

PHYSICS

HL

PAPER 2

2017 — 2022



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1 - (PHYSI/21_HL_Summer_2017_Q7) - Oscillations & Waves, Measurements & Uncertainties

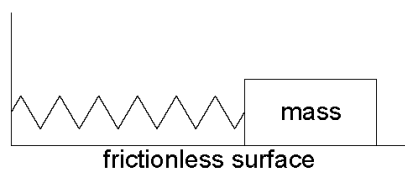


A student is investigating a method to measure the mass of a wooden block by timing the period of its oscillations on a spring.

- (a) Describe the conditions required for an object to perform simple harmonic motion (SHM). [2]

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- (b) A 0.52 kg mass performs simple harmonic motion with a period of 0.86 s when attached to the spring. A wooden block attached to the same spring oscillates with a period of 0.74 s.



Calculate the mass of the wooden block.

[2]

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- (c) In carrying out the experiment the student displaced the block horizontally by 4.8 cm from the equilibrium position. Determine the total energy in the oscillation of the wooden block.

[3]

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- (d) A second identical spring is placed in parallel and the experiment in (b) is repeated. Suggest how this change affects the fractional uncertainty in the mass of the block.

[3]



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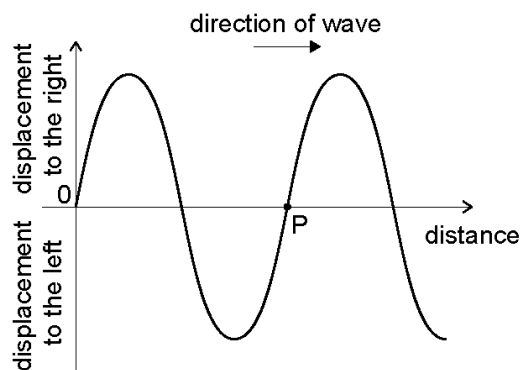
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- (e) With the block stationary a longitudinal wave is made to travel through the original spring from left to right. The diagram shows the variation with distance x of the displacement y of the coils of the spring at an instant of time.



A point on the graph has been labelled that represents a point P on the spring.

- (i) State the direction of motion of P on the spring.

[1]

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- (ii) Explain whether P is at the centre of a compression or the centre of a rarefaction.

[2]

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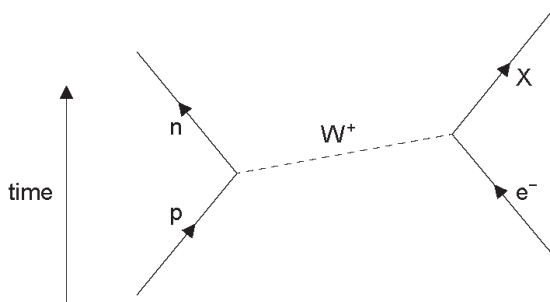
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2 - (PHYSI/20_HL_Winter_2017_Q3) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl), Measurements & Uncertainties



(a) The Feynman diagram shows electron capture.



(i) State and explain the nature of the particle labelled X.

[3]

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(ii) Distinguish between hadrons and leptons.

[2]

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(b) Particles can be used in scattering experiments to estimate nuclear sizes.



(i) Outline how these experiments are carried out.

[2]

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(ii) Outline why the particles must be accelerated to high energies in scattering experiments.

[3]

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(c) State and explain **one** example of a scientific analogy.

[2]

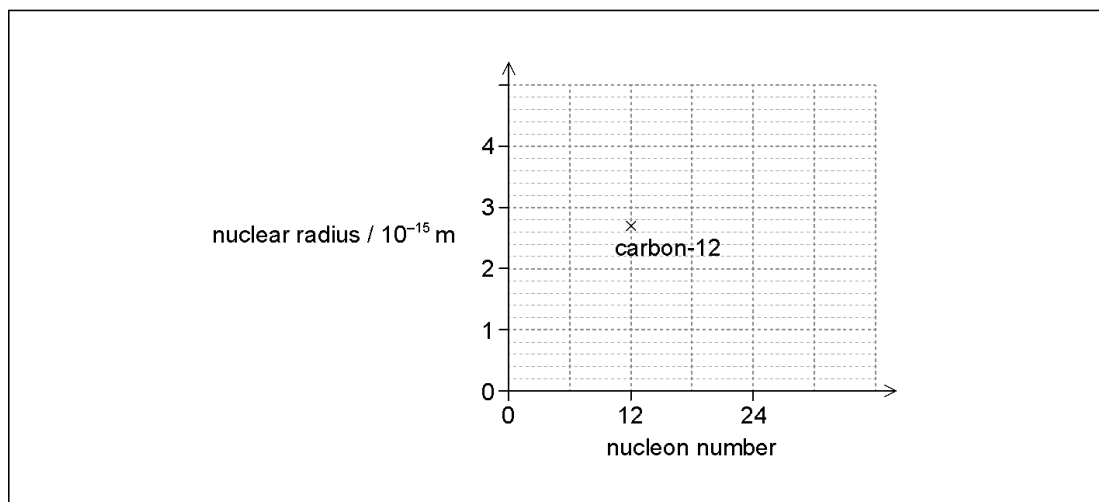
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- (d) Electron diffraction experiments indicate that the nuclear radius of carbon-12 ($^{12}_6\text{C}$) is $2.7 \times 10^{-15} \text{ m}$. The graph shows the variation of nuclear radius with nucleon number. The nuclear radius of the carbon-12 is shown on the graph.



- (i) Determine the radius of the magnesium-24 ($^{24}_{12}\text{Mg}$) nucleus. [2]

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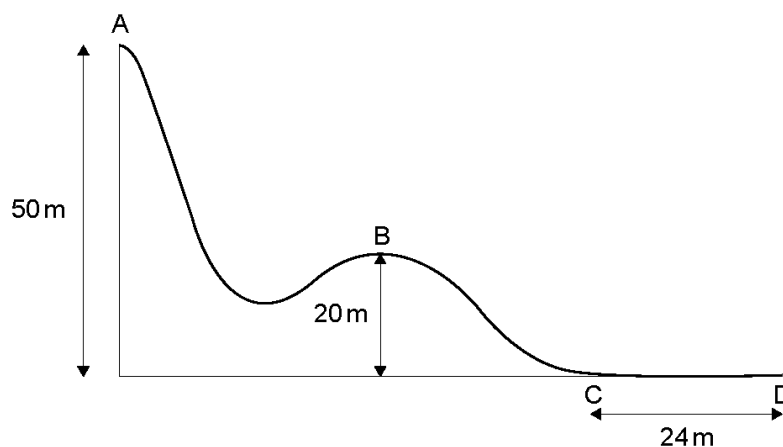
- (ii) Plot the position of magnesium-24 on the graph. [1]

- (iii) Draw a line on the graph, to show the variation of nuclear radius with nucleon number. [2]

1 – (PHYSI/21_HL_Summer_2017_Q1) – Mechanics, Thermal Physics



The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



- (a) A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

- (i) From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 ms^{-1} .

