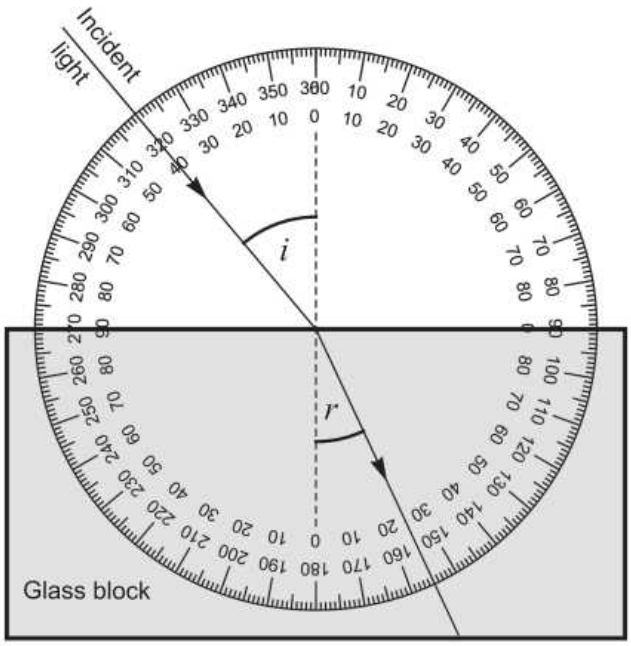
The diagram below shows how the kinetic energy of the liberated electrons is measured. The ammeter measures the photocurrent and the battery can reverse and vary the potential difference between the metal plate and the detector. The potential is increased until the ammeter reads zero.



(d) Below is a graph of photocurrent versus potential difference. On this graph, draw the resulting curve when light of the same frequency but lower power is shone on the same metal. (3 marks)



Description	Marks
Start at A	1
Lower value than B at y intercept	1
Lower value than C for steady photocurrent	1
Total	**3**

2021 Section 2 Question 16 **Wave particle duality and the quantum theory**	Light does not travel at the same speed in all materials. When travelling from air into a different material, light slows down and refracts. The amount of refraction is determined by the refractive index (n) of the material. It is calculated using the following equation: $$n = \frac{c}{v}$$ where v is the speed of light in the material and c is the speed of light in a vacuum.  Figure 1: Light refracting at the boundary between two media. From Figure 1, the following relationship can be demonstrated. This is known as Snell's Law. $$n_1 \sin i = n_2 \sin r$$ A group of students try to determine the refractive index of a glass block by measuring the refraction of light incident on the block. Below is a schematic of their experiment showing the angle of incidence i and the angle of refraction r. 

They varied the angle and found that white light produced a rainbow effect, which made measuring r very difficult. So they changed the light source to a monochromatic red light laser. They obtained the results in the table below.

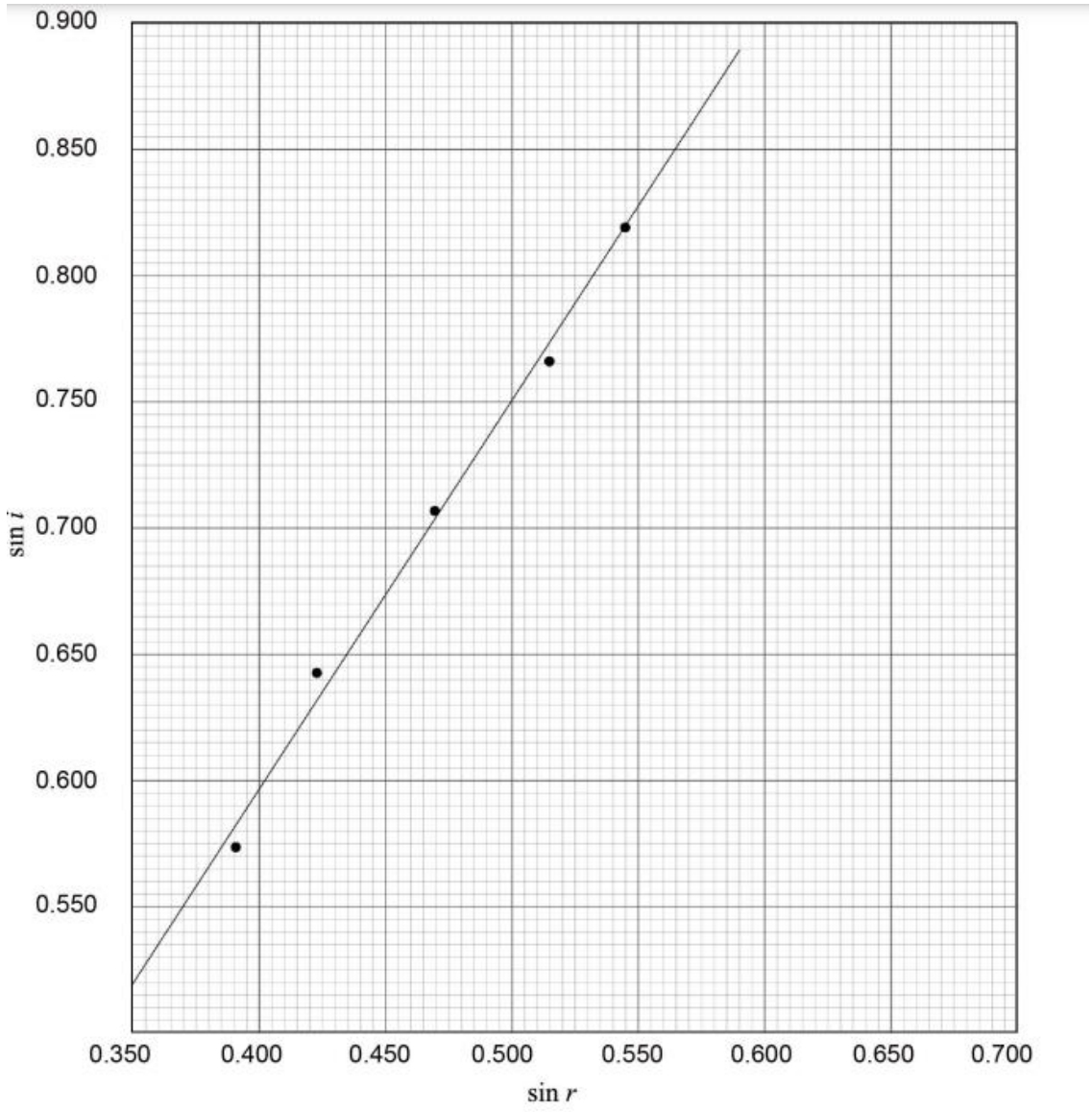
Angle	$i \pm 1°$	35	40	45	50	55
	$\sin i$					
Angle	$r \pm 1°$	23	25	28	31	33
	$\sin r$					

(a) Complete the table, giving the values of sine to three significant figures. (2 marks)

i(degrees) ± 1°	35	40	45	50	55
$\sin i$	0.573	0.643	0.707	0.766	0.819
r(degrees) ± 1°	23	25	28	31	33
$\sin r$	0.391	0.423	0.469	0.515	0.545

Description	Marks
Correct values	1
3 significant figures	1
Total	**2**

(b) Graph sin *i* vs sin *r* on the graph below. Include a line of best fit. (3 marks)



Description	Marks
All points plotted	1
Accurate plot	1
LOBF	1
Total	**3**

(c) The refractive index of air (n_1) is 1.00. Using your line of best fit, determine the refractive index of the prism (n_2). Indicate clearly which two points on your line of best fit you used in your calculation. Give your answer to two significant figures. (4 marks)

Element	Description	Marks
2 points clearly shown on graph		1
Calculates gradient correctly	1.52 – 1.55	1
Realises gradient equals RI		1
Max 2 significant figures	1.5 or 1.6 (must be consistent)	1
	Total	**4**

(d) There are two phenomena described in this question that support the wave behaviour of light. List them below. (2 marks)

Description	Marks
refraction	1
dispersion	1
Total	**2**

(e) The tolerance for all angles was ± 1°. How does the percentage error change as the angle measured increases? Use calculations in your answer. (3 marks)

Element	Description	Marks
Calculates percentage error for 2 angles	eg. 1/35 x 100 = 2.85% 1/ 60 x 100 = 1.67%	1
Expresses as percentage		1
States percentage error decreases as angle increases		1
	Total	**3**

(f) Using the following trigonometric identity, calculate the percentage error of the sine of an angle of incidence of 50.0°. (4 marks)

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$$

Element	Description	Marks
Uses 50.0° as angle and 1° as error		1
Substitutes angles correctly	sin (50.0 + 1) = sin 50.0 cos1 ± cos 50.0 sin 1	1
Correctly calculates answer	0.766 ± 0.011	1
Calculates % error correctly	0.011/0.766 x 100 = 1.4 %	1
	Total	**4**

2021 Section 2 Question 18

Wave particle duality and the quantum theory

In an experiment, two neutrally-charged subatomic particles, A and B, each of mass m, are fired directly toward each other. Both have a speed of 0.600 c, as seen by the observer O shown in Figure 1. The particles collide and become one particle, C, which O observes to be stationary. No energy is lost due to interactions with the environment and no other particles, e.g. photons, are emitted.

Figure 1: Two particles of equal mass and opposite velocities collide

(a) Using conservation of relativistic energy, calculate the mass of the combined particle m_C Give your answer in terms of m, the mass of each of the original particles. (4 marks)

Element	Description	Marks
$E_{before} = E_{after}$	$2 \times mc^2/\sqrt{1-0.600^2} = m_Cc^2/\sqrt{1-0^2}$	1
Realises v_{after} = 0 m s^{-1}		1
Simplifies equation	$2m / 0.800 = m_c$	1
Expresses m_C in terms of m	$m_C = 2.50\ m$	1
	Total	**4**

(b) Explain why the velocity of the combined particle has to be 0 m s^{-1}. (2 marks)

Description	Marks
Σp before = 0 as velocities are in opposite directions and masses are identical.	1
(Conservation of momentum means) p after = 0 therefore v after = 0	1
Total	**2**

For parts (c) and (d) consider the same collision viewed by an observer X, who is moving with a velocity of −0.600 c (i.e. the same velocity that Particle B had before the collision). X maintains this velocity after the collision.

Figure 2: Observer X is now shown.

(c) Using the formulas for relativistic velocity addition and relativistic momentum, determine the momentum of the system before the collision, as determined by X. Express your answer in terms of *m* and *c*, the speed of light. (5 marks)

Element	Description	Marks
Adds velocities correctly	$v_A = 0.600c + 0.600c / 1 + 0.600^2$	1
From O's pov, $v_B = 0$		1
Correctly calculates v_A	$0.88235\ c$	1
Uses rel p formula	$p = m \times 0.88235c / \sqrt{1 - 0.88235^2}$	1
Correctly calculates p in terms of mc	$p = 1.87\ mc$	1
	Total	**5**

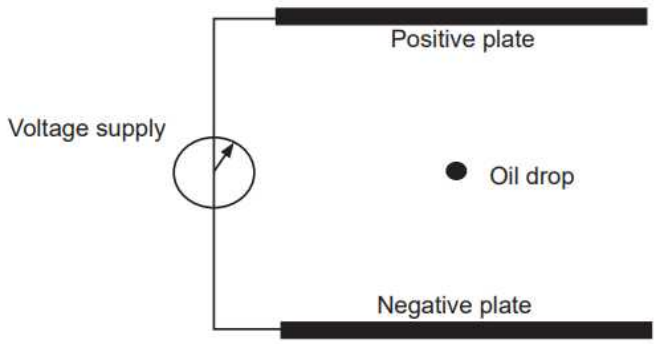
(d) With the use of a calculation, show that your answer in part (c) is the same as the momentum of the system after the collision, as determined by X. (4 marks)

Element	Description	Marks
Uses relative. momentum equation for combined particle and substitutes values of mass from part (a) and $0.600c$ for v. Uses γ from part (a).	$p = \gamma mv = 1.25 \times 2.50\ m \times 0.600\ c$	2
Correctly calculates answer	$p = 1.87\ mc$	1
States momentum is the same as momentum in part c		1
	Total	**4**

2020 Section 2 Question 13

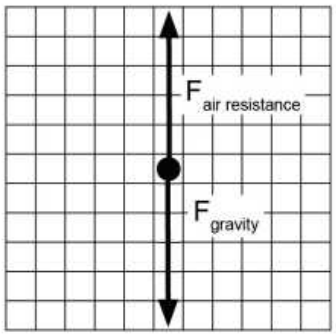
Wave particle duality and the quantum theory

In an experiment to measure the charge of an electron, a student creates many tiny oil drops and allows some to enter the space between two horizontal plates that are connected to a variable voltage supply. A diagram of the apparatus is shown below.



Initially there is no potential difference between the plates and the student chooses an oil drop and, using a microscope, watches as it slowly falls, measuring its speed. The student determines that the speed is constant at 0.0313 mm s^{-1}.

(a) On the grid below, draw a free body diagram showing all the forces acting on the oil drop as it falls. (2 marks)



Description	Marks
correctly labelled weight and air resistance forces	1
must be equal magnitude	1
Total	**2**

Using the speed of the oil drop and other known quantities the student calculates the mass of the oil drop as 6.88 $\times 10^{-16}$ kg. The oil drop is exposed briefly to radiation and it captures one or more electrons and hence becomes negatively charged.

The student turns on the voltage supply and adjusts the potential difference between the upper and lower plates until the oil drop stops moving. The potential difference at this point is 346 V.

(b) Name the **two** forces now acting on the oil drop. (2 marks)

Description	Marks
weight force	1
electrostatic force	1
Total	**2**

(c) If the plate separation is 7.71 mm, what is the electric field strength experienced by the oil drop? (2 marks)

Element	Description	Marks
converts mm to m	$E = V/d = 346/7.71 \times 10^{-3}$	1
correct/consistent answer	4.49×10^{4} V m^{-1}	1
	Total	**2**

(d) Calculate the electric charge of the oil drop. (3 marks)

Element	Description	Marks
rearranges $E = F/q$ and substitutes mg for F	$q = mg/E$ $q = (6.88 \times 10^{-16}) \times (9.8/4.49 \times 10^{4})$	1–2
correct/consistent answer	$q = 1.50 \times 10^{-19}$ C	1
	Total	**3**

The student repeats this procedure several times for different oil drops (possibly carrying different numbers of electrons), and calculates the charge for each drop.

Trial number	Charge ($\times 10^{-19}$ C)
1	5.99
2	2.99
3	4.49
4	7.53
5	3.01
6	7.50

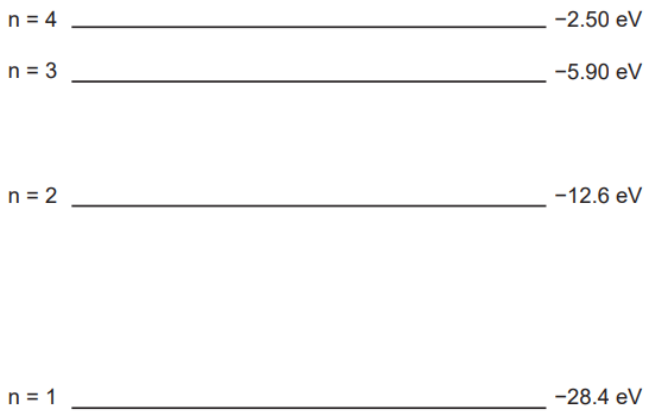
(e) Solely on the basis of this data, what does the student estimate the electron charge is most likely to be? (1 mark)

Description	Marks
1.50×10^{-19} C	1
Total	**1**

2019 Section 2 Question 14

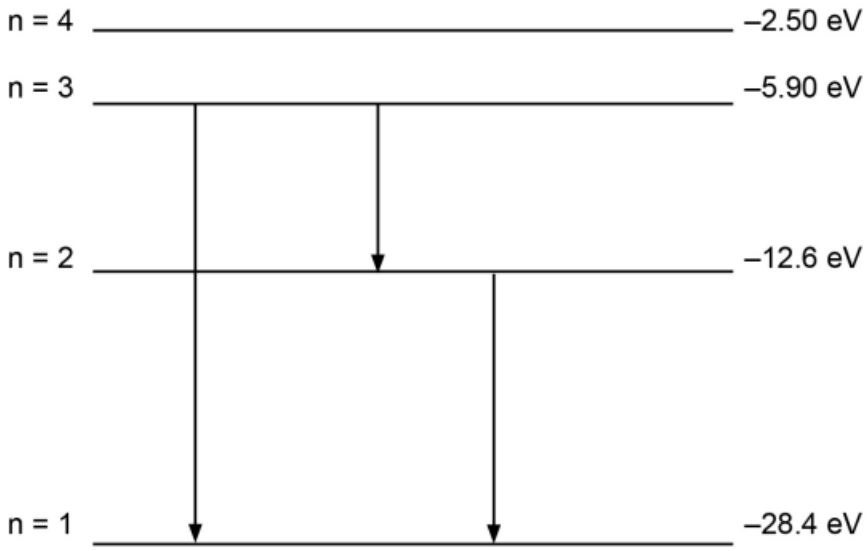
Wave particle duality and the quantum theory

When gaseous mercury atoms are excited, they emit photons of varying wavelengths. Some of the energy levels in a mercury atom are shown in the diagram below.



A mercury lamp is used to produce light which is first fed through a filter that eliminates all wavelengths except those produced from the n = 2 to n = 1 transition. The resultant light is then shone onto a potassium metal plate whose work function is 2.00 eV.

(a) On the diagram above, show all the possible downward electron transitions that can occur in a mercury atom after a successful collision with an incoming electron with an energy of 23.0 eV. (4 marks)



Description	Marks
3 to 1: 22.5 eV (possible) 4 to 1: 25.9 eV not possible	1
diagram three lines with downward arrows: 1 mark each	1–3
Total	**4**

(b) Calculate the wavelength of the photon from part (a) that strikes the potassium metal plate. (3 marks)

Description	Marks
$28.4 - 12.6 = 15.8$ eV	1
$\lambda = ch/E = 3.0 \times 10^{8} \times 6.63 \times 10^{-34} / 15.8 \times 1.6 \times 10^{-19}$	1
$= 7.87 \times 10^{-8}$ m	1
Total	**3**

(c) Calculate the maximum velocity of any electrons liberated from the potassium metal plate. Ignore relativistic effects. (5 marks)

Description	Marks
$E_K = hf - W$ $= (28.4 - 12.6) - 2 = 13.8$ eV	1–2
$v = \sqrt{2\,E_K/m}$	1
$= \sqrt{2 \times 13.8 \times 1.6 \times 10^{-19} / 9.11 \times 10^{-31}}$	1
$= 2.20 \times 10^{6}$ m s^{-1}	1
Total	**5**

(d) State a formal definition of the term 'work function' and explain why part (c) refers to maximum velocity. (3 marks)

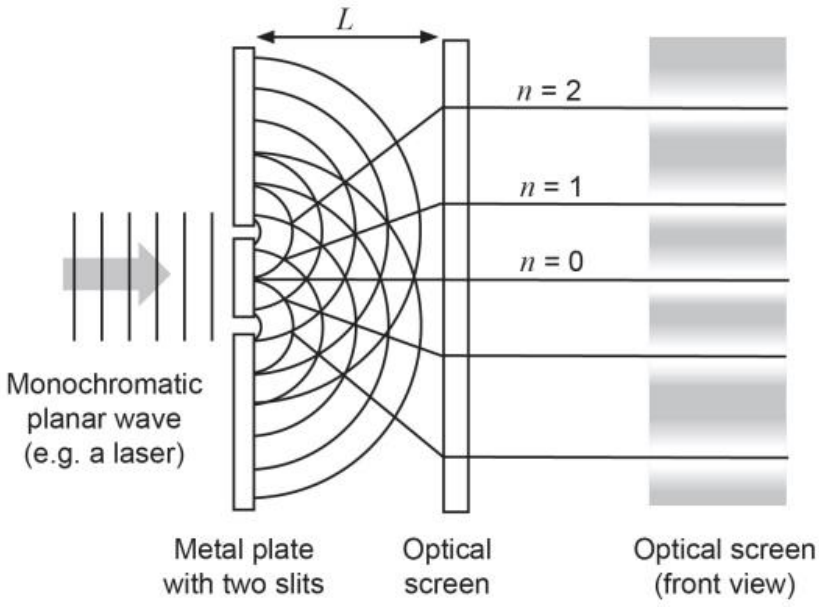
Description	Marks
Work function is the minimum amount of work required to remove an electron from the (surface) of a metal.	1
Maximum velocity is attained when liberated electrons have the maximum kinetic energy. Not all electrons have this as they are liberated from atoms below the surface and expend energy getting to the surface or other electrons collide with other electrons and lose energy.	1–2
Total	**3**

2019 Section 2 Question 17

Wave particle duality and the quantum theory

The first serious challenge to the particle theory of light was made by the English scientist Thomas Young in 1803. Young reasoned that if light were actually a wave phenomenon, as he suspected, then a similar interference effect observed with sound waves should occur for light. This line of reasoning led Young to perform an experiment which is nowadays referred to as 'Young's double-slit experiment'.

In Young's double-slit experiment, two very narrow parallel slits, separated by a distance *d*, are cut into a plate made of thin metal. Monochromatic light, from a distant light source, passes through the slits and eventually hits an optical screen a comparatively large distance *L* from the slits. The experimental setup is shown in the diagram below.



Young observed a series of alternating parallel light and dark bands on the screen, with the central band being bright.

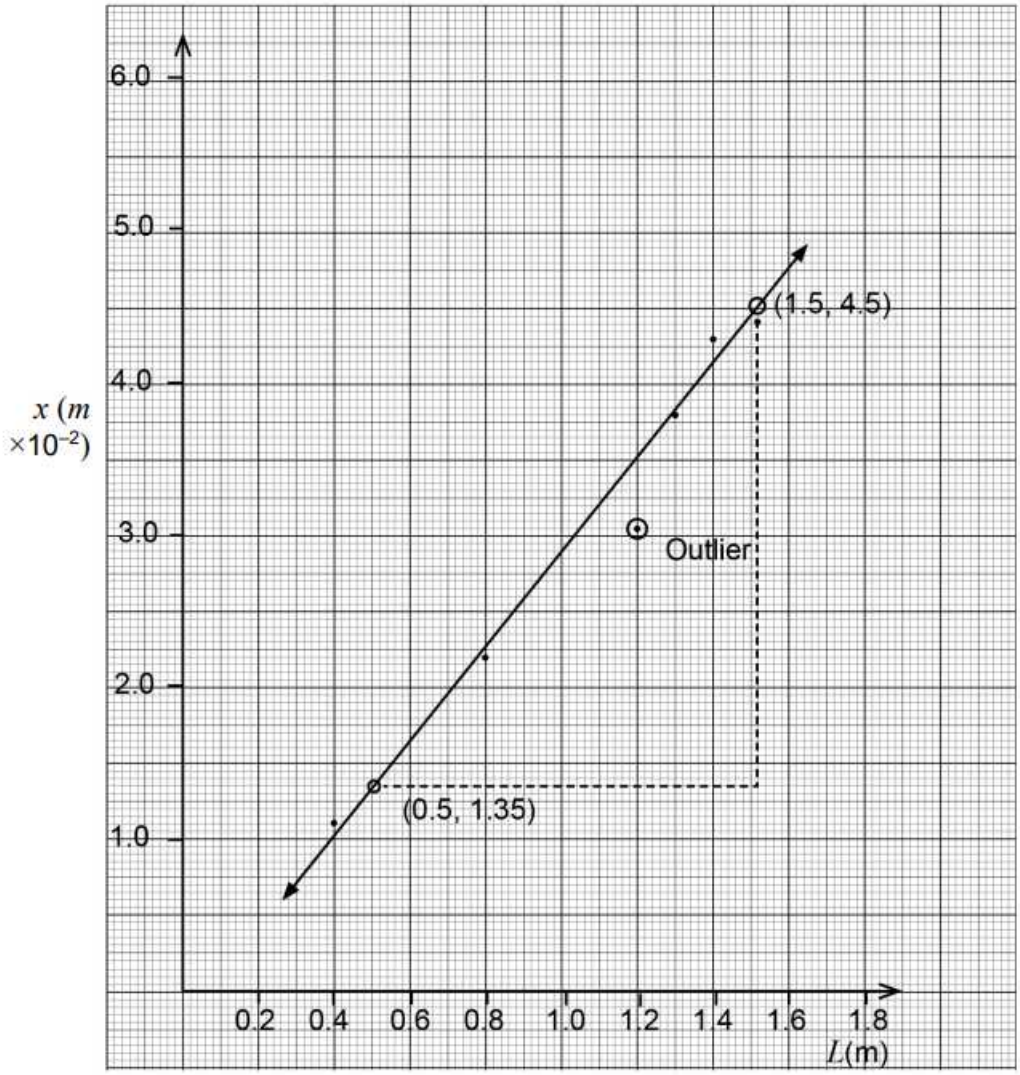
From his research, he established the following relationship between *L*, the distance between the slits and the screen; *d*, the distance between the two slits; λ, the wavelength of the monochromatic light and *x*, the distance between the centres of adjacent light bands in the interference patterns:

$$\frac{x}{L} = \frac{n\lambda}{d}$$

A group of students set up an experiment to measure the wavelength of light produced by a laser pointer. Using a commercially-produced metal plate where d = 2.19×10^{-5} m, they varied the distance from the slits to the optical screen (L) and measured the distance between the centre light band and the one closest to it (n = 1). Their results are shown in the table below.

L (m) ± 0.002 m	0.400	0.800	1.200	1.300	1.400	1.500
x (m × 10^{-2}) ± 0.002 m	1.12	2.21	3.06	3.76	4.28	4.38

(a) Graph x vs L on the grid paper provided on page 23 *(below)*. Include the line of best fit. Do **not** include uncertainties. (5 marks)



Description	Marks
correct orientation of axes	1
correct labelling of axes including units	1
accurate plotting	1
line of best fit.(LOBF) (not through origin)	1
outlier clearly identified	1
Total	**5**

(b) From your graph, calculate the gradient of the line of best fit. Show construction lines on your graph. Use correct significant figures. (3 marks)

Description	Marks
using points (0.50,1.35) and (1.50, 4.50) (must be on LOBF not data points)	1
$m = (4.50 - 1.35) \times 10^{-2} / (1.50 - 0.50) = 3.2 \times 10^{-2}$	1
appropriate significant figures	1
Total	**3**

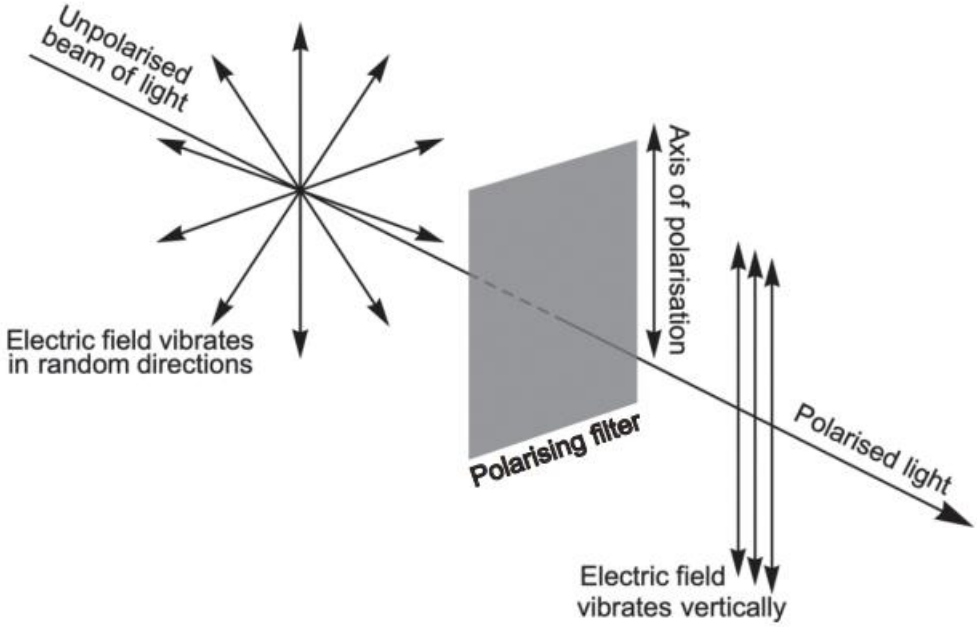
(c) Using the gradient from part (b), calculate the wavelength of the monochromatic light used. Use correct significant figures. (4 marks)

Description	Marks
$x = \lambda L / d$ but λ / d = gradient (m) $So\ \lambda = d \times m$	1–2
$= 2.19 \times 10^{-5} \times 3.15 \times 10^{-2} = 6.90 \times 10^{-7}$ m = 690 nm	1
appropriate significant figures	1
Total	**4**

The students were disappointed when they found their answer was 10% different from the wavelength supplied by the manufacturers of the laser pointer. When the teacher helped them use the uncertainties associated with their experiment, they found the manufacture's value fell within the accepted range of uncertainty.

(d) Using the same values as in part (b), recalculate your gradient including uncertainties to show that a 10% difference falls within the accepted range. (5 marks)

Description	Marks
using points (0.50, 1.35) and (1.50, 4.50) (must be same points as part (b).) $\Delta y = 3.15 \times 10^{-2} \pm 0.004$m	1
% uncertainty = (0.004 / 0.0315) × 100 = 12.7 %	1
$\Delta x = 1.50 - 0.50 = 1.00 \pm 0.004$ m	1
% uncertainty = (0.004 / 1.0) × 100 = 0.4) × 100 = 0.4%	1
(Assuming value of gradient is the same) Total uncertainty of gradient = 13.1% so 10% is OK	1
Total	**5**

2023 Section 3 Question 20 **Wave particle duality and the quantum theory**	**Polarisation of light**  Figure 1: Pair of polarised sunglasses When you buy a pair of polarised sunglasses, the main purpose they serve is to reduce the intensity of light hitting your eyes. How they achieve this is described below.  Figure 2: Randomly polarised light passing through a polarising filter Light waves are a combination of oscillating magnetic and electric fields. As the magnetic field changes, it induces a changing electric field, which in turn induces a magnetic field and so on. A beam of light consists of transverse waves oscillating in all directions around the line of propagation. A polarised filter can be thought of as a series of slits that only allows those waves to pass through with their electric fields oscillating in the same direction as the axis in the filter. But the filters do not have actual slits in them. The material consists of long chain polymers. Electrons in these chains are free to move along the chains but not between them. A light wave's electric field does work on these electrons and causes them to absorb the wave's energy. Therefore, light waves which are polarised parallel to the chains get absorbed and those travelling perpendicular pass through undisturbed. Those travelling at an angle to the chains are partially absorbed. The axis of the filter is perpendicular to the chains

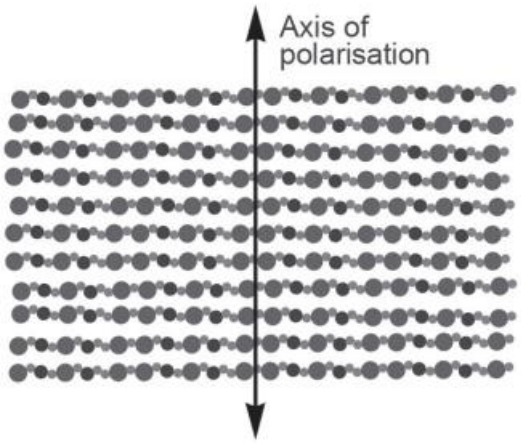


Figure 3: Axis of polarisation is perpendicular to the aligned long chain polymer molecules

Figure 4 illustrates this point. Only the component of the electric field parallel to the axis of a polarising filter is allowed to pass. In the diagram, angle θ represents the angle between the direction of polarisation of incident light and the axis of a polarising filter. After passing through the filter, the amplitude of the electric field has been reduced by a factor of $\cos\theta$.