[2]

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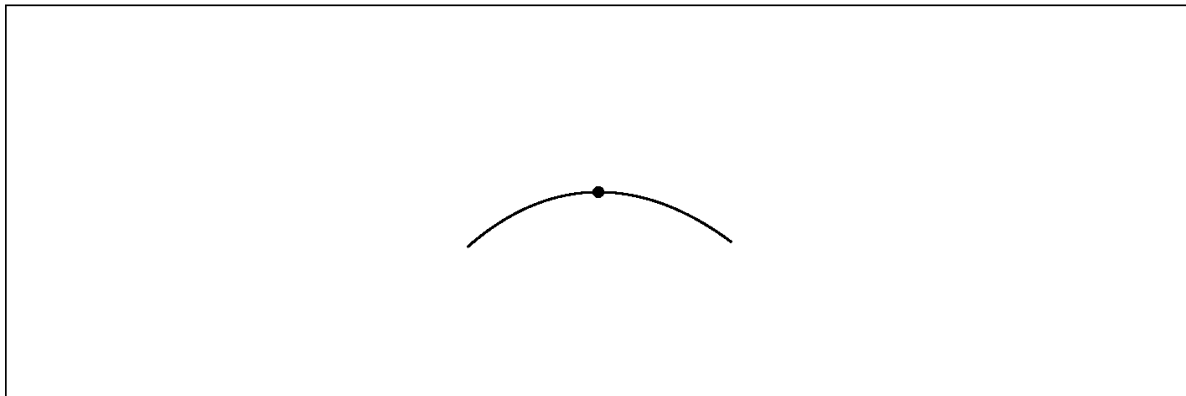
- (ii) Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature.

[2]

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- (b) (i) The dot on the following diagram represents the skier as she passes point B. Draw and label the vertical forces acting on the skier.

[2]



- (ii) The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B.

[3]

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- (c) The skier reaches point C with a speed of 8.2 ms^{-1} . She stops after a distance of 24 m at point D.

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

[3]

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- (d) At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 ms^{-1} .



- (i) Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer.

[2]

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- (ii) Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier.

[2]

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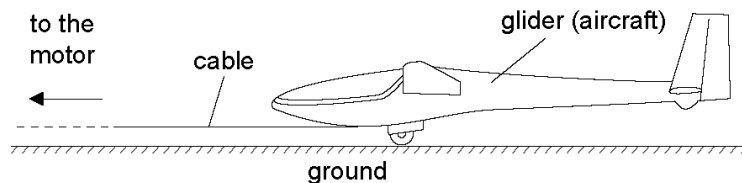
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2 – (PHYSI/22_HL_Summer_2017_Q1) – *Mechanics*

A glider is an aircraft with no engine. To be launched, a glider is uniformly accelerated from rest by a cable pulled by a motor that exerts a horizontal force on the glider throughout the launch.



- (a) The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s . Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground.

[2]

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- (b) The glider and pilot have a total mass of 492 kg . During the acceleration the glider is subject to an average resistive force of 160 N . Determine the average tension in the cable as the glider accelerates.

[3]

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- (c) The cable is pulled by an electric motor. The motor has an overall efficiency of 23%. Determine the average power input to the motor.

[3]



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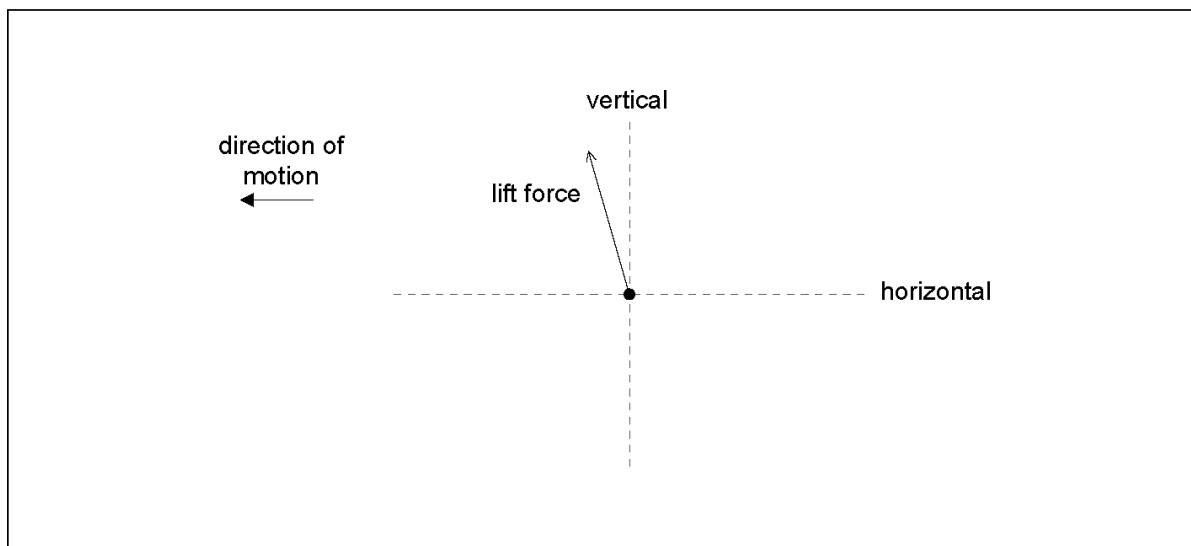
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- (d) After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider.



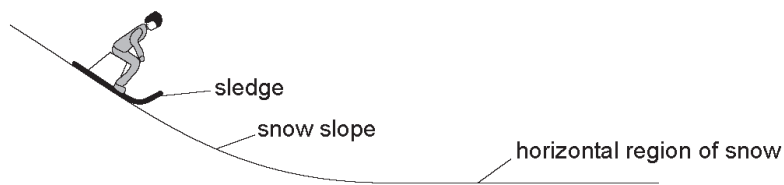
Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions.

[2]

3 – (PHYSI/20_HL_Winter_2017_Q1) – Mechanics



A girl on a sledge is moving down a snow slope at a uniform speed.



- (a) Draw the free-body diagram for the sledge at the position shown on the snow slope. [2]

- (b) After leaving the snow slope, the girl on the sledge moves over a horizontal region of snow. Explain, with reference to the physical origin of the forces, why the vertical forces on the girl must be in equilibrium as she moves over the horizontal region. [3]

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- (c) When the sledge is moving on the horizontal region of the snow, the girl jumps off the sledge. The girl has no horizontal velocity after the jump. The velocity of the sledge immediately after the girl jumps off is 4.2 m s^{-1} . The mass of the girl is 55 kg and the mass of the sledge is 5.5 kg . Calculate the speed of the sledge immediately before the girl jumps from it.

[2]



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- (d) The girl chooses to jump so that she lands on loosely-packed snow rather than frozen ice. Outline why she chooses to land on the snow.

[3]

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- (e) The sledge, without the girl on it, now travels up a snow slope that makes an angle of 6.5° to the horizontal. At the start of the slope, the speed of the sledge is 4.2 m s^{-1} . The coefficient of dynamic friction of the sledge on the snow is 0.11.



- (i) Show that the acceleration of the sledge is about -2 m s^{-2} .

[3]

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- (ii) Calculate the distance along the slope at which the sledge stops moving. Assume that the coefficient of dynamic friction is constant.

[2]

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- (f) The coefficient of static friction between the sledge and the snow is 0.14. Outline, with a calculation, the subsequent motion of the sledge.