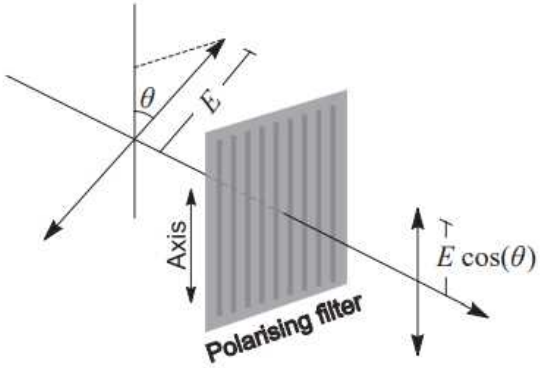


Figure 4: Polarising filter with angle θ shown

Since intensity of a wave is proportional to its amplitude squared, the intensity I of the transmitted wave is related to the initial intensity I_0 of the incident light by the following relationship, known as Malus' Law:

$$I = I_0 \cos^2\theta.$$

A single polarising filter reduces the wave's intensity by exactly 50.0%. Intensity is measured in watts per square metre (W m^{-2}).

(a) With reference to Figure 3 on page 35 *(above in question)*, discuss how unpolarised light can become polarised. (4 marks)

Description	Marks
the material consists of long chain polymers	1
electrons in these chains are free to move along the chains but not between them	1
a light wave's electric field does work on these electrons and causes them to absorb the waves' energy	1
therefore, light waves which are polarised parallel to the chains get absorbed and those travelling perpendicular pass through undisturbed	1
Total	**4**

(b) Define the axis of a polarising filter and describe its function. (2 marks)

Description	Marks
the axis of a polarising filter is perpendicular to the long chain polymers in the filter	1
it allows light waves travelling parallel to it to pass through	1
Total	**2**

(c) According to Malus' Law, at what angle to the direction of polarisation of the incident light should the axis of a polarising filter be oriented in order to

(i) allow the light to pass without reduction in intensity? (1 mark)

Description	Marks
0°	1
Total	**1**

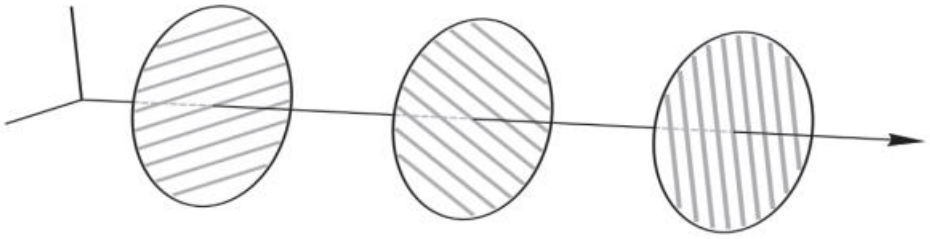
(ii) completely block the passage of the light? (1 mark)

Description	Marks
90°	1
Total	**1**

(d) Use Malus' Law to calculate the angle between the direction of polarisation of the incident light and the axis of a polarising filter if the incoming light has its intensity reduced by 75.0%. (4 marks)

Element	Description	Marks
Uses 0.25 I_0 for I	$0.25\ I_0 = I_0 \cos^2 \theta$	1
Cancels I_0	$\cos^2 \theta = 0.25$	1
Takes the square root of both sides	$\cos \theta = 0.50$	1
Calculates angle	$\theta = 60.0°$	1
	Total	**4**

(e)



A group of students placed two polarising filters at right angles and saw no light being transmitted. They placed a third filter between the first two at 45.0° to each one and noticed light was transmitted.

(i) Explain how inserting the third filter allowed light to hit the screen when no light was hitting it before. (3 marks)

Description	Marks
the polarised light hitting the third filter strikes the axis of polarization at 45.0°	1
a component of the light is transmitted to the last screen at 45.0° to the axis of polarisation	1
therefore a component of light emerges from the last filter and hits the screen	1
Total	**3**

(ii) What percentage of the original light's intensity is hitting the screen with the third filter in place? (2 marks)

Description	Marks
$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}=\frac{1}{8}$	1
$\frac{1}{8}\times 100 = 12.5\%$	1
Total	**2**

(f) A photon's energy is given by $E = hf$. When light passes through a polarising filter, the total energy transmitted is reduced but the frequency of each photon remains the same. Using the particle model of light, account for the reduction in transmitted energy. (3 marks)

Description	Marks
the total amount of energy is proportional to the number of photons emerging per second	1
the intensity is reduced by reducing the number of photons per second rather than reducing the energy of each photon	1
therefore the frequency and hence wavelength of each photon is unaffected by polarisation	1
Total	**3**

2022 Section 3 Question 18

Wave particle duality and the quantum theory

Light-emitting diodes (LEDs)

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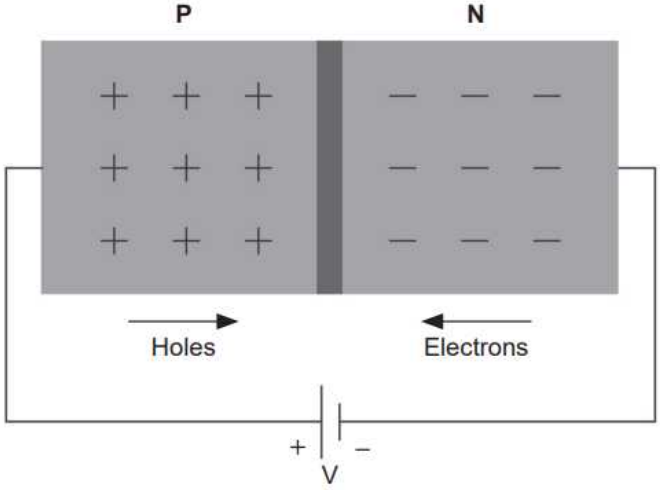

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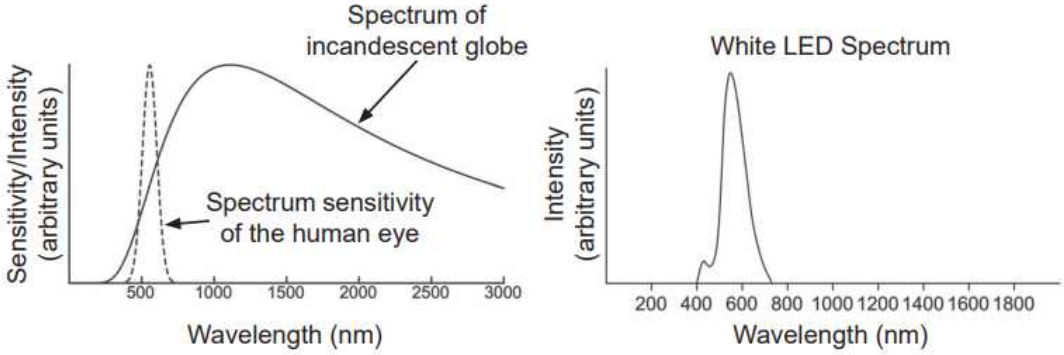

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Efficacy

LEDs are also known for having the best 'efficacy' of all light sources. Efficacy is the measure of how well a light source produces visible light. It is measured in lumens per watt, or how much light is provided for every watt of power consumed. The power is calculated by multiplying the forward voltage (the lowest voltage at which current starts to flow in the normal conducting direction, V_F) by the operating current measured in amperes. In order to make sure that the correct voltage gets dropped across the LED, a voltage greater than the minimum required to produce the desired wavelength is used. A table of specific crystals, their forward voltages and the wavelengths they produce is given below. To increase brightness, the current is increased.

Typical LED characteristics			
Semiconductor material	**Wavelength (nm)**	**Colour**	**V_F**
GaAs	850–940	Infra-red	1.20 V
GaAsP	630–660	Red	1.80 V
GaAsP	605–620	Amber	2.00 V
GaAsP:N	585–595	Yellow	2.20 V
AlGaP	550–570	Green	3.50 V
SiC	430–505	Blue	3.60 V
GaInN	450–650	White	4.00 V

(a) Explain how a PN junction produces visible light. (4 marks)

Description	Marks
For copyright reasons this text cannot be reproduced in the online version of this document	1
	1
	1
	1
Total	**4**

The Law of Conservation of Energy states: 'Energy is neither created nor destroyed; it only moves from one place to another - from one type of energy to another.'

(b) LEDs and incandescent light bulbs are equally efficient at converting energy drawn from the mains into different types of energy. Why then does the passage on page 33 *(above)* state that LEDs are far more efficient than incandescent light bulbs? Reference must be made to the graphs of intensity versus wavelength. (4 marks)

Description	Marks
The graphs show the majority of wavelengths produced by an LED are in the visible range.	1
A significant proportion of wavelengths produced by an incandescent globe are outside the visible range.	1
An LED has far greater efficacy. It produces more Lumens per Watt.	1
LEDs are therefore more efficient in terms of useful output/input. (60 W vs 10 W)	1
Total	**4**

(c) The efficacy of a particular LED is 120 lumens W^{-1}. Using information in the passage and table on page 33 *(above)*, calculate how much current would need to run through a blue SiC LED light bulb operating at minimum V_F to produce 840 lumens. (4 marks)

Element	Description	Marks
Calculates power needed	840/120 = 7.00 W	1
Uses correct voltage	V_F = 3.60 V	1
Uses $P = VI$ and isolates I	I = 7.00/3.60	1
Calculates correct answer	I = 1.94 A	1
	Total	**4**

(d) With the use of a calculation and data from the table on page 33 *(above)*, show how the minimum V_F for SiC crystals is large enough to produce photons with the lowest energy required for blue light. (4 marks)

Element	Description	Marks
Calculates energy of electron	$E = Vq = 3.60 \times 1.60 \times 10^{-19}$ $= 5.76 \times 10^{-19}$ J	1
Substitutes $\frac{c}{\lambda}$ for f into $E = hf$	$E = \frac{hc}{\lambda}$	1
Isolates λ and calculates it	$\lambda = 3.00 \times 10^{8} \times 6.63 \times 10^{-34} / 5.76 \times 10^{-19}$ $= 3.45 \times 10^{-7}$ m	1
States wavelength is shorter than 5.05×10^{-7} m therefore energetic enough		1
	Total	**4**

(e) Lighting accounts for 15% of yearly global electricity consumption (194 EJ or 194×10^{18} J). Roughly 40% of this is supplied by LEDs. Each tonne of coal produces, on average, 21 GJ of energy. Eighty per cent of world energy consumption is derived from fossil fuels. Using the efficiencies stated in the passage, estimate the mass of coal the world could save per year if 100% of lighting was provided by LEDs. (5 marks)

Element	Description	Marks
Calculates energy for lighting	$194 \times 10^{18} \times 0.15 = 2.91 \times 10^{19}$ J	1
Calculates energy from incandescent globes	$2.91 \times 10^{19} \times 0.60 = 1.746 \times 10^{19}$ J	1
Uses 50/60 ratio from passage to calculate energy savings	$1.746 \times 10^{19} \times 5/6 = 1.455 \times 10^{19}$ J	1
Calculates mass of coal saving	$(1.455 \times 10^{19} / 21 \times 10^{9}) \times 0.8$ $= 5.54 \times 10^{8}$ Tonnes	1
2 significant figures	5.5×10^{8} Tonnes	1
	Total	**5**

2021 Section 3 Question 20

Wave particle duality and the quantum theory

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Rembrandt's *The Night Watch* was painted in 1642. But there is something odd about the name 'The Night Watch': it was not the name of the original painting. After it was restored, it became obvious that it was a daytime scene.

By the end of the 18th century, the painting had accumulated so many layers of varnish and dirt that it looked like the scene took place at night – and hence, it was misnamed 'The Night Watch'. The Rijksmuseum in Amsterdam carried out the largest research and restoration project ever. With the aid of X-ray fluorescence spectrometry, expensive paintings can be investigated harmlessly before restoration. This ensures sophisticated preservation of valuable art objects. It also allows the paintings to be restored securely in the buildings where the public can still enjoy them.

Depending on its energy, the X-ray beam penetrates into different depths of the painting's surface. This allows us to examine different layers of paint and even detect corrections made by Rembrandt without having to remove any paint. It is already known today that Rembrandt lengthened lances (spears) and changed the positioning of the people in the picture.

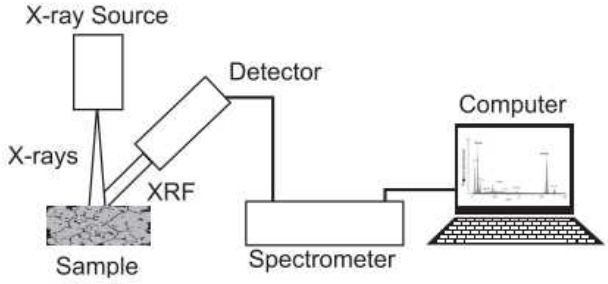


Figure 1: Schematic of process of X-ray fluorescence spectrometry

The spectrometer analyses the specific wavelengths of light given off by each sample of paint. It produces a printout similar to the one in Figure 2 showing the abundance of each wavelength emitted versus their energies.

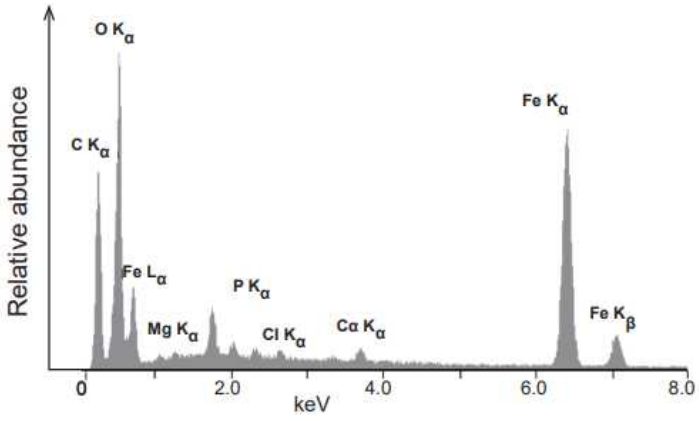


Figure 2: The relative abundance of energies of emitted photons

X-ray fluorescence analysis (XRF) is based on the detection of the fluorescence produced after the sample is bombarded with X-rays. Inner electrons are ejected by the incoming X-rays and then other electrons in higher energy shells cascade downward in smaller steps, emitting photons with specific wavelengths corresponding to the energy difference between shells. This fluorescence radiation is element-specific as the energy of each shell '*n*' is given by:

where *Z* is the charge on the nucleus, which is directly proportional to the number of protons in the nucleus. (For the K shell $n = 1$, for the L shell $n = 2$, and for the M shell $n = 3$.)

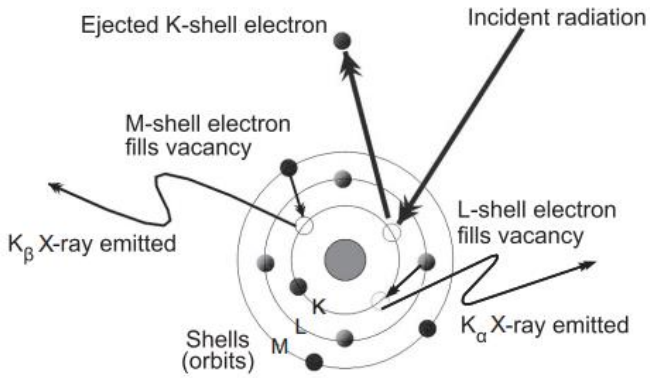


Figure 3: Electron transitions between K, L and M energy shells

The main spectral lines correspond to electron transitions to the K shell. Transitions from the L shell to K shell produce K*α* photons and those from the M shell to K shell produce K*β* photons. This process is described in Figure 3.

(a) List two properties of X-rays that make them suitable for X-ray fluorescence spectrometry. (2 marks)

Description	Marks
Short wavelength	1
High energy	1
Could also mention high penetrative ability	
Total	**2**

(b) Explain how we now know that Rembrandt's original painting had lances of different length and some of the people were in different positions. (2 marks)

Description	Marks
Depending on its energy, the X-ray beam penetrates into different depths of the painting's surface.	1
This allows us to examine different layers of paint and even detect corrections made by Rembrandt without having to remove any paint. It is already known today that Rembrandt lengthened lances or changed the positioning of figures in the picture.	1
Total	**2**

(c) Give **two** advantages of using X-ray spectrometry to analyse old paintings. (2 marks)

Description	Marks
Expensive paintings can harmlessly be investigated before restoration. (This ensures sophisticated preservation of valuable art objects.)	1
It also allows the paintings to be restored securely in the buildings where the public can still enjoy them.	1
Total	**2**
Note: Accept other correct, relevant answers	

(d) Explain why the fluorescent radiation is element specific. (3 marks)

Description	Marks
Energy level values are dependent on Z, the charge on the nucleus.	1
Z is directly proportional to the number of protons in the nucleus, which defines the element.	1
Fluorescent wavelengths correspond to energy transitions; therefore are element-specific.	1
Total	**3**

(e) (i) Estimate the values of the M and L energy shells relative to the K shell for iron (Fe) displayed in Figure 2 and place them in the corresponding spaces below. (3 marks)

Description	Marks
Level 3: (7.1 – 7.2) x 10^3 eV or 7.1 – 7.2 keV	1
Level 2: (6.3 – 6.4) x 10^3 eV or 6.3 – 6.4 keV	1
Max 2 Sig Figs	1
Total	**3**

(ii) Estimate the wavelength of the photon given off when an electron falls from the M shell to the L shell in an iron atom. (4 marks)

Element	Description	Marks
Converts keV to Joules	$(0.7 \rightarrow 0.9) \times 10^3 \times 1.60 \times 10^{-19}$ $= (1.12 \rightarrow 1.44) \times 10^{-16}$ J	1
Substitutes c/λ for f in $E = hf$	$E = ch/\lambda$	1
Correctly calculates answer	$\lambda = \frac{3.00 \times 10^8 \times 6.63 \times 10^{-34}}{(1.12 \rightarrow 1.44) \times 10^{-16}}$ $= (1.4 \rightarrow 1.8) \times 10^{-9}$m	1
Max 2 significant figures		1
	Total	**4**
Note: Ranges expressed do not include incorrect answers from part (i). Do not penalise for consequential errors		

(iii) To which part of the electromagnetic spectrum does this wavelength belong? (1 mark)

Description	Marks
X-rays or UV (or answer consistent with e(ii) wavelength value)	1
Total	**1**

(f) How would the graph in Figure 2 change if the operators of the spectrometer increased the power of the X-ray beam while keeping the wavelength constant? Explain your answer.

(i) Change (1 mark)

Description	Marks
Peaks would be higher	1
Total	**1**

(ii) Explanation (2 marks)

Description	Marks
If power is increased while λ is constant, more photons per second are hitting the target	1
More photons per second will increase the intensity of photons emitted	1
Total	**2**

OR

(i) Change (1 mark)

Description	Marks
Peaks will be the same	1
Total	**1**

(ii) Explanation: (2 marks)

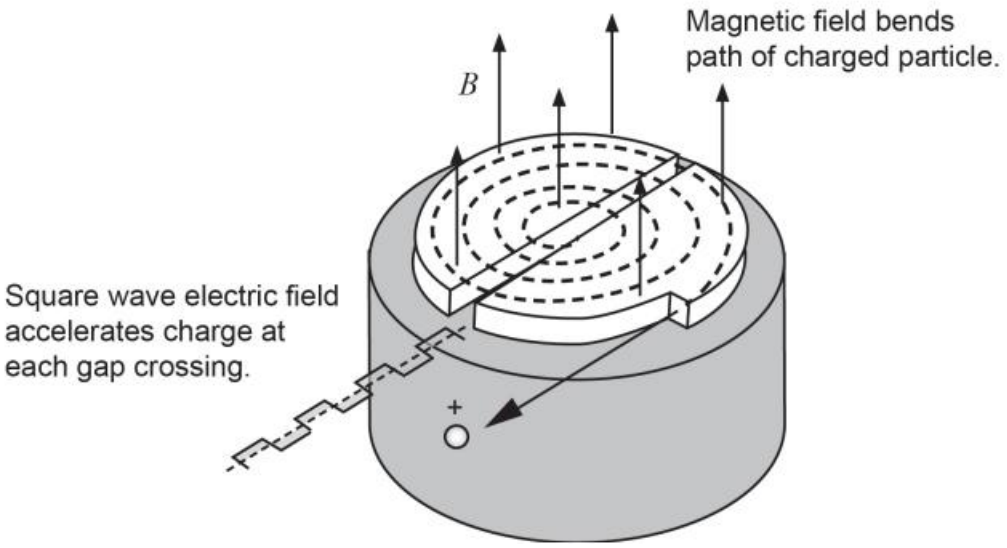
Description	Marks
If power is increased while λ is constant, more photons per second are hitting the target	1
As all emitted wavelengths have increased, the relative abundance remains constant.	1
Total	**2**

2020 Section 3 Question 20

Wave particle duality and the quantum theory

A cyclotron is a particle accelerator. It is an electrically-powered machine that produces a beam of charged particles that can be used for medical, industrial and research purposes. A cyclotron accelerates charged particles in a spiral path, which allows for a much longer path for acceleration than a straight-line accelerator.

A cyclotron consists of two semicircular charged plates in a flat vacuum chamber called 'dees' because of their shape. The chamber sits between the poles of a magnet that creates a strong and vertical magnetic field. A stream of charged particles is fed into the centre of the chamber and a high-frequency alternating voltage is applied across the plates. This voltage accelerates the charged particles across the gap every half turn. Combined with the magnetic field, this process causes the particles to spiral outwards until they exit the cyclotron.



The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.

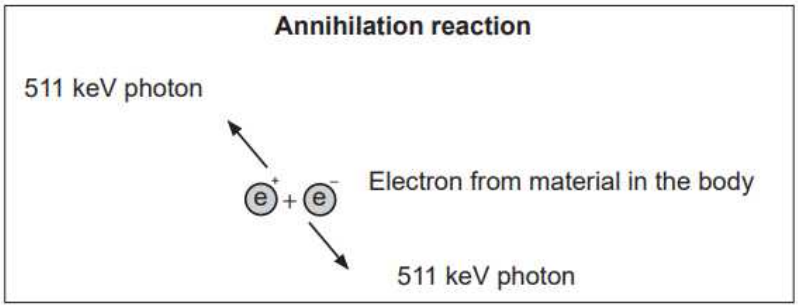
Medical cyclotrons

Medical cyclotrons produce proton beams that are used to manufacture radioisotopes used in medical diagnosis. Radioisotopes produced in a cyclotron decay by either positron emission or electron capture. Positron emission tomography (PET) and single photon emission computed tomography (SPECT), which utilises gamma ray emission, are two imaging techniques that rely on cyclotron-produced radioisotopes.

(a) The diagram above shows the acceleration of a positive particle in a cyclotron. Describe one change that would need to be made in order to use the same machine to produce a beam of negatively-charged particles exiting from the same place, and explain why. (3 marks)

Description	Marks
reverse the direction of the magnetic field	1
The direction of the force on the negatively-charged particle will be in the opposite direction.	1
This will negate the reversal of force direction due to change of charge so the particles will go in the same direction as before.	1
Total	**3**

Positrons (e^+) are examples of antimatter and have the same properties as electrons (e^-) except for having a positive charge. When they collide with an electron, the following process occurs.



(b) (i) Calculate the wavelength of the photons produced in the annihilation described in the diagram above. (3 marks)

Element	Description	Marks
substitutes c/λ for f	$E = hf = ch/\lambda$	1
converts Ev to Joules	$= (3.0 \times 10^8 \times 6.63 \times 10^{-34})/(511 \times 10^3 \times 1.6 \times 10^{-19})$	1
correct answer	$= 2.43 \times 10^{-12}$ m	1
	Total	**3**

(ii) To which part of the electromagnetic spectrum does the photon belong? (1 mark)

Description	Marks
gamma rays or x-rays	1
Total	**1**

(c) Explain why increasing the strength of the magnetic field would increase the velocity of the particles leaving the cyclotron. (4 marks)

Description	Marks
$r = mv/Bq$	1
as B increases, r decreases	1
If r decreases, the number of revolutions before exiting increases.	1
The particle accelerates every time in passes between the dees so its velocity will be greater when it exits.	1
Total	**4**

(d) (i) Explain why the voltage across the dees must alternate. (2 marks)

Description	Marks
In order to accelerate across a potential difference, the plate opposite must have the opposite charge to the particle to attract it.	1
When the particle approaches the electric field from the opposite direction, the polarity of the field must change for the acceleration to remain positive.	1
Total	**2**

On page 31 *(above)* the text states: 'The cyclotron frequency (how often the electric field between the dees reverses) is independent of both the velocity of the particles and the radius of the circular path they follow.'

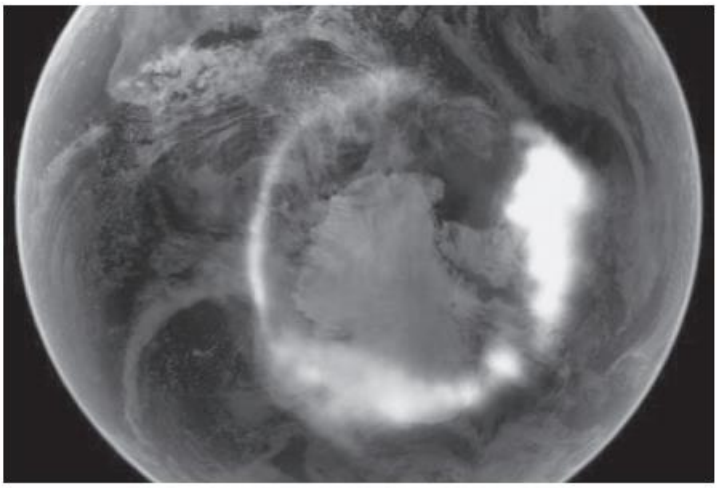
(ii) Derive an expression for the cyclotron frequency and use the expression to explain why this statement is correct. (Ignore relativistic effects.) (6 marks)

Description	Marks
$r = mv/Bq$	1
$v = rBq/m$	1
$T = 2\pi r/2v$ or $v = \pi r/T$ (or $v = 2\pi r/T$)	1
substitute f for $1/T$	1
$\pi rf = Bqr/m$ or $f = Bq/\pi m$	1
frequency is independent of both velocity and radius of the circular path	1
Total	**6**

2019 Section 3 Question 20

Wave particle duality and the quantum theory

Auroras: What are they and how are they created?



The Aurora Australis, captured by NASA's IMAGE satellite and overlaid onto a photograph of the earth. (NASA: public domain)

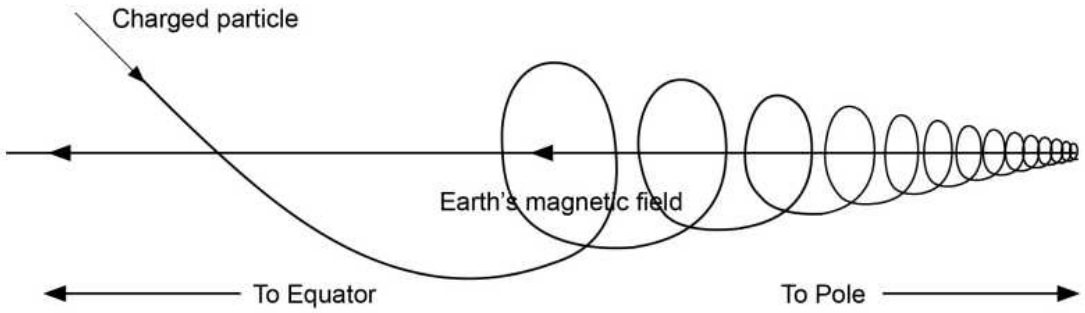
(a) (i) Estimate how much time it takes for the plasma from a typical CME to reach the earth's magnetic field. (2 marks)

Description	Marks
$s = vt,\ t = s/v$	1
t = 150 x 10^6/6 x 10^6 = 25 hours	1
Total	**2**

(ii) Give **two** reasons why your answer to part (a) (i) is only an estimate. (2 marks)

Description	Marks
varying speeds of more than six million kilometres per hour	1
around 150 million kilometres	1
Total	**2**

(b) Draw the possible path of a charged particle travelling along a magnetic field line after approaching it at an angle other than 90°. The field strength increases as the particle moves toward the pole. (3 marks)

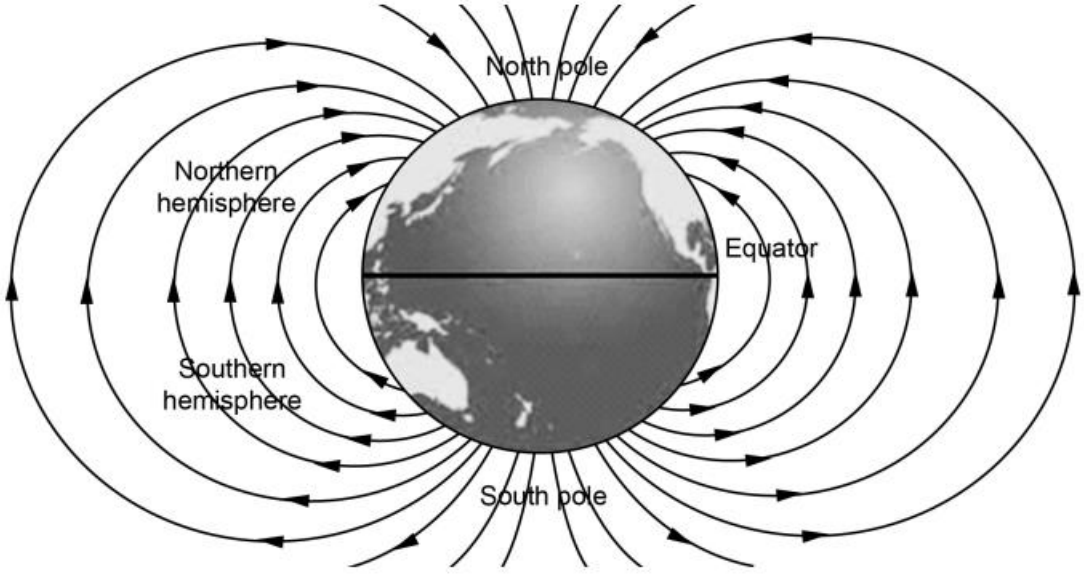


Description	Marks
spiral-shaped	1
radius decreasing as it approaches pole	1
loops closer together as it approaches pole	1
Total	**3**

A spare diagram is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and clearly indicate that you have redrawn it on the spare page.