[2]

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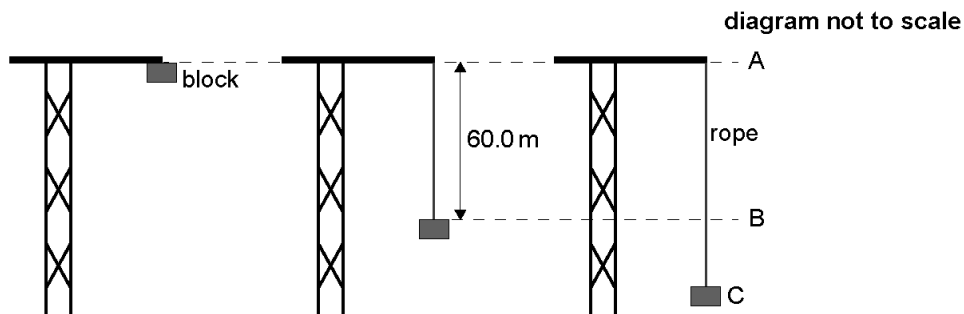
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4 – (PHYSI/21_HL_Summer_2018_Q1) – Mechanics



An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

- (a) At position B the rope starts to extend. Calculate the speed of the block at position B. [2]

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- (b) At position C the speed of the block reaches zero. The time taken for the block to fall between B and C is 0.759 s. The mass of the block is 80.0 kg.

- (i) Determine the magnitude of the average resultant force acting on the block between B and C. [2]

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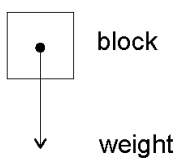
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- (ii) Sketch on the diagram the average resultant force acting on the block between B and C. The arrow on the diagram represents the weight of the block.

[2]



- (iii) Calculate the magnitude of the average force exerted by the rope on the block between B and C.

[2]

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(c) For the rope and block, describe the energy changes that take place

(i) between A and B.

[1]



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(ii) between B and C.

[1]

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(d) The length reached by the rope at C is 77.4m. Suggest how energy considerations could be used to determine the elastic constant of the rope.

[2]

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(e) In another test, the block hangs in equilibrium at the end of the same elastic rope. The elastic constant of the rope is 400 Nm^{-1} . The block is pulled 3.50 m vertically below the equilibrium position and is then released from rest.

(i) Calculate the time taken for the block to return to the equilibrium position for the first time.

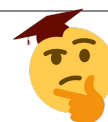
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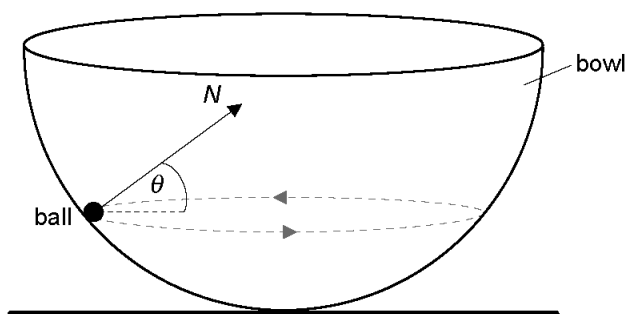
(ii) Calculate the speed of the block as it passes the equilibrium position.

[2]

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5 – (PHYSI/22_HL_Summer_2018_Q1) – *Mechanics, Circular Motion & Gravitation*

- (a) A small ball of mass m is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.



The normal reaction force N makes an angle θ to the horizontal.

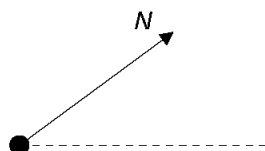
- (i) State the direction of the resultant force on the ball.

[1]

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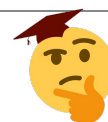
- (ii) On the diagram, construct an arrow of the correct length to represent the weight of the ball.

[2]



- (iii) Show that the magnitude of the net force F on the ball is given by the following equation.

[3]



$$F = \frac{mg}{\tan \theta}$$

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- (b) The radius of the bowl is 8.0 m and $\theta = 22^\circ$. Determine the speed of the ball.

[4]

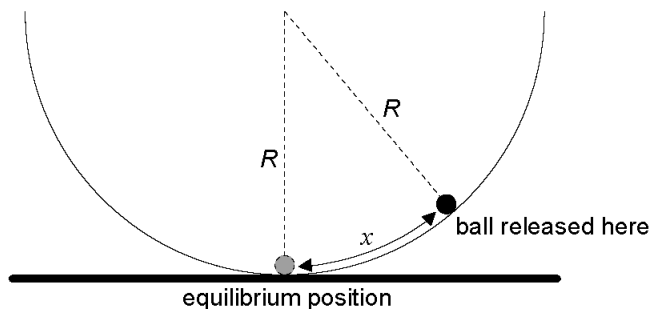
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- (c) Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl.

[2]

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- (d) The ball is now displaced through a small distance x from the bottom of the bowl and is then released from rest.



The magnitude of the force on the ball towards the equilibrium position is given by

$$\frac{mgx}{R}$$

where R is the radius of the bowl.

- (i) Outline why the ball will perform simple harmonic oscillations about the equilibrium position.

[1]

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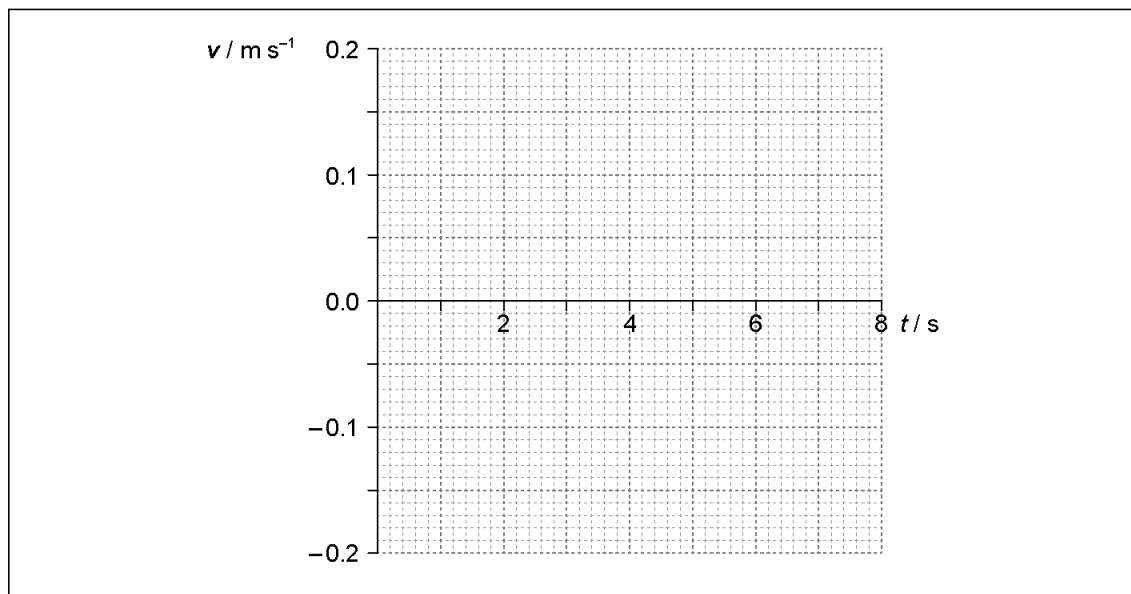
- (ii) Show that the period of oscillation of the ball is about 6 s.

[2]

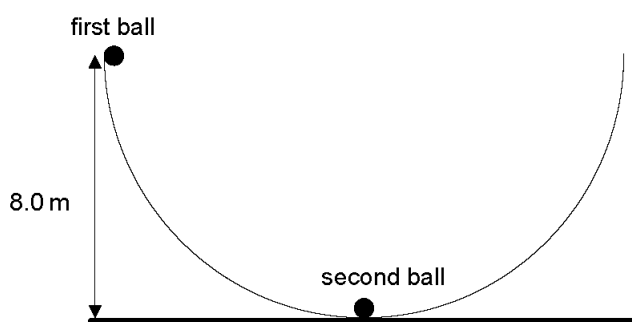
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- (iii) The amplitude of oscillation is 0.12 m. On the axes, draw a graph to show the variation with time t of the velocity v of the ball during one period.

[3]



- (e) A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m.



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Calculate, in m, the maximum height reached by the two balls.

[3]

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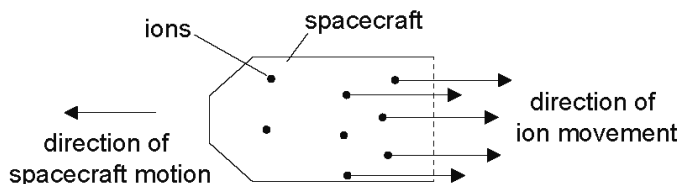
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6 - (PHYSI/20_HL_Winter_2018_Q1) - Mechanics



Ion-thrust engines can power spacecraft. In this type of engine, ions are created in a chamber and expelled from the spacecraft. The spacecraft is in outer space when the propulsion system is turned on. The spacecraft starts from rest.



The mass of ions ejected each second is $6.6 \times 10^{-6} \text{ kg}$ and the speed of each ion is $5.2 \times 10^4 \text{ m s}^{-1}$. The initial total mass of the spacecraft and its fuel is 740 kg. Assume that the ions travel away from the spacecraft parallel to its direction of motion.

(a) Determine the initial acceleration of the spacecraft.

[2]

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- (b) An initial mass of 60 kg of fuel is in the spacecraft for a journey to a planet. Half of the fuel will be required to slow down the spacecraft before arrival at the destination planet.



- (i) Estimate the maximum speed of the spacecraft.

[2]

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- (ii) Outline why the answer to (b)(i) is an estimate.

[1]

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- (iii) Outline why scientists sometimes use estimates in making calculations.

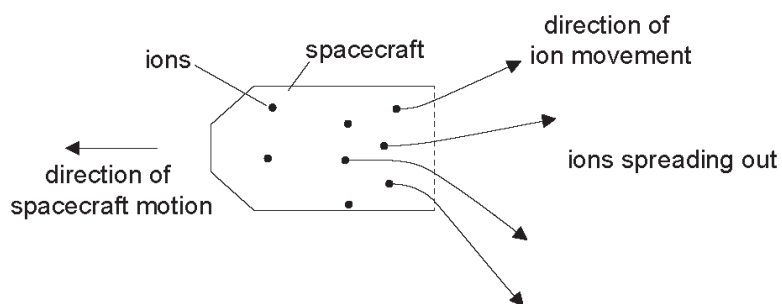
[1]

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- (c) In practice, the ions leave the spacecraft at a range of angles as shown.



- (i) Outline why the ions are likely to spread out.

[2]

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- (ii) Explain what effect, if any, this spreading of the ions has on the acceleration of the spacecraft.

[2]

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7 – (PHYSI/20_HL_Winter_2018_Q3) – Mechanics

(a) Define *impulse*.

[1]

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(b) A chicken's egg of mass 58 g is dropped onto grass from a height of 1.1 m.
Assume that air resistance is negligible and that the egg does not bounce or break.

(i) Show that the kinetic energy of the egg just before impact is about 0.6 J.

[1]

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(ii) The egg comes to rest in a time of 55 ms. Determine the magnitude of the
average decelerating force that the ground exerts on the egg.

[4]

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(iii) Explain why the egg is likely to break when dropped onto concrete from the
same height.

[2]

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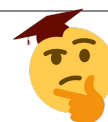
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8 – (PHYSI/21_HL_Summer_2019_Q1) – *Mechanics, Electricity & Magnetism*

A girl rides a bicycle that is powered by an electric motor. A battery transfers energy to the electric motor. The emf of the battery is 16 V and it can deliver a charge of 43 kC when discharging completely from a full charge.

- (a) The maximum speed of the girl on a horizontal road is 7.0 m s^{-1} with energy from the battery alone. The maximum distance that the girl can travel under these conditions is 20 km.

- (i) Show that the time taken for the battery to discharge is about $3 \times 10^3 \text{ s}$. [1]

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- (ii) Deduce that the average power output of the battery is about 240 W. [2]

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- (iii) Friction and air resistance act on the bicycle and the girl when they move. Assume that all the energy is transferred from the battery to the electric motor. Determine the total average resistive force that acts on the bicycle and the girl. [2]

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- (b) The bicycle and the girl have a total mass of 66 kg. The girl rides up a slope that is at an angle of 3.0° to the horizontal.



- (i) Calculate the component of weight for the bicycle and girl acting down the slope. [1]

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- (ii) The battery continues to give an output power of 240 W. Assume that the resistive forces are the same as in (a)(iii).

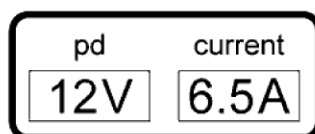
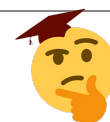
Calculate the maximum speed of the bicycle and the girl up the slope. [2]

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- (c) On another journey up the slope, the girl carries an additional mass. Explain whether carrying this mass will change the maximum distance that the bicycle can travel along the slope. [2]

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- (d) The bicycle has a meter that displays the current and the terminal potential difference (pd) for the battery when the motor is running. The diagram shows the meter readings at one instant. The emf of the cell is 16 V.



Determine the internal resistance of the battery.

[2]

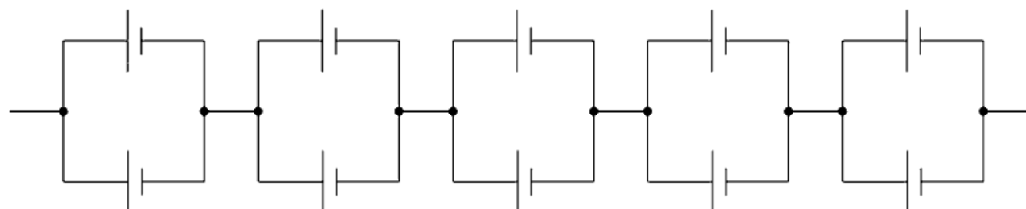
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- (e) The battery is made from an arrangement of 10 identical cells as shown.



Calculate

- (i) the emf of **one** cell.

[1]

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- (ii) the internal resistance of **one** cell.