(c) (i) Draw the magnetic field around the earth on the diagram below before any distortion occurs due to a CME. (3 marks)

Description	Marks
direction	1
shape	1
relative intensity	1
Total	**3**



(ii) Using information from the text, suggest a reason why auroras are usually seen at the north and south poles but not at the equator. (3 marks)

Description	Marks
the plasma travels along our planet's magnetic field lines towards the poles	1
the maximum altitude above the Earth's surface where auroras occur is 300 km	1
particles only enter the atmosphere below 300 km when the field lines turn downwards towards the Earth's surface at the poles	1
Total	**3**

(d) Using specific information from the passage, explain why the same photon-producing electron transition produces red light in neutral molecular nitrogen and blue light in ionised molecular nitrogen. (5 marks)

Description	Marks
the electrons are more tightly bound due to ionisation	1
more energy is needed to excite an electron to a higher level due to being more tightly bound	1
when excited electrons fall back down in an excited ionised nitrogen molecule, they give off more energy	1
if energy difference is greater the wavelength is shorter	1
blue light has a shorter wavelength than red	1
Total	**5**

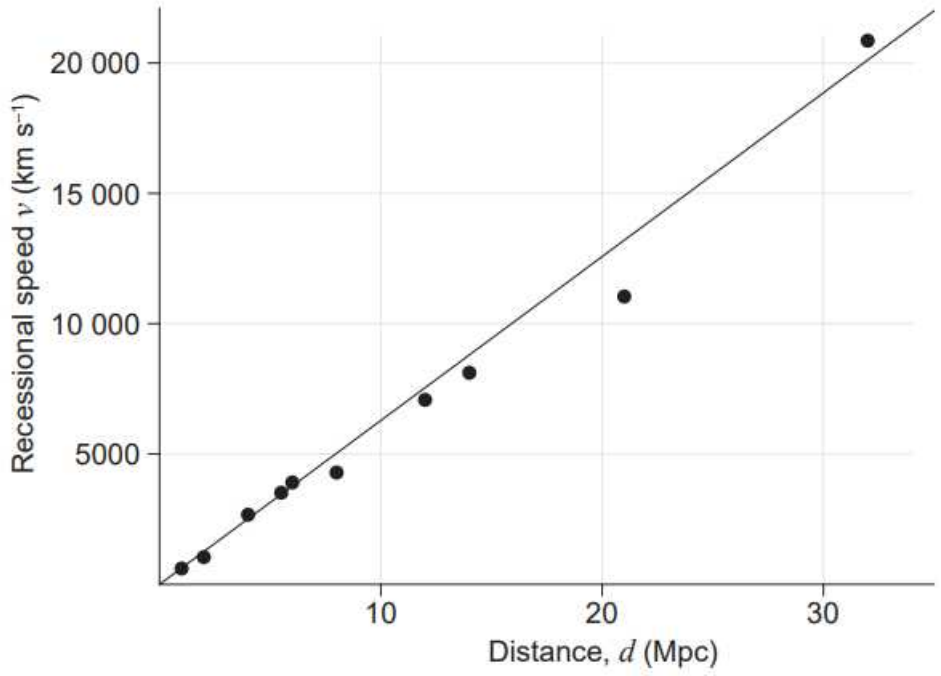
Unit 4 – Special relativity

Section 1

2023 Section 1 Question 8

Special relativity

Edwin Hubble found that the further a galaxy is away from an observer, the faster it is receding. Below is a graph of data showing this relationship.

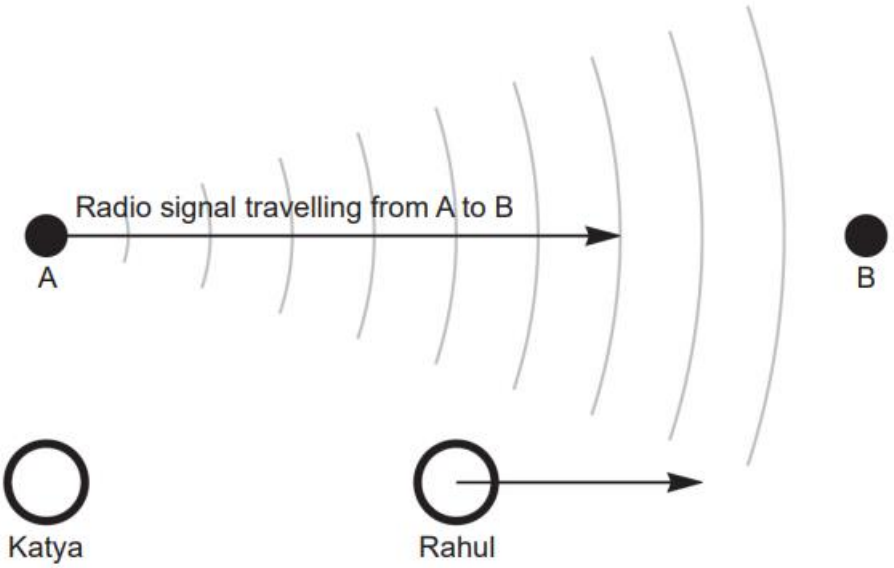


Using the graph above, estimate the distance in kilometres to a galaxy that is receding at 4.5% of the speed of light. (6 marks)

Answer: _____ km

2023
Section 1
Question 9

Special relativity



A radio signal is emitted from Spaceship 'A' and arrives at Spaceship 'B'. A and B are stationary with respect to Katya. In her frame of reference, A and B are a distance d_1 apart, and the signal takes time t_1 to travel.

Rahul is moving parallel to the radio waves between A and B with constant velocity near the speed of light with respect to Katya and the two spaceships. In his frame of reference, A and B are a distance d_2 apart, and the signal takes time t_2 to travel.

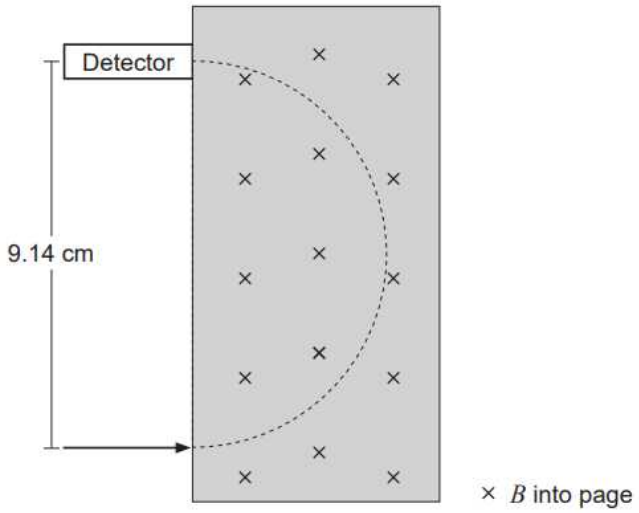
Derive an expression for d_2 in terms of d_1, t_1 and t_2. Show your reasoning and state any assumptions. (Hint: It is not necessary to use length contraction or time dilation.)

Answer: d_2 = _____

2022 Section 1 Question 4

Special relativity

A charged particle enters a 0.350 mT magnetic field at right angles to the field with a velocity of 2.81 × 10^6 m s^{-1}. The magnitude of the charge of the particle is 1.60 × 10^{-19} C. It lands on the detector 9.14 cm from where it entered after completing 180° of its circular path.



(a) Calculate the mass of the particle. (4 marks)

Answer: _____ kg

(b) Which of the following could the particle be? Circle your answer. (1 mark)

A proton
B electron
C anti-proton
D positron
E none of the above

2022 Section 1 Question 11 **Special relativity**	Salman and Priyanka have identical 1.00 m rulers. Priyanka takes her ruler and sets off in a rocket. She travels past Salman at a speed of 0.800 c. Their metre rulers are aligned in the direction of Priyanka's travel. Each then measures the length of the other's ruler by carefully determining the position of each end of the ruler at the same instant, and measuring the distance between these positions. (a) How long does Salman measure Priyanka's ruler to be? (2 marks) Answer: _____ m (b) How long does Priyanka measure Salman's ruler to be? (1 mark) Answer: _____ m (c) When Priyanka returns, she and Salman compare the results of their measurements. How are they able to explain their seemingly contradictory results? (3 marks)

2020 Section 1 Question 9

Special relativity

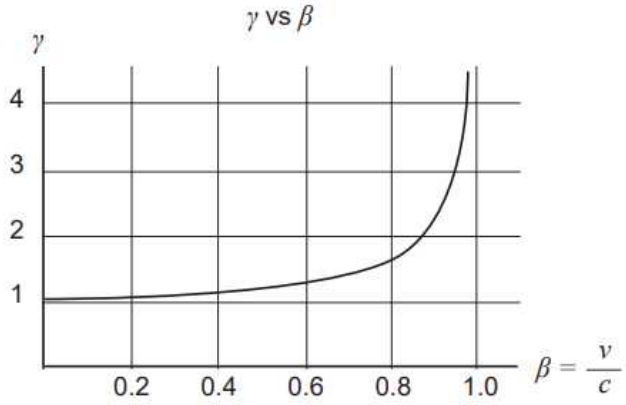
The Lorentz transformation equation for total relativistic energy states

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This can be simplified to $E = \gamma mc^2$ where

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

With reference to the graph of γ vs β (v/c) and the equation for relativistic energy, explain why it is impossible for any particle with mass to achieve the speed of light.



2019 Section 1 Question 5 **Special relativity**	In 2012 scientists at the European Organisation for Nuclear Research (CERN) in Switzerland claimed to have found the Higgs boson. They measured its rest energy to be 126 GeV. Show that the mass of the Higgs boson is 2.24×10^{-25} kg.

2019 Section 1 Question 9 **Special relativity**	With the use of a relevant formula, explain why time dilation is negligible at a speed of 100 km h^{-1}.

2019 Section 1 Question 11 **Special relativity**	Chloe is piloting the spaceship *Antilles*. It is 1.10 km long and travelling at 0.80*c* past a spaceport controlled by Zhang. Zhang needs to measure the speed of passing spaceships. Chloe steers the spaceship between two beacons 1000 m apart as measured by Zhang. The beacons are placed parallel to the *Antilles'* path. Both Chloe and Zhang start their timers when the front of the *Antilles* reaches the first beacon. (a) Calculate the time elapsed on Zhang's clock (as observed by Zhang) when the front of *Antilles* reaches the second beacon. (1 mark) _____ s (b) Calculate the distance Chloe observes between the beacons before she passes the first beacon. (2 marks) _____ m

	(c) At one stage, Zhang observes Antilles fits completely between the two beacons. Chloe says that at no time did the spaceship completely fit between the beacons. Explain how they can both be correct, and why. (4 marks)

Section 2

2020 Section 2 Question 14

Special relativity

Muons and anti-muons are unstable, with the decay process producing three particles. When an anti-muon (μ) decays, one of these particles is an electron neutrino (ν_e).

(a) Complete the table below and use your answers to identify the missing particle X. (3 marks)

$$\overline{\mu} = X + \nu_e + \overline{\nu_\mu}$$

Reaction	$\overline{\mu}$	=	X	ν_e	$\overline{\nu_\mu}$
Conservation of electron charge	+1	=		0	0
Conservation of Lepton number	–1	=		+1	–1

Particle X: _____

Muons created in the upper atmosphere (approximately 10 km above the Earth's surface) are secondary products from highly-energetic cosmic ray interactions with nuclei of atmospheric particles. In their own frame, muons have a mean lifetime of 2.20×10^{-6} s, with some lasting for up to 3.0×10^{-6} s.

The speed of muons from cosmic rays entering the Earth's atmosphere moving in the direction of the observer on the Earth is in the range of $2.960 \times 10^8 - 2.997 \times 10^8$ m s^{-1}. (Ignore the effect of the Earth's magnetic field on the muons when answering the following questions.)

(b) Use non-relativistic physics to calculate the mean distance muons moving at 2.991×10^8 m s^{-1} could travel. (2 marks)

_____ m

(c) (i) Calculate the mean lifetime of muons travelling at 0.997c as observed from the Earth. (2 marks)

_____ s

(ii) What is the actual mean distance travelled by such muons through the atmosphere as observed from the Earth? (2 marks)

_____ km

(d) Using information from the question, explain why a small number of muons reach the Earth. (2 marks)

(e) With the use of a calculation, explain why these muons reach the Earth from the perspective of the muons. (4 marks)

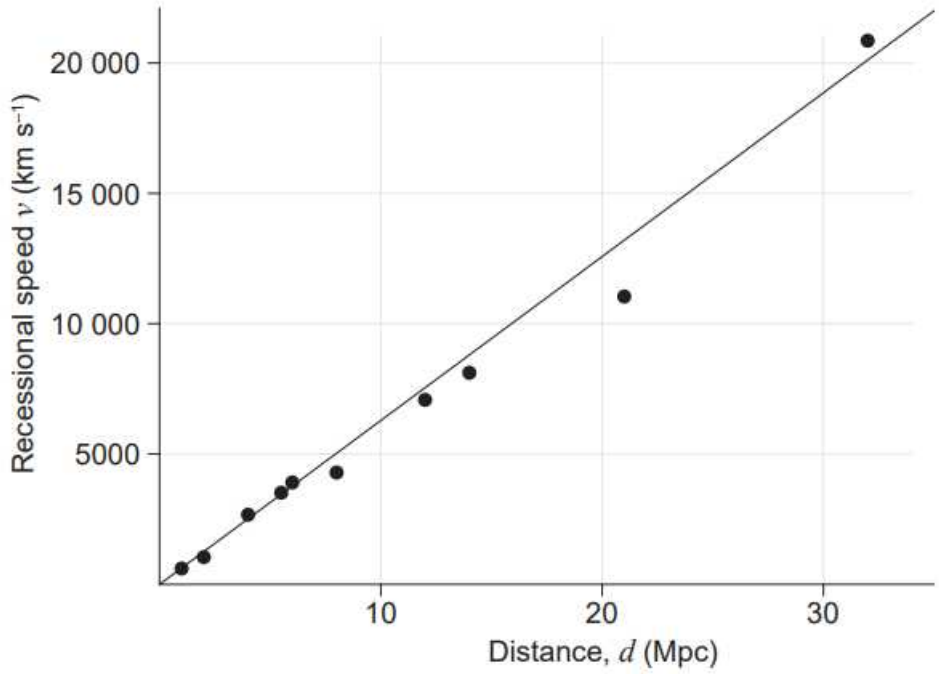
Section 3

There have been no questions on this topic for this section in the exams of recent years.

2023 Section 1 Question 8

Special relativity

Edwin Hubble found that the further a galaxy is away from an observer, the faster it is receding. Below is a graph of data showing this relationship.

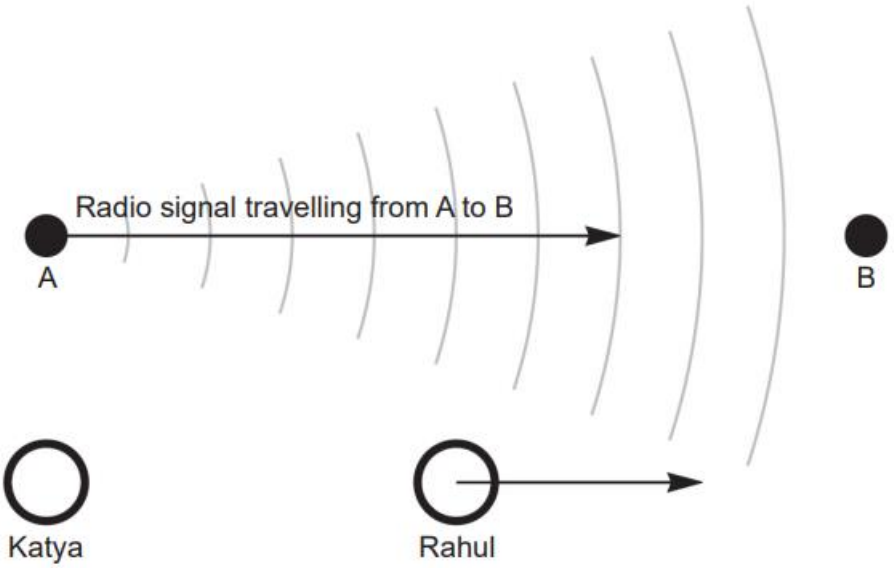


Using the graph above, estimate the distance in kilometres to a galaxy that is receding at 4.5% of the speed of light. (6 marks)

Element	Description	Marks
Calculates recessional velocity	$0.045 \times 3.00 \times 10^8 = 1.35 \times 10^7$ m s^{-1}	1
Converts to km s^{-1}	1.35×10^4 km s^{-1}	1
Locates correctly on y-axis		1
Reads corresponding value on x-axis	Roughly 22 Megaparsecs	1
Calculates distance	$22 \times 3.09 \times 10^{19} = 6.798 \times 10^{20}$ km	1
2 significant figures	$6.8 (\pm 0.3) \times 10^{20}$ km	1
	Total	**6**

2023
Section 1
Question 9

Special relativity



A radio signal is emitted from Spaceship 'A' and arrives at Spaceship 'B'. A and B are stationary with respect to Katya. In her frame of reference, A and B are a distance d_1 apart, and the signal takes time t_1 to travel.