[2]

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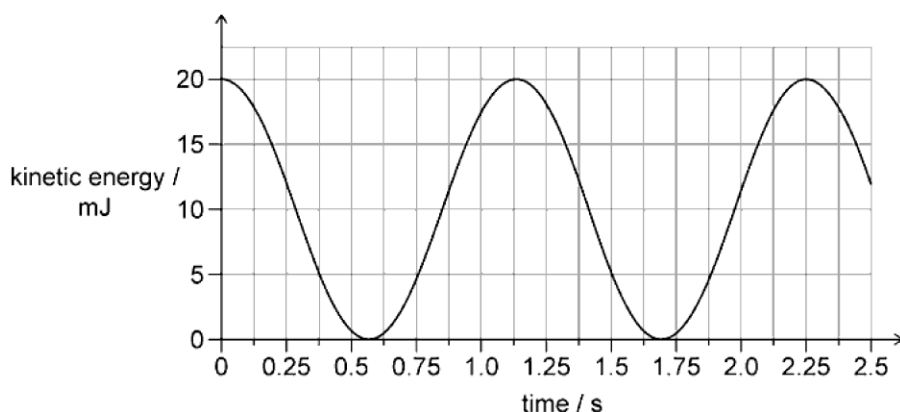
9 – (PHYSI/21_HL_Summer_2019_Q6) – Mechanics, Oscillations & Waves



A small metal pendulum bob is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible.

The pendulum begins to oscillate. Assume that the motion of the system is simple harmonic, and in one vertical plane.

The graph shows the variation of kinetic energy of the pendulum bob with time.



- (a) (i) Calculate, in m, the length of the thread. State your answer to an appropriate number of significant figures.

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- (ii) Label on the graph with the letter X a point where the speed of the pendulum is half that of its initial speed.

[1]

- (iii) The mass of the pendulum bob is 75g. Show that the maximum speed of the bob is about 0.7 ms^{-1} .

[2]

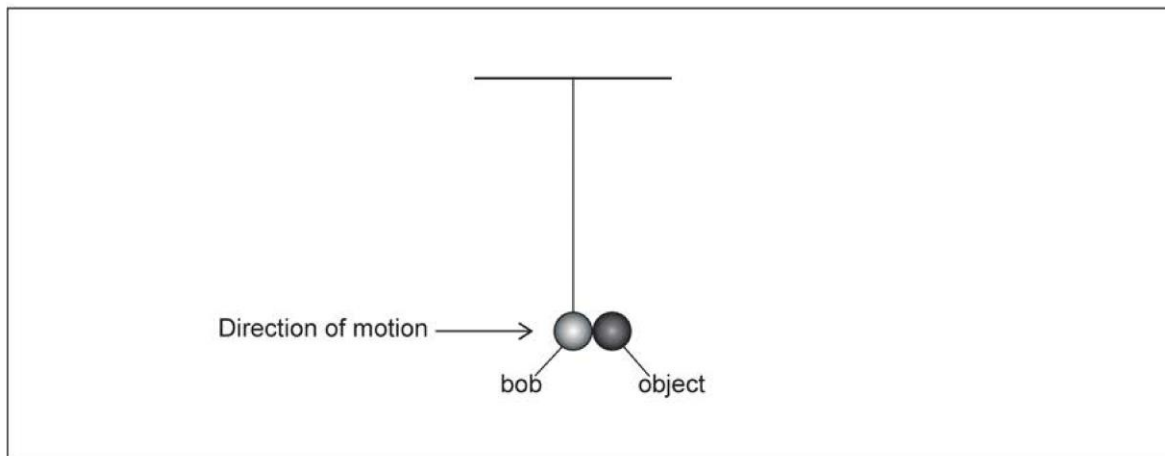
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- (b) When the 75 g bob is moving horizontally at 0.80 m s^{-1} , it collides with a small stationary object also of mass 75 g. The object and the bob stick together.



- (i) Calculate the speed of the combined masses immediately after the collision. [1]

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- (ii) Show that the collision is inelastic. [3]

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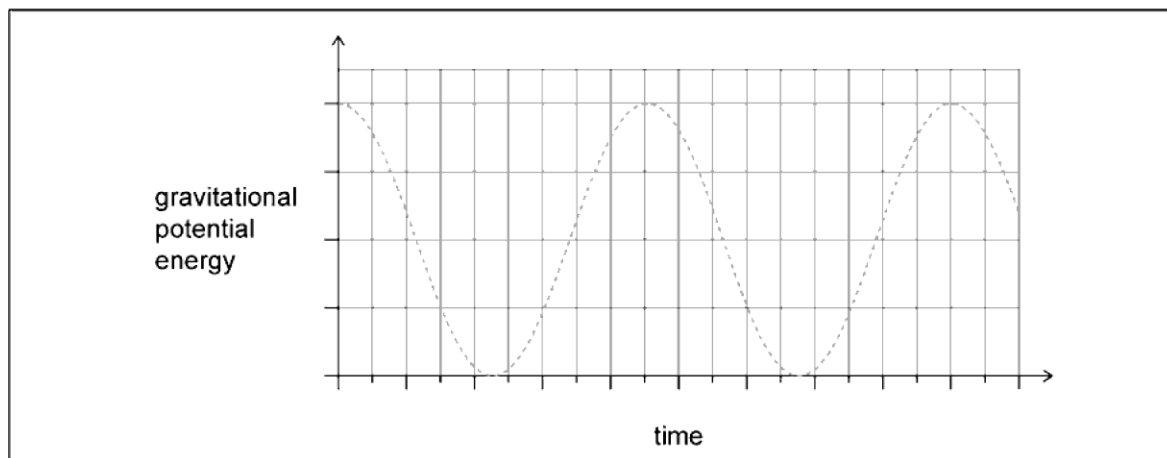
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- (iii) Sketch, on the axes, a graph to show the variation of gravitational potential energy with time for the bob and the object after the collision. The data from the graph used in (a) is shown as a dashed line for reference.

[2]



- (iv) The speed after the collision of the bob and the object was measured using a sensor. This sensor emits a sound of frequency f and this sound is reflected from the moving bob. The sound is then detected by the sensor as frequency f' .

Explain why f and f' are different.

[3]

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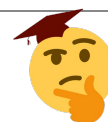
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10 – (PHYSI/22_HL_Summer_2019_Q1) – Mechanics



A student strikes a tennis ball that is initially at rest so that it leaves the racquet at a speed of 64 m s^{-1} . The ball has a mass of 0.058 kg and the contact between the ball and the racquet lasts for 25 ms .

(a) Calculate the

(i) average force exerted by the racquet on the ball.

[2]

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(ii) average power delivered to the ball during the impact.

[2]

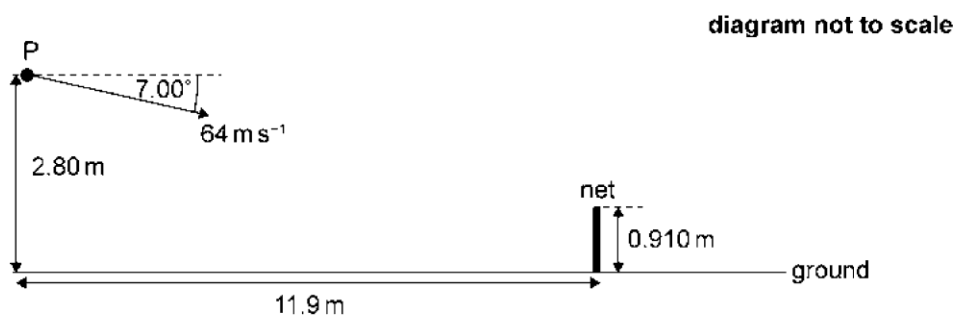
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(b) The student strikes the tennis ball at point P. The tennis ball is initially directed at an angle of 7.00° to the horizontal.