Rahul is moving parallel to the radio waves between A and B with constant velocity near the speed of light with respect to Katya and the two spaceships. In his frame of reference, A and B are a distance d_2 apart, and the signal takes time t_2 to travel.

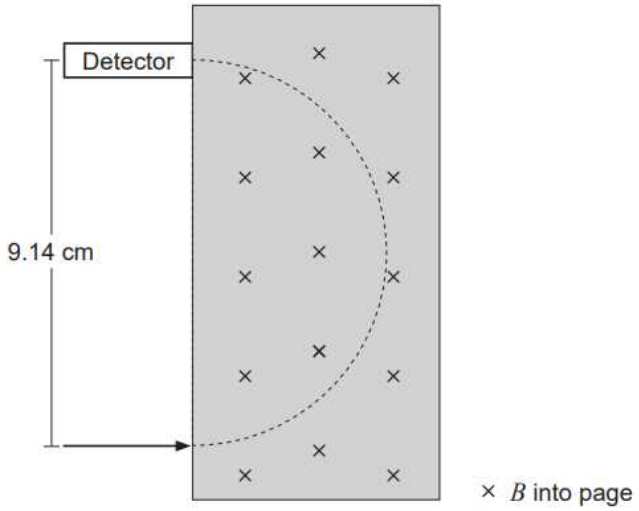
Derive an expression for d_2 in terms of d_1, t_1 and t_2. Show your reasoning and state any assumptions. (Hint: It is not necessary to use length contraction or time dilation.)

Description	Marks
every observer measures the speed of light as c	1
therefore $d_1/t_1 = c$, and $d_2/t_2 = c = d_1/t_1$	1
rearrange for d_2 : $d_2 = d_1/t_1 \times t_2$	1
Total	**3**

2022 Section 1 Question 4

Special relativity

A charged particle enters a 0.350 mT magnetic field at right angles to the field with a velocity of 2.81 × 10^6 m s^{-1}. The magnitude of the charge of the particle is 1.60 × 10^{-19} C. It lands on the detector 9.14 cm from where it entered after completing 180° of its circular path.



(a) Calculate the mass of the particle. (4 marks)

Element	Description	Marks
Isolates m from equation	$m = rBq/v$	1
Divides 9.14 cm by 2 and converts to m.		1
Puts correct values into equation	$m = 0.0457 \times 3.50 \times 10^{-4} \times 1.60 \times 10^{-19}/2.81 \times 10^{6}$	1
Calculates correct answer	$m = 9.11 \times 10^{-31}$ kg	1
	Total	**4**

(b) Which of the following could the particle be? Circle your answer. (1 mark)

A proton
B electron
C anti-proton
D positron
E none of the above

Description	Marks
D Positron	1
Total	**1**

2022 Section 1 Question 11

Special relativity

Salman and Priyanka have identical 1.00 m rulers. Priyanka takes her ruler and sets off in a rocket. She travels past Salman at a speed of 0.800 c. Their metre rulers are aligned in the direction of Priyanka's travel. Each then measures the length of the other's ruler by carefully determining the position of each end of the ruler at the same instant, and measuring the distance between these positions.

(a) How long does Salman measure Priyanka's ruler to be? (2 marks)

Element	Description	Marks
Uses correct equation and places correct values in correct place	$l = l_0\sqrt{1-0.800^2}$	1
Calculates correct answer	l = 0.60 m	1
	Total	**2**

(b) How long does Priyanka measure Salman's ruler to be? (1 mark)

Description	Marks
0.60 m	1
Total	**1**

(c) When Priyanka returns, she and Salman compare the results of their measurements. How are they able to explain their seemingly contradictory results? (3 marks)

Description	Marks
To successfully measure the length of the ruler moving relative to them, they determine the position of the ends of the ruler at the same time and measure the distance between these two positions.	1
Each thought the other's measurements were not made simultaneously.	1
Therefore they both measure the other's ruler as a different length to 1.00 m.	1
Total	**3**

2020 Section 1 Question 9

Special relativity

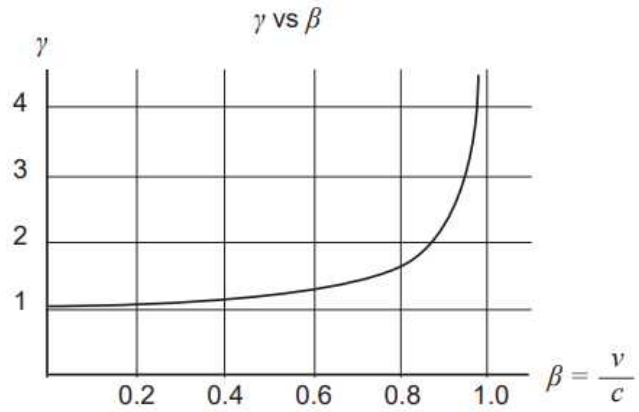
The Lorentz transformation equation for total relativistic energy states

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This can be simplified to $E = \gamma mc^2$ where

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

With reference to the graph of γ vs β (v/c) and the equation for relativistic energy, explain why it is impossible for any particle with mass to achieve the speed of light.



Description	Marks
as v approaches c, β approaches 1	1
as β approaches 1, γ approaches infinity	1
to accelerate the mass particle to a greater speed requires energy	1
to achieve c, a mass particle requires infinite energy which is impossible	1
Total	**4**

2019 Section 1 Question 5

Special relativity

In 2012 scientists at the European Organisation for Nuclear Research (CERN) in Switzerland claimed to have found the Higgs boson. They measured its rest energy to be 126 GeV. Show that the mass of the Higgs boson is 2.24×10^{-25} kg.

Description	Marks
$m = E/c^2$	1
$= 126 \times 10^9 \times 1.6 \times 10^{-19} / 9 \times 10^{16}$ $= 2.24 \times 10^{-25}$ kg	1–3
Total	**4**

2019 Section 1 Question 9

Special relativity

With the use of a relevant formula, explain why time dilation is negligible at a speed of 100 km h^{-1}.

Description	Marks
$t = t_0 / \sqrt{1 - v^2/c^2}$	1
As 100 km h^{-1} is considerably less than c, v^2/c^2 is close to zero so dilation is not noticeable.	1–2
Total	**3**

2019 Section 1 Question 11

Special relativity

Chloe is piloting the spaceship *Antilles*. It is 1.10 km long and travelling at 0.80*c* past a spaceport controlled by Zhang. Zhang needs to measure the speed of passing spaceships. Chloe steers the spaceship between two beacons 1000 m apart as measured by Zhang. The beacons are placed parallel to the *Antilles'* path. Both Chloe and Zhang start their timers when the front of the *Antilles* reaches the first beacon.

(a) Calculate the time elapsed on Zhang's clock (as observed by Zhang) when the front of *Antilles* reaches the second beacon. (1 mark)

Description	Marks
$t = 1000/0.8 \times 3.0 \times 10^8 = 4.17 \times 10^{-6}$ s	1
Total	**1**

(b) Calculate the distance Chloe observes between the beacons before she passes the first beacon. (2 marks)

Description	Marks
$l = 1000\sqrt{1 - 0.8^2}$	1
$= 600$ m	1
Total	**2**

(c) At one stage, Zhang observes Antilles fits completely between the two beacons. Chloe says that at no time did the spaceship completely fit between the beacons. Explain how they can both be correct, and why. (4 marks)

Description	Marks
• Observing the whole of *Antilles* between the beacons at a particular time requires you to measure the positions of the front and back simultaneously. • Simultaneity is not the same for each observer. • Due to length contraction, Zhang observes length of *Antilles* as 660 m so it fits easily between the beacons. • Chloe observes distance between the beacons contract to 600 m so *Antilles* does not fit.	1–4
Total	**4**

2020 Section 2 Question 14

Special relativity

Muons and anti-muons are unstable, with the decay process producing three particles. When an anti-muon (μ) decays, one of these particles is an electron neutrino (ν_e).

(a) Complete the table below and use your answers to identify the missing particle X. (3 marks)

Description	Marks
charge = +1	1
lepton number = −1	1
particle is a positron	1
Total	**3**

Muons created in the upper atmosphere (approximately 10 km above the Earth's surface) are secondary products from highly-energetic cosmic ray interactions with nuclei of atmospheric particles. In their own frame, muons have a mean lifetime of 2.20×10^{-6} s, with some lasting for up to 3.0×10^{-6} s.

The speed of muons from cosmic rays entering the Earth's atmosphere moving in the direction of the observer on the Earth is in the range of $2.960 \times 10^8 - 2.997 \times 10^8$ m s^{-1}. (Ignore the effect of the Earth's magnetic field on the muons when answering the following questions.)

(b) Use non-relativistic physics to calculate the mean distance muons moving at 2.991×10^8 m s^{-1} could travel. (2 marks)

Description	Marks
$s = vt$	1
$s = 2.991 \times 10^8 \times 2.20 \times 10^{-6} = 658$ m	1
Total	**2**

(c) (i) Calculate the mean lifetime of muons travelling at $0.997c$ as observed from the Earth. (2 marks)

Element	Description	Marks
uses time dilation formula correctly	$t = \gamma \times 2.20 \times 10^{-6}$	1
correct/consistent answer	$= 2.84 \times 10^{-5}$ s	1
	Total	**2**

(ii) What is the actual mean distance travelled by such muons through the atmosphere as observed from the Earth? (2 marks)

Description	Marks
$s = vt = 2.84 \times 10^{-5} \times 2.991 \times 10^8 = 8494$ m	1
$s = 8.49$ km (correctly converts to km)	1
Total	**2**

(d) Using information from the question, explain why a small number of muons reach the Earth. (2 marks)

Description	Marks
The lifetime is a mean lifetime. Some will live longer and reach the Earth.	1
The muons with a longer lifetime due to time dilation will live long enough to reach Earth.	1
Total	**2**

(e) With the use of a calculation, explain why these muons reach the Earth from the perspective of the muons. (4 marks)

Element	Description	Marks
uses length contraction formula correctly	$l = l_o / \gamma$	1
calculates length contraction correctly	$l = 7.746 \times 10^{-1}$ km	1
calculates lifetime required to reach Earth	$t = 774.6/2.991 \times 10^{8} = 2.59 \times 10^{-6}$ s	1
compares time to mean lifetime	this is slightly greater than the mean lifetime of 2.20×10^{-6} s therefore some muons reach Earth	1
	Total	**4**

Marking Guide – Section 3

There have been no questions on this topic for this section in the exams of recent years.

Unit 4 – The Standard Model

Section 1

2023 Section 1 Question 11

The Standard Model

The table below lists four subatomic particles. Identify the category to which they belong in the second column and state whether or not they are bound by the strong nuclear force in the third column. (4 marks)

Particle	Category (meson, baryon or lepton)	Bound by strong nuclear force (yes or no)
Proton		
Pion		
Neutrino		
Muon		

2021 Section 1 Question 2

The Standard Model

Using information from the Formulae and Data Booklet, calculate the mass of a bottom quark in kg.

Answer _____ kg

2021 Section 1 Question 4

The Standard Model

A proton in a linear particle accelerator is given an energy of 0.100 TeV. Using the equation for mass-energy equivalence, calculate the speed of the proton in terms of *c*. Give your answer to five significant figures.

Answer _____ *c*

2021 Section 1 Question 5

The Standard Model

(a) State **two** main differences between hadrons and leptons. (2 marks)

One	
Two	

(b) Identify an example of a hadron and a lepton from the list provided and write your choice in the spaces below. (2 marks)

(i) Proton (ii) Meson (iii) Tau neutrino (iv) Neutron (v) Muon (vi) Baryon

Hadron: _____

Lepton: _____

2021 Section 1 Question 8

The Standard Model

Complete the following table for an anti-proton. (4 marks)

Name	Symbol	Quark composition	Electric charge	Mass (GeV/c^2)
proton	p	uud	1	0.938
anti-proton				

2021 Section 1 Question 12

The Standard Model

Cosmic Microwave Background radiation (CMB) was first observed in 1965 by Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in Murray Hill, New Jersey. They had built a Dicke radiometer that they intended to use for radio astronomy and satellite communication experiments. They detected the CMB in every direction they pointed their radiometer.

(a) Briefly explain the origin of CMB as part of the Big Bang theory. (2 marks)

(b) How does the study of CMB provide evidence that the universe is expanding? (2 marks)

2020 Section 1 Question 12

The Standard Model

Exchange particles (gauge bosons) mediate interactions between elementary particles such as quarks and leptons. The gauge bosons (see the Formulae and Data Booklet) have different fundamental properties.

(a) Choose the appropriate combination of relevant fundamental force and property from the table below that corresponds to the gauge bosons listed. Place the number of your choice in the spaces provided. (4 marks)

Number	Fundamental forces	Properties
1	strong nuclear	massless
2	strong nuclear	has mass
3	weak nuclear	massless
4	weak nuclear	has mass
5	electromagnetic	massless
6	electromagnetic	has mass

i. Gluon Answer: _____

ii. Photon Answer: _____

iii. Z Boson Answer: _____

iv. W Boson Answer: _____

(b) Which of the fundamental forces below has the longest range of interaction? (1 mark)

i. weak nuclear
ii. electromagnetic
iii. strong nuclear

Answer: _____

Section 2

2022 Section 2 Question 14

The Standard Model

When a stationary neutron decays into a proton, an electron and an electron anti-neutrino are also produced. Total energy is conserved during the decay process. The reaction is described by the following equation:

$$n^0 \longrightarrow p^+ + e^- + \bar{\nu}_e$$

(a) In the reaction, the quark composition of a neutron changes from udd to uud. Show how the reaction conserves both baryon number and lepton number by filling in the table below. (6 marks)

	n^0	→	p^+	+	e^-	+	$\bar{\nu}_e$
Baryon number		→		+		+	
Lepton number		→		+		+	

(b) The mass of a stationary neutron is 1.675×10^{-27} kg. The mass of a proton is 1.673×10^{-27} kg. The mass of an electron is 9.109×10^{-31} kg. If we assume the total energy of the anti-neutrino is 0 J, calculate the total kinetic energy of the particles emitted in keV. (5 marks)

Answer: _____ keV

(c) If the electron accounts for 90.0% of the kinetic energy produced, calculate the velocity of the emitted proton in terms of *c*. If you could not determine an answer for part (b), use 581 keV (9.30×10^{-14} J). (4 marks)

Answer: _____ *c*

2020 Section 2 Question 19

The Standard Model

Hubble's law states:

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From this law comes Hubble's equation:

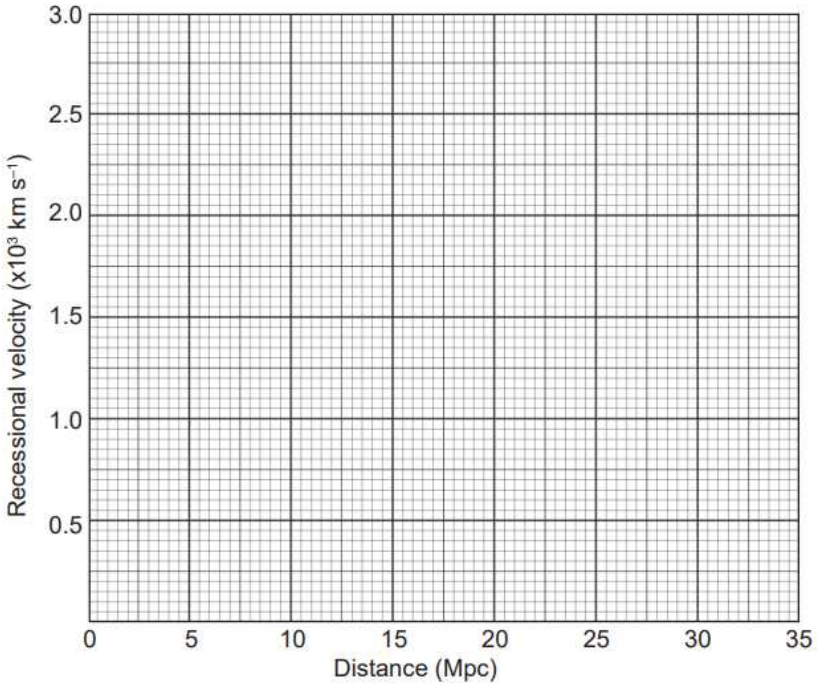
$$v = H_0 d$$

where v = recessional velocity
d = distance from the Earth
H_0 = Hubble's constant.

Below is some data Hubble used to graphically determine his constant.

Galaxy	Distance (Mpc)	Velocity ($\times 10^3$ km s^{-1})
NGC 1357	24.7	2.19
NGC 1832	31.0	2.82
NGC 2775	17.9	1.46
NGC 2903	6.96	0.45
NGC 3368	11.9	0.88

(a) Graph the recessional velocity versus distance on the set of axes provided below and draw a line of best fit. Do not take your line through the origin. (3 marks)



(b) Use two **non-data** points on your line of best fit to calculate Hubble's constant. Circle the two points you used and give your answer to two significant figures. (4 marks)

_____ 10^3 km s^{-1} Mpc^{-1}

Hubble measured the red shift of the galaxies to calculate their recessional velocities. The equation for the Doppler effect is shown below:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$\Delta\lambda$ = wavelength shift
λ_0 = wavelength of source not moving
v = velocity of source – line of sight
c = speed of light.

(c) (i) The galaxy NGC 2013 is 7.42 x 10^7 ly away from the Earth. Convert this distance into megaparsecs (Mpc). (2 marks)

_____ Mpc

(ii) Using your line of best fit and the value from part (c)(i), calculate the observed red-shifted wavelength emitted from NGC 2013 if λ_0 is 840.0 nm. (6 marks)

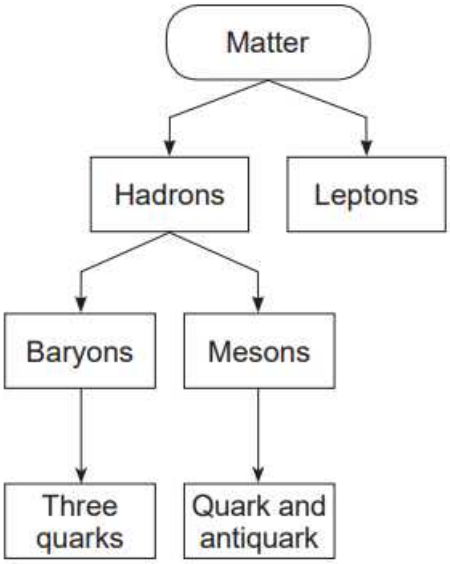
_____ nm

(d) In Hubble's early data, he noticed that one particular spiral galaxy close to the Earth, seen edge on, had two values of v at its extremes. One was positive and one was negative. Assuming this was not an instrumental or human error, explain how this could occur. (4 marks)

2019 Section 2 Question 15

The Standard Model

The table below shows the classification of matter.



A kaon is a subatomic particle first detected in cosmic rays in 1947. There are four types:

K^-	a negatively-charged particle consisting of a strange quark and an up antiquark
K^+	a positively-charged antiparticle of the K^- kaon
K^0	a neutrally-charged particle consisting of a strange antiquark and a down quark
K^{0-}	the antiparticle of the K^0.

(a) Are kaons classified as baryons or mesons? (1 mark)

(b) Justify your answer to part (a). (2 marks)

(c) Name the quarks that make up the K^{0-} particle. (2 marks)

(d) K^- particles have a mean lifetime of 1.238×10^{-8} s in their own frame of reference. Kaons produced in a particle accelerator were found to be moving at $0.850c$. Calculate their mean lifetime in the frame of reference of a stationary observer. (3 marks)

_____ s

Kaons were produced in the Tevatron, a particle accelerator in the United States. Protons were accelerated in a linear accelerator (LINAC) containing a strong electric field. Then they were injected into the circular main injector ring to be accelerated to energies of up to 1 TeV.

(e) With the use of appropriate equations, explain how the protons were:

(i) accelerated to high speeds in the linear accelerator. (2 marks)

(ii) held in circular paths in the main ring. (2 marks)

2023 Section 3 Question 19 **The Standard Model**	**The Big European Bubble Chamber (BEBC)**  Figure 1: The BEBC Fundamental particles are extremely small and usually fast moving. This makes them hard to detect. If they are passed through a medium which records the path of their movement, new particles can be identified by their behaviour. The products of collisions between known particles can also be observed. One such medium is superheated hydrogen. A superheated liquid is one which is held just above its natural boiling point. These liquids are unstable and 'boil' when the slightest disturbance is experienced. Charged particles moving at high speeds will cause the formation of tiny bubbles in the hydrogen and therefore leave a trace of the particles' trajectory. An example of this is shown in Figure 2 on page 31 (below). ***Copyright restrictions prohibit the release of this SCSA exam material.*** Figure 2: The collision of a gamma ray and a hydrogen atom's electron in a bubble chamber A gamma ray enters from the left and collides with the electron of a hydrogen atom. It is neutral so there is no trace. Its path is shown as a dotted line. The gamma ray loses some energy which creates an electron and its antiparticle, a positron. The electron from the hydrogen atom recoils to the bottom right. Because the chamber is in a strong magnetic field, the charged particles spiral in different directions and with different momenta.

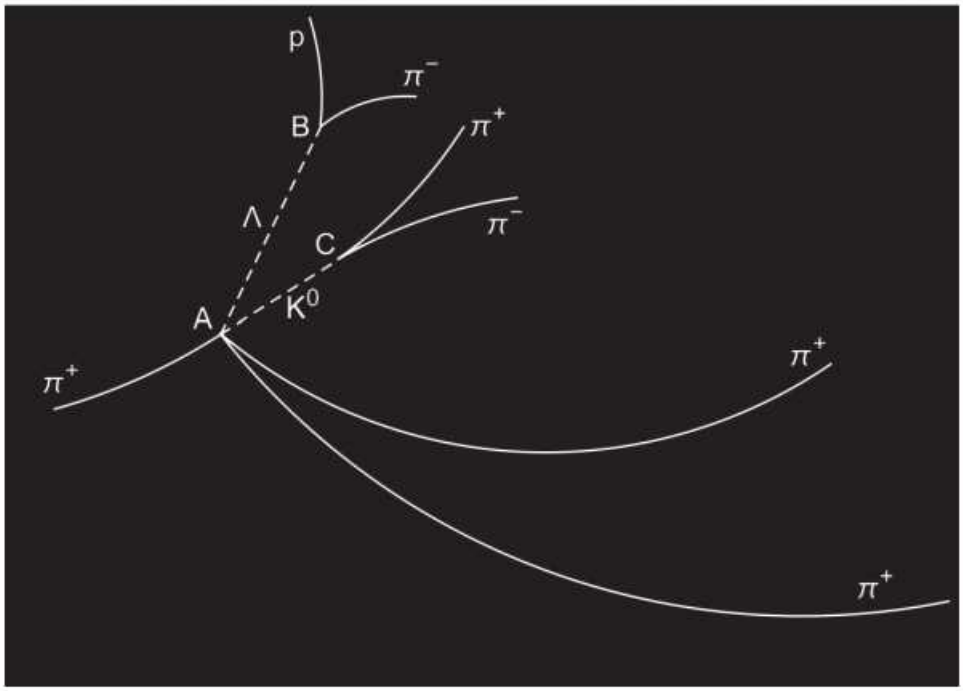


Figure 3: The collision between a positive pion and a proton in a bubble chamber

In Figure 3, a positive meson called a pion (π^+) enters from the left and strikes a proton at A. The pion and the proton become two new pions, a kaon (K^0) and a lambda particle (Λ). Both the kaon and lambda particles are neutral so they travel in straight lines and do not leave a trail. The lambda particle decays into a proton and a negative pion at B. The kaon decays into a positive and a negative pion at C.

In summary, a proton and one pion have been converted into a proton and five pions. There are three varieties of pion: +, –, and 0. The antiparticle of the positive pion is the negative pion and the π^0 is its own antiparticle.

(a) Discuss how the diagram in Figure 2 on page 31 *(above in question)*, shows that the two charged particles produced in the collision have different momenta. (4 marks)

(b) Explain how one proton and one pion can be converted into one proton and five pions. (3 marks)

(c) Why do the lambda and kaon particles leave no tracks in the bubble chamber? (2 marks)

(d) Is charge conserved in the overall reaction? Justify your answer with a calculation of the total charge before and after the collision. (4 marks)

(e) List a possible quark composition of the π^+ and π^- particles. (3 marks)

Particle	Quark composition
π^+	
π^-	

(f) The approximate mass of the incoming π^+ is 2.48×10^{-28} kg. If the radius of the circular path the pion is taking is 2.30 mm and it has a forward velocity of 3.70×10^5 m s^{-1}, estimate the strength of the magnetic field in the bubble chamber. (5 marks)

Answer: _____ T

Marking Guide – Section 1

2023 Section 1 Question 11

The Standard Model

The table below lists four subatomic particles. Identify the category to which they belong in the second column and state whether or not they are bound by the strong nuclear force in the third column. (4 marks)

Description			Marks
Particle	**Category (meson, baryon or lepton)**	**Bound by strong nuclear force (yes or no)**	
Proton	baryon	yes	1
Pion	meson	yes	1
Neutrino	lepton	no	1
Muon	lepton	no	1
		Total	**4**

2021 Section 1 Question 2

The Standard Model

Using information from the Formulae and Data Booklet, calculate the mass of a bottom quark in kg.

Element	Description	Marks
Student uses correct value from data sheet	4.18 GeV/c^2	1
Student converts eV to Joules	$4.18 \times 10^{9} \times 1.6 \times 10^{-19} = 6.69 \times 10^{-10}$ J	1
Student correctly calculates mass	$6.69 \times 10^{-10} / 9 \times 10^{16} = 7.43 \times 10^{-27}$ kg	1
	Total	**3**

2021 Section 1 Question 4

The Standard Model

A proton in a linear particle accelerator is given an energy of 0.100 TeV. Using the equation for mass-energy equivalence, calculate the speed of the proton in terms of *c*. Give your answer to five significant figures.

Element	Description	Marks
Uses relativistic energy formula	$E = \gamma mc^2$	1
Converts TeV to Joules	$0.100 \times 10^{12} \times 1.60 \times 10^{-19} = 1.60 \times 10^{-8}$ J	1
Uses correct algebra	$1/\gamma = 1.67 \times 10^{-27} \times 9.00 \times 10^{16} / 1.60 \times 10^{-8}$ $= 9.393750 \times 10^{-3}$	1
Correctly calculates answer	$\sqrt{1 - x^2} = 9.393750 \times 10^{-3}$ $1 - x^2 = 8.824254 \times 10^{-5}$ $x = 0.9999559$	1
Gives answer in terms of c and to 5 significant figures	$v = 0.99996\ c$	1
	Total	**5**
Note: $E_k = (\gamma - 1)mc^2$ is also acceptable		

2021 Section 1 Question 5

The Standard Model

(a) State **two** main differences between hadrons and leptons. (2 marks)

1 mark per difference

Description	Marks
Differences between hadrons and leptons explicitly stated	1–2
Total	**2**
• Hadrons are made of quarks (not fermions), leptons are fundamental particles (fermions) • Leptons are generally less massive than hadrons • Hadrons are subject to the strong nuclear force that holds the nuclei together, and leptons are subject only to the weak nuclear force	
Note: Answer must include reference to hadrons and leptons	

(b) Identify an example of a hadron and a lepton from the list provided and write your choice in the spaces below. (2 marks)

Description		Marks
Correctly identifies particles		1–2
	Total	**2**
Hadron	(i) proton, (ii) meson, (iv) neutron or (vi) baryon	
Lepton	(iii) tau neutrino or (v) muon	

2021 Section 1 Question 8

The Standard Model

Complete the following table for an anti-proton. (4 marks)

1 mark for each box

Name	Symbol	Quark composition	Electric charge	Mass (GeV/c^2)
proton	p	uud	1	0.938
anti-proton	$\overline{p}$	$\overline{u}\,\overline{u}\,\overline{d}$	-1	0.938

2021 Section 1 Question 12

The Standard Model

Cosmic Microwave Background radiation (CMB) was first observed in 1965 by Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in Murray Hill, New Jersey. They had built a Dicke radiometer that they intended to use for radio astronomy and satellite communication experiments. They detected the CMB in every direction they pointed their radiometer.

(a) Briefly explain the origin of CMB as part of the Big Bang theory. (2 marks)

Description	Marks
The Big Bang theory states the original temperature of the universe would need to be very high/high energy.	1
The universe would have given off (black body) radiation in all directions.	1
Total	**2**

(b) How does the study of CMB provide evidence that the universe is expanding? (2 marks)

Description	Marks
Originally the radiation given off would have had much shorter wavelengths and higher energy.	1
As the universe expanded, so did the wavelengths of this background radiation and it became less energetic microwaves.	1
Total	**2**

2020 Section 1 Question 12

The Standard Model

Exchange particles (gauge bosons) mediate interactions between elementary particles such as quarks and leptons. The gauge bosons (see the Formulae and Data Booklet) have different fundamental properties.