The following data are available.

Height of P	= 2.80 m
Distance of student from net	= 11.9 m
Height of net	= 0.910 m
Initial speed of tennis ball	= 64 m s^{-1}

(i) Calculate the time it takes the tennis ball to reach the net.

[2]



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(ii) Show that the tennis ball passes over the net.

[3]

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(iii) Determine the speed of the tennis ball as it strikes the ground.

[2]

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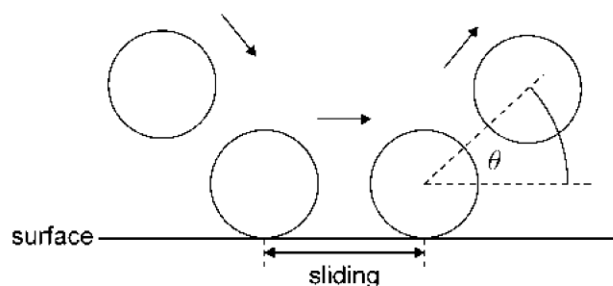
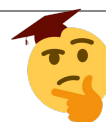
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- (c) The student models the bounce of the tennis ball to predict the angle θ at which the ball leaves a surface of clay and a surface of grass.



The model assumes

- during contact with the surface the ball slides.
- the sliding time is the same for both surfaces.
- the sliding frictional force is greater for clay than grass.
- the normal reaction force is the same for both surfaces.

Predict for the student's model, without calculation, whether θ is greater for a clay surface or for a grass surface.

[3]

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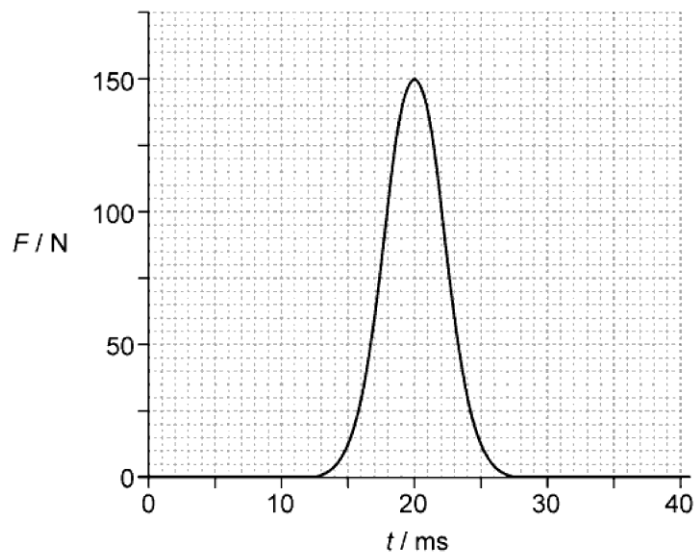
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11 – (PHYSI/20_HL_Winter_2019_Q1) – Mechanics



The graph shows the variation with time t of the horizontal force F exerted on a tennis ball by a racket.



The tennis ball was stationary at the instant when it was hit. The mass of the tennis ball is $5.8 \times 10^{-2} \text{ kg}$. The area under the curve is 0.84 N s.

(a) Calculate the speed of the ball as it leaves the racket.

[2]

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(b) Show that the average force exerted on the ball by the racket is about 50 N.

[2]

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- (c) Determine, with reference to the work done by the average force, the horizontal distance travelled by the ball while it was in contact with the racket.

[3]



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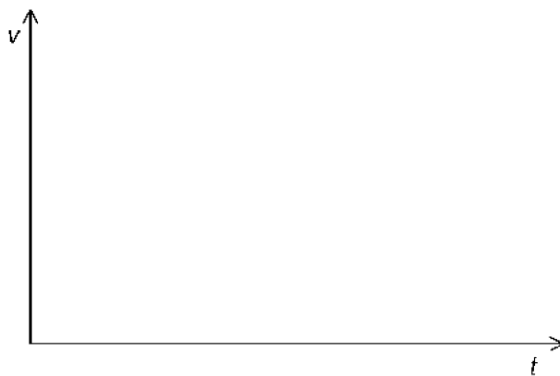
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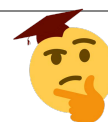
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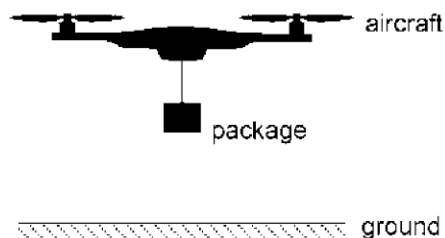
- (d) Draw a graph to show the variation with t of the horizontal speed v of the ball while it was in contact with the racket. Numbers are **not** required on the axes.

[2]



12 – (PHYSI/20_HL_Winter_2020_Q1) – *Mechanics*

A company delivers packages to customers using a small unmanned aircraft. Rotating horizontal blades exert a force on the surrounding air. The air above the aircraft is initially stationary.



The air is propelled vertically downwards with speed v . The aircraft hovers motionless above the ground. A package is suspended from the aircraft on a string. The mass of the aircraft is 0.95 kg and the combined mass of the package and string is 0.45 kg. The mass of air pushed downwards by the blades in one second is 1.7 kg.

- (a) (i) State the value of the resultant force on the aircraft when hovering. [1]

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- (ii) Outline, by reference to Newton's third law, how the upward lift force on the aircraft is achieved. [2]

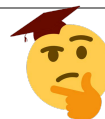
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- (iii) Determine v . State your answer to an appropriate number of significant figures. [3]

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(iv) Calculate the power transferred to the air by the aircraft.

[2]



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(b) The package and string are now released and fall to the ground. The lift force on the aircraft remains unchanged. Calculate the initial acceleration of the aircraft.

[2]

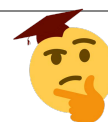
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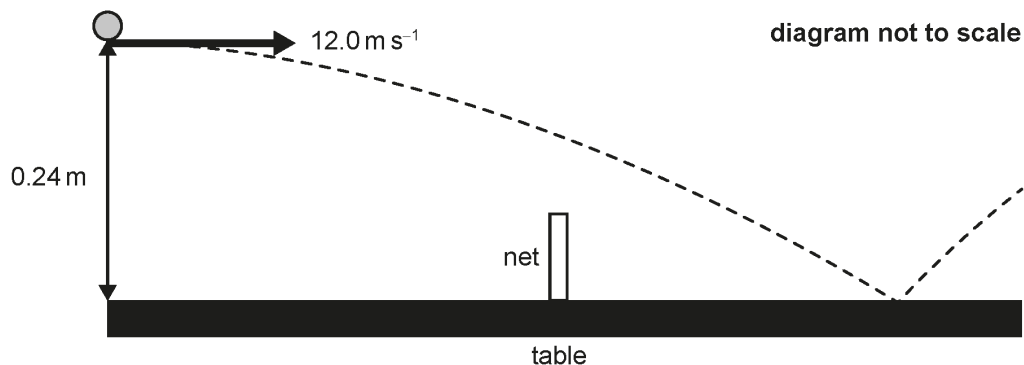
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13 – (PHYSI/21_HL_Summer_2021_Q1) – Mechanics



Two players are playing table tennis. Player A hits the ball at a height of 0.24 m above the edge of the table, measured from the top of the table to the bottom of the ball. The initial speed of the ball is 12.0 m s^{-1} horizontally. Assume that air resistance is negligible.

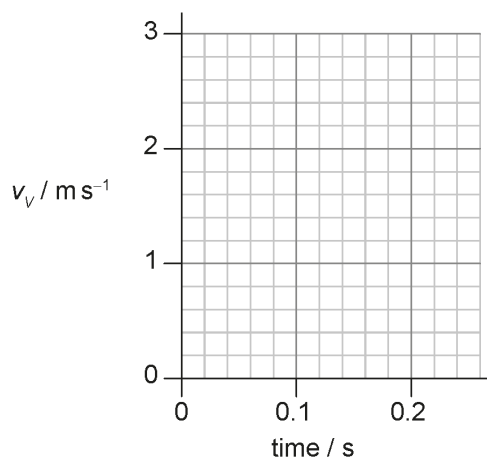


- (a) Show that the time taken for the ball to reach the surface of the table is about 0.2 s. [1]

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- (b) Sketch, on the axes, a graph showing the variation with time of the vertical component of velocity v_v of the ball until it reaches the table surface. Take g to be $+10 \text{ m s}^{-2}$. [2]



- (c) The net is stretched across the middle of the table. The table has a length of 2.74 m and the net has a height of 15.0 cm.



Show that the ball will go over the net.

[3]

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- (d) The ball bounces and then reaches a peak height of 0.18 m above the table with a horizontal speed of 10.5 m s^{-1} . The mass of the ball is 2.7 g.

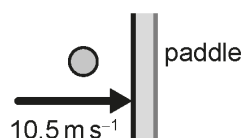
- (i) Determine the kinetic energy of the ball immediately after the bounce.

[2]

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- (ii) Player B intercepts the ball when it is at its peak height. Player B holds a paddle (racket) stationary and vertical. The ball is in contact with the paddle for 0.010 s. Assume the collision is elastic.



Calculate the average force exerted by the ball on the paddle. State your answer to an appropriate number of significant figures.

[3]

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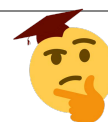
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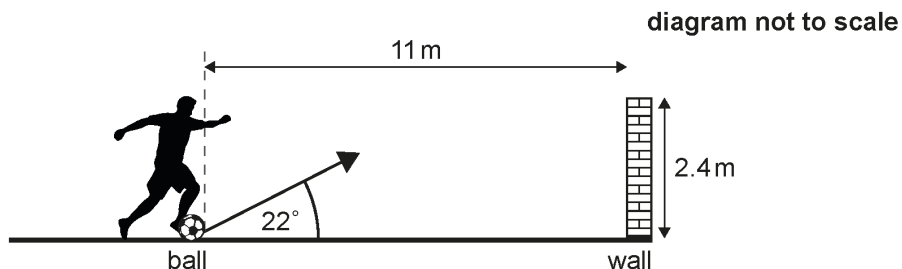
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14 – (PHYSI/22_HL_Summer_2021_Q1) – Mechanics



A football player kicks a stationary ball of mass 0.45 kg towards a wall. The initial speed of the ball after the kick is 19 m s^{-1} and the ball does not rotate. Air resistance is negligible and there is no wind.



- (a) The player's foot is in contact with the ball for 55 ms . Calculate the average force that acts on the ball due to the football player.

[2]

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- (b) (i) The ball leaves the ground at an angle of 22° . The horizontal distance from the initial position of the edge of the ball to the wall is 11 m . Calculate the time taken for the ball to reach the wall.

[2]

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- (ii) The top of the wall is 2.4 m above the ground. Deduce whether the ball will hit the wall.

[3]



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- (c) In practice, air resistance affects the ball. Outline the effect that air resistance has on the vertical acceleration of the ball. Take the direction of the acceleration due to gravity to be positive.

[2]

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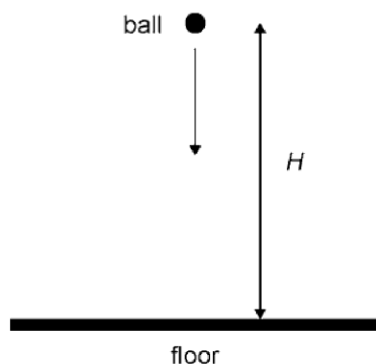
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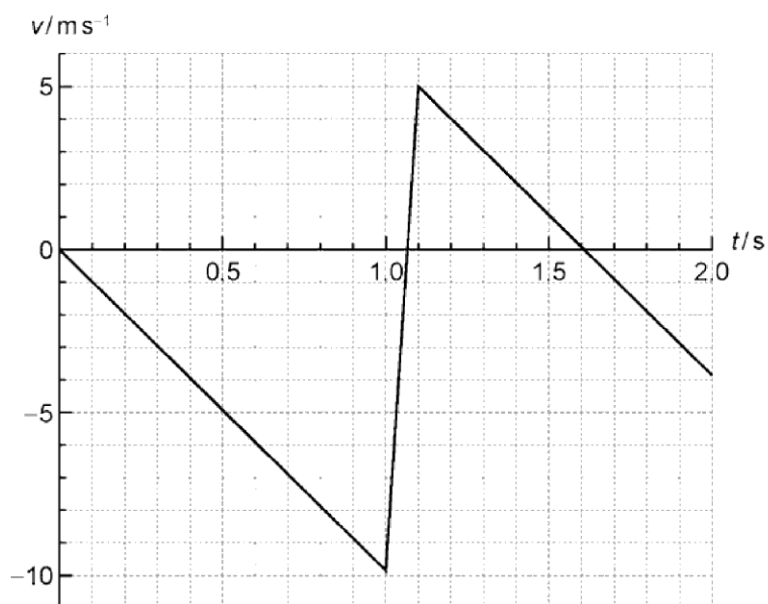
15 – (PHYSI/20_HL_Winter_2021_Q1) – Mechanics



A ball of mass 0.250 kg is released from rest at time $t = 0$, from a height H above a horizontal floor.

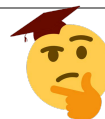


The graph shows the variation with time t of the velocity v of the ball. Air resistance is negligible. Take $g = -9.80\text{ m s}^{-2}$. The ball reaches the floor after 1.0 s .



(a) Determine H .

[1]



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(b) (i) Label the time and velocity graph, using the letter M, the point where the ball reaches the maximum rebound height.

[1]

(ii) State the acceleration of the ball at the maximum rebound height.

[1]

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(iii) Draw, on the axes, a graph to show the variation with time of the height of the ball from the instant it rebounds from the floor until the instant it reaches the maximum rebound height. No numbers are required on the axes.

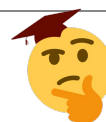
[1]

height ↑

time →

- (c) Estimate the loss in the mechanical energy of the ball as a result of the collision with the floor.

[1]



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- (d) (i) Determine the average force exerted on the floor by the ball.

[3]

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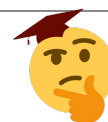
- (ii) Suggest why the momentum of the ball was not conserved during the collision with the floor.