(a) Choose the appropriate combination of relevant fundamental force and property from the table below that corresponds to the gauge bosons listed. Place the number of your choice in the spaces provided. (4 marks)

Number	Fundamental forces	Properties
1	strong nuclear	massless
2	strong nuclear	has mass
3	weak nuclear	massless
4	weak nuclear	has mass
5	electromagnetic	massless
6	electromagnetic	has mass

Description		Marks
(i)	1	1
(ii)	5	1
(iii)	4	1
(iv)	4	1
	Total	**4**

(b) Which of the fundamental forces below has the longest range of interaction? (1 mark)

i. weak nuclear
ii. electromagnetic
iii. strong nuclear

Description		Marks
(ii)		1
	Total	**1**

2022 Section 2 Question 14

The Standard Model

When a stationary neutron decays into a proton, an electron and an electron anti-neutrino are also produced. Total energy is conserved during the decay process. The reaction is described by the following equation:

$$n^0 \longrightarrow p^+ + e^- + \bar{\nu}_e$$

(a) In the reaction, the quark composition of a neutron changes from udd to uud. Show how the reaction conserves both baryon number and lepton number by filling in the table below. (6 marks)

	n^0	→	p^+	+	e^-	+	$\bar{\nu}_e$
Baryon number	+1	→	+1	+	0	+	0
Lepton number	0	→	0	+	+1	+	-1

Description	Marks
Baryon number for neutron = ⅓ + ⅓ + ⅓ = 1	1
Baryon number for proton = ⅓ + ⅓ + ⅓ = 1	1
All baryon numbers correct	1
Baryon number conserved	1
Lepton numbers correct	1
Lepton number conserved	1
Total	**6**

(b) The mass of a stationary neutron is 1.675×10^{-27} kg. The mass of a proton is 1.673×10^{-27} kg. The mass of an electron is 9.109×10^{-31} kg. If we assume the total energy of the anti-neutrino is 0 J, calculate the total kinetic energy of the particles emitted in keV. (5 marks)

Element	Description	Marks
Uses total energy equation to determine $\Delta mc^2 = \Delta\Sigma KE$		1
Calculates Δm	$1.675 \times 10^{-27} - 1.673 \times 10^{-27} - 9.109 \times 10^{-31}$ $= 1.0891 \times 10^{-30}$ kg	1
Converts to energy	$1.0891 \times 10^{-30} \times 9.000 \times 10^{16}$ $= 9.8019 \times 10^{-14}$ J	1
Converts to eV	$9.8019 \times 10^{-14} / 1.600 \times 10^{-19}$ $= 6.1262 \times 10^{5}$ eV	1
Expresses answer in keV	613 keV	1
	Total	**5**

(c) If the electron accounts for 90.0% of the kinetic energy produced, calculate the velocity of the emitted proton in terms of *c*. If you could not determine an answer for part (b), use 581 keV (9.30×10^{-14} J). (4 marks)

Element	Description	Marks
Calculates 10.0% of energy from part (b)	$0.100 \times 9.8019 \times 10^{-14}$ $= 9.8019 \times 10^{-15}$	1
Rearranges equation correctly	$v = \sqrt{\frac{2 \times 9.8019 \times 10^{-15}}{1.673 \times 10^{-27}}}$	1
Calculates correct answer	$v = 3.423 \times 10^{6}$ m s^{-1}	1
Expresses answer in terms of c	$v = 0.0114\ c$	1
	Total	**4**
Note: If used 5.81×10^{5} eV, $v = 3.33 \times 10^{6}$ m s^{-1} = 0.0111 c		

2020 Section 2 Question 19

The Standard Model

Hubble's law states:

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From this law comes Hubble's equation:

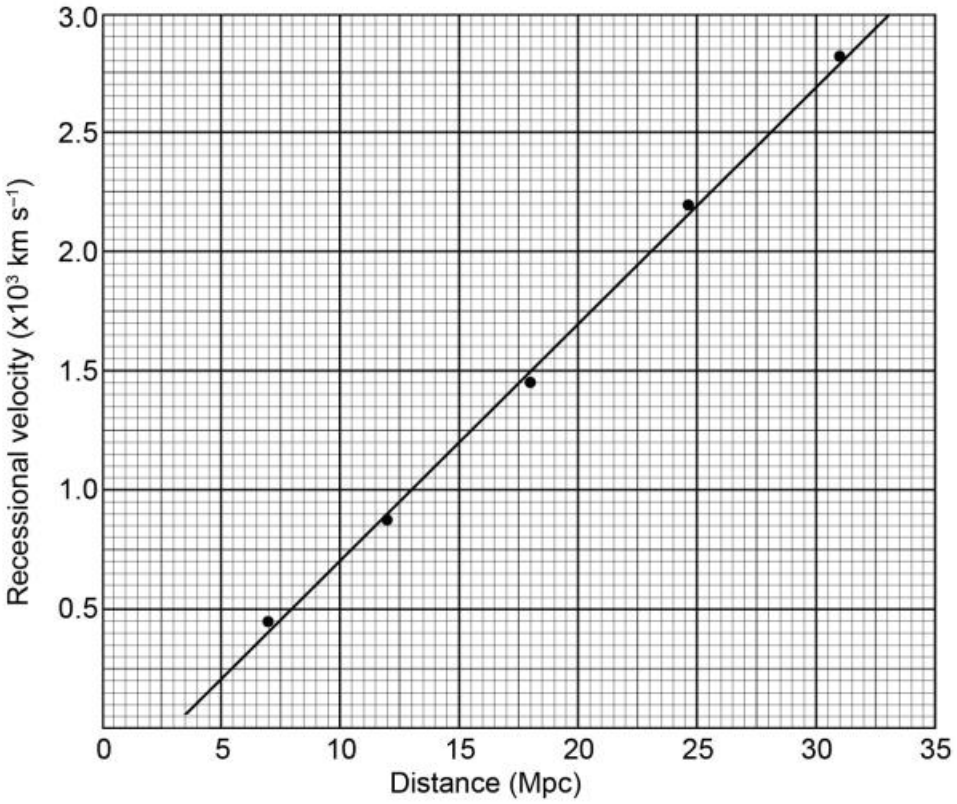
$$v = H_0 d$$

where v = recessional velocity
d = distance from the Earth
H_0 = Hubble's constant.

Below is some data Hubble used to graphically determine his constant.

Galaxy	Distance (Mpc)	Velocity (x10^3 km s^{-1})
NGC 1357	24.7	2.19
NGC 1832	31.0	2.82
NGC 2775	17.9	1.46
NGC 2903	6.96	0.45
NGC 3368	11.9	0.88

(a) Graph the recessional velocity versus distance on the set of axes provided below and draw a line of best fit. Do not take your line through the origin. (3 marks)



Description	Marks
correctly plotted all points	1
line of best fit clear and straight	1
not connected to origin	1
Total	**3**

(b) Use two **non-data** points on your line of best fit to calculate Hubble's constant. Circle the two points you used and give your answer to two significant figures. (4 marks)

Element	Description	Marks
uses non data points		1
circles points used		1
calculates gradient	$\Delta y/\Delta x$	1
two significant figures	0.10×10^3 km s^{-1} Mpc^{-1}	1
	Total	**4**
Note: accept gradient between 0.095 to 0.105		

Hubble measured the red shift of the galaxies to calculate their recessional velocities. The equation for the Doppler effect is shown below:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

$\Delta\lambda$ = wavelength shift
λ_0 = wavelength of source not moving
v = velocity of source – line of sight
c = speed of light.

(c) (i) The galaxy NGC 2013 is 7.42 x 10^7 ly away from the Earth. Convert this distance into megaparsecs (Mpc). (2 marks)

Description	Marks
uses conversion factor from data sheet	1
$(7.42 \times 10^7)/(3.26 \times 10^6) = 22.8$ Mpc	1
Total	**2**

(ii) Using your line of best fit and the value from part (c)(i), calculate the observed red-shifted wavelength emitted from NGC 2013 if λ_0 is 840.0 nm. (6 marks)

Element	Description	Marks
correctly locates value of distance corresponding to value in part (i)		1
correctly reads velocity	2.0×10^3 km s^{-1}	1
uses correct values in calculation	$\Delta\lambda = 2.0 \times 10^6 \times 840 \times 10^{-9}/3.0 \times 10^8$	1–2
calculates $\Delta\lambda$ correctly/consistently	$\Delta\lambda = 5.6 \times 10^{-9}$ m = 5.6 nm	1
adds $\Delta\lambda$ to λ_0	840.0 + 5.6 = 845.6 nm	1
	Total	**6**

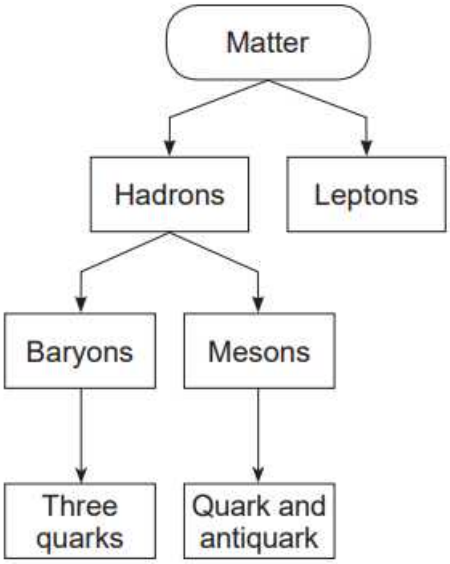
(d) In Hubble's early data, he noticed that one particular spiral galaxy close to the Earth, seen edge on, had two values of *v* at its extremes. One was positive and one was negative. Assuming this was not an instrumental or human error, explain how this could occur. (4 marks)

Description	Marks
Positive value of v means galaxy is moving away from observer.	1
Negative value of v means light is blue shifted and galaxy is moving towards the Earth.	1
This means galaxy is swirling where one side is coming towards the Earth.	1
Rotational speed of side of galaxy must be greater than recessional velocity of galaxy.	1
Total	**4**

2019 Section 2 Question 15

The Standard Model

The table below shows the classification of matter.



A kaon is a subatomic particle first detected in cosmic rays in 1947. There are four types:

K^- a negatively-charged particle consisting of a strange quark and an up antiquark
K^+ a positively-charged antiparticle of the K^- kaon
K^0 a neutrally-charged particle consisting of a strange antiquark and a down quark
K^{0-} the antiparticle of the K^0.

(a) Are kaons classified as baryons or mesons? (1 mark)

Description	Marks
meson/s	1
Total	**1**

(b) Justify your answer to part (a). (2 marks)

Description	Marks
meson are comprised of two quarks, one quark and one antiquark	1
kaons are made up of a strange and an up antiquark: meson	1
Total	**2**

(c) Name the quarks that make up the K^{0-} particle. (2 marks)

Description	Marks
strange quark	1
down antiquark	1
Total	**2**

(d) K^- particles have a mean lifetime of 1.238×10^{-8} s in their own frame of reference. Kaons produced in a particle accelerator were found to be moving at $0.850c$. Calculate their mean lifetime in the frame of reference of a stationary observer. (3 marks)

Description	Marks
$t = t_0 / \sqrt{1 - v^2/c^2}$ $= 1.2380 \times 10^{-8} / \sqrt{1 - 0.85^2}$	1–2
$= 2.35 \times 10^{-8}$ s	1
Total	**3**

Kaons were produced in the Tevatron, a particle accelerator in the United States. Protons were accelerated in a linear accelerator (LINAC) containing a strong electric field. Then they were injected into the circular main injector ring to be accelerated to energies of up to 1 TeV.

(e) With the use of appropriate equations, explain how the protons were:

(i) accelerated to high speeds in the linear accelerator. (2 marks)

Description	Marks
Charged particles are accelerated to higher speeds using electric fields.	1
$F = Eq = ma$	1
Total	**2**

(ii) held in circular paths in the main ring. (2 marks)

Description	Marks
Charged particles are held in circular paths by strong magnetic fields.	1
$r = mv/Bq$	1
Total	**2**

2023 Section 3 Question 19 **The Standard Model**	**The Big European Bubble Chamber (BEBC)**  Figure 1: The BEBC Fundamental particles are extremely small and usually fast moving. This makes them hard to detect. If they are passed through a medium which records the path of their movement, new particles can be identified by their behaviour. The products of collisions between known particles can also be observed. One such medium is superheated hydrogen. A superheated liquid is one which is held just above its natural boiling point. These liquids are unstable and 'boil' when the slightest disturbance is experienced. Charged particles moving at high speeds will cause the formation of tiny bubbles in the hydrogen and therefore leave a trace of the particles' trajectory. An example of this is shown in Figure 2 on page 31 (below). ***Copyright restrictions prohibit the release of this SCSA exam material.*** Figure 2: The collision of a gamma ray and a hydrogen atom's electron in a bubble chamber A gamma ray enters from the left and collides with the electron of a hydrogen atom. It is neutral so there is no trace. Its path is shown as a dotted line. The gamma ray loses some energy which creates an electron and its antiparticle, a positron. The electron from the hydrogen atom recoils to the bottom right. Because the chamber is in a strong magnetic field, the charged particles spiral in different directions and with different momenta.

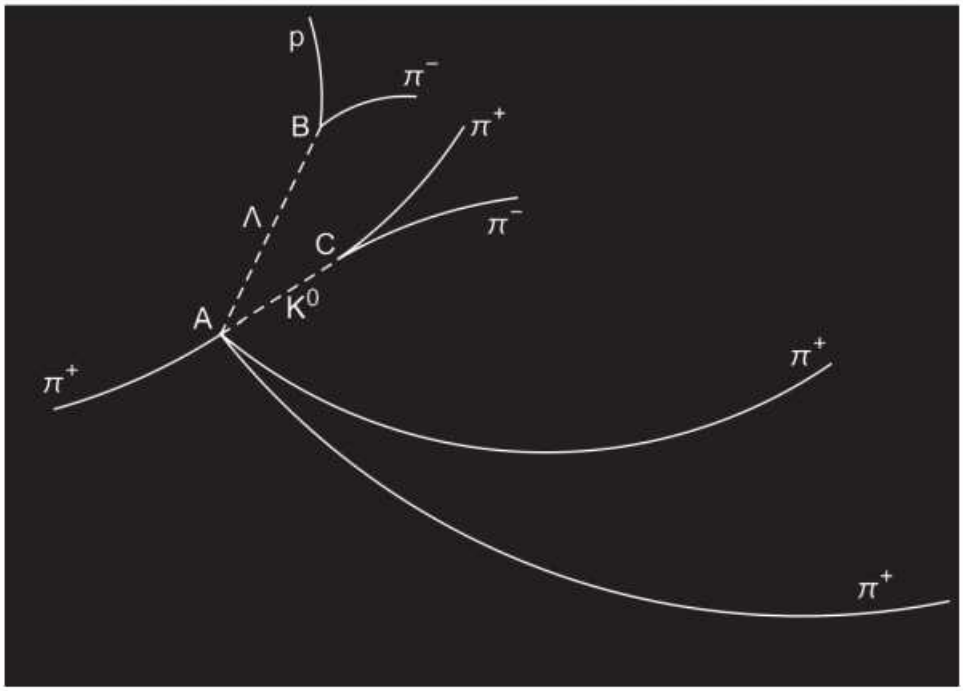


Figure 3: The collision between a positive pion and a proton in a bubble chamber

In Figure 3, a positive meson called a pion (π^+) enters from the left and strikes a proton at A. The pion and the proton become two new pions, a kaon (K^0) and a lambda particle (Λ). Both the kaon and lambda particles are neutral so they travel in straight lines and do not leave a trail. The lambda particle decays into a proton and a negative pion at B. The kaon decays into a positive and a negative pion at C.

In summary, a proton and one pion have been converted into a proton and five pions. There are three varieties of pion: +, –, and 0. The antiparticle of the positive pion is the negative pion and the π^0 is its own antiparticle.

(a) Discuss how the diagram in Figure 2 on page 31 *(above in question)*, shows that the two charged particles produced in the collision have different momenta. (4 marks)

Description	Marks
the radius of the circular path of each particle is given by $r = \frac{mv}{Bq}$	1
m and q are the same for e^- and e^+ as is B	1
different radii means different velocities	1
momentum (p) = mv so different v, same m means different p	1
Total	**4**

(b) Explain how one proton and one pion can be converted into one proton and five pions. (3 marks)

Description	Marks
$E = mc^2$	1
energy and mass are interchangeable	1
some of the energy of the incoming pion is converted to the mass of the extra pions	1
Total	**3**

(c) Why do the lambda and kaon particles leave no tracks in the bubble chamber? (2 marks)

Description	Marks
the tracks are produced by charged particles causing the unstable medium to 'boil'	1
lambda and kaon particles are neutral so they do not cause the medium to boil	1
Total	**2**

(d) Is charge conserved in the overall reaction? Justify your answer with a calculation of the total charge before and after the collision. (4 marks)

Description	Marks
before: π^+ (+1) and p (+1) = +2	1
after: 2 × π^- (–2) , p (+1) and 3 × π^+ (+3)	1
total after: +2	1
therefore, yes, charge is conserved	1
Total	**4**

(e) List a possible quark composition of the π^+ and π^- particles. (3 marks)

Description	Marks
pion+ must contain one of u, c or t only	1
pion+ must contain one of an anti d, s or b only	1
pion– must be anti-particle version of pion+	1
Total	**3**

(f) The approximate mass of the incoming π^+ is 2.48×10^{-28} kg. If the radius of the circular path the pion is taking is 2.30 mm and it has a forward velocity of 3.70×10^5 m s^{-1}, estimate the strength of the magnetic field in the bubble chamber. (5 marks)

Element	Description	Marks
Rearranges $r = \frac{mv}{Bq}$ to isolate B	$B = \frac{mv}{rq}$	1
Uses 2.30×10^{-3} m for r		1
Uses 1.60×10^{-19} for q		1
Calculates answer	$B = \frac{2.48\times10^{-28}\times3.70\times10^{5}}{2.30\times10^{-3}\times1.60\times10^{-19}} = 0.249$ T	1
2 or 3 significant figures	0.25 T	1
	Total	**5**