[1]

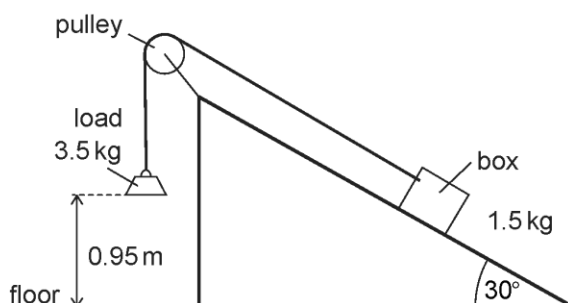
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16 – (PHYSI/21_HL_Summer_2022_Q1) – Mechanics



A student uses a load to pull a box up a ramp inclined at 30° . A string of constant length and negligible mass connects the box to the load that falls vertically. The string passes over a pulley that runs on a frictionless axle. Friction acts between the base of the box and the ramp. Air resistance is negligible.



The load has a mass of 3.5 kg and is initially 0.95 m above the floor. The mass of the box is 1.5 kg.

The load is released and accelerates downwards.

- (a) Outline **two** differences between the momentum of the box and the momentum of the load at the same instant.

[2]

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- (b) The vertical acceleration of the load downwards is 2.4 m s^{-2} .

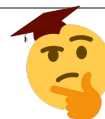
Calculate the tension in the string.

[2]

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- (c) Show that the speed of the load when it hits the floor is about 2.1 ms^{-1} .

[2]



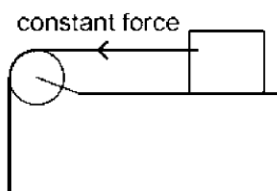
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- (d) After the load has hit the floor, the box travels a further 0.35 m along the ramp before coming to rest. Determine the average frictional force between the box and the surface of the ramp.

[4]

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- (e) The student then makes the ramp horizontal and applies a constant horizontal force to the box. The force is just large enough to start the box moving. The force continues to be applied after the box begins to move.



Explain, with reference to the frictional force acting, why the box accelerates once it has started to move.

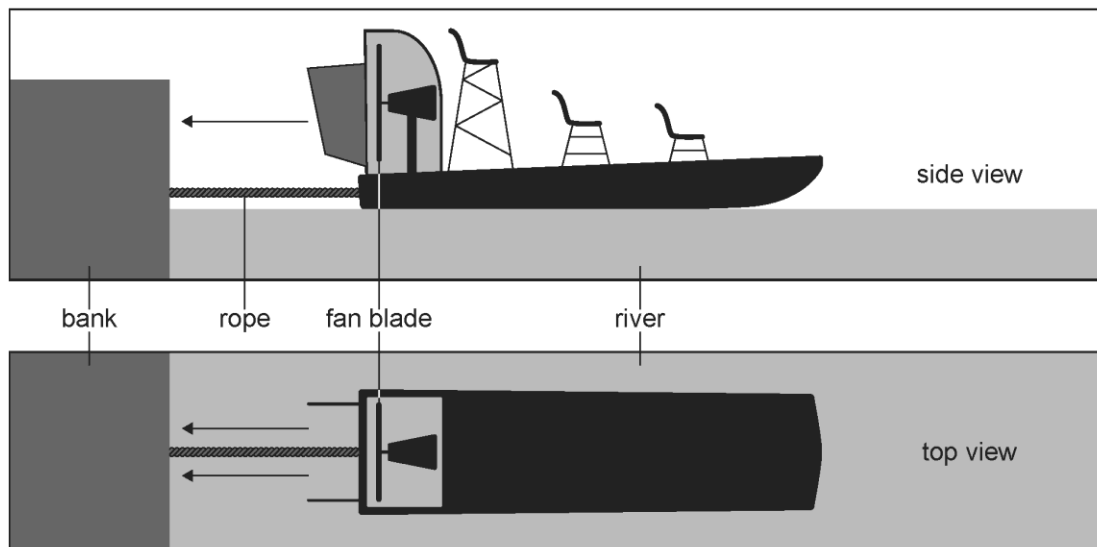
[3]

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17 – (PHYSI/22_HL_Summer_2022_Q1) – Mechanics



Airboats are used for transport across a river. To move the boat forward, air is propelled from the back of the boat by a fan blade.



An airboat has a fan blade of radius 1.8 m . This fan can propel air with a maximum speed relative to the boat of 20 m s^{-1} . The density of air is 1.2 kg m^{-3} .

(a) Outline why a force acts on the airboat due to the fan blade.

[3]

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- (b) In a test the airboat is tied to the river bank with a rope normal to the bank. The fan propels the air at its maximum speed. There is no wind.



- (i) Show that a mass of about 240 kg of air moves through the fan every second.

[2]

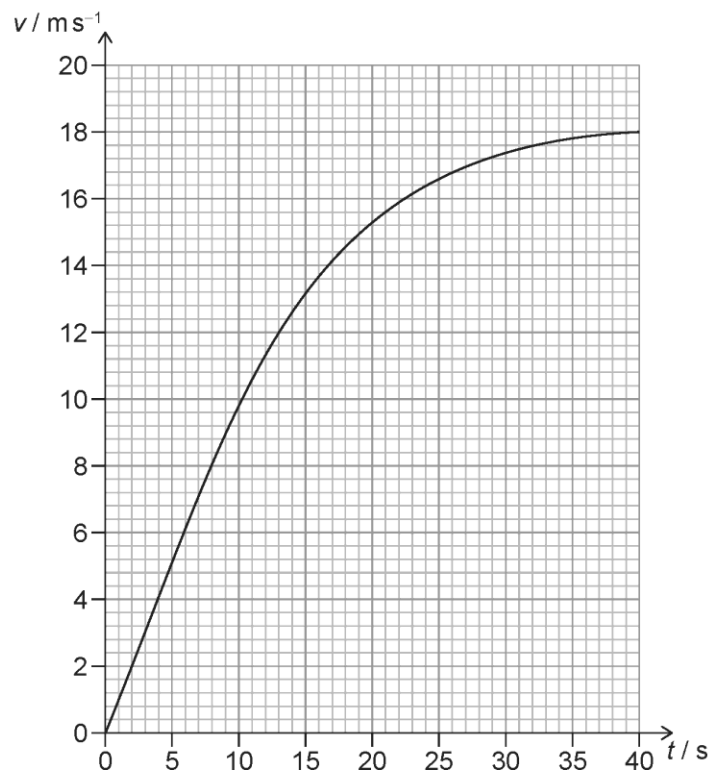
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- (ii) Show that the tension in the rope is about 5 kN.

[1]

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- (c) The rope is untied and the airboat moves away from the bank. The variation with time t of the speed v of the airboat is shown for the motion.



(i) Explain why the airboat has a maximum speed under these conditions.

[2]



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(ii) Estimate the distance the airboat travels to reach its maximum speed.

[2]

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(iii) Deduce the mass of the airboat.

[3]

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18 – (PHYSI/20_HL_Winter_2022_Q1) – *Mechanics*

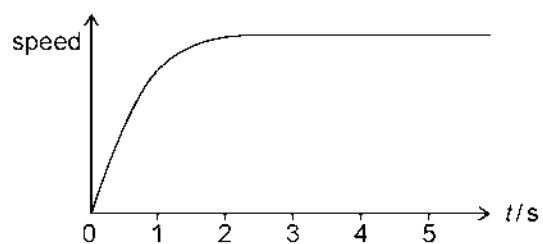
A raindrop falls vertically from rest.

(a) State the initial acceleration of the raindrop.

[1]

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The graph shows how the speed of the raindrop varies with time t .

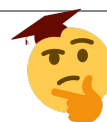


(b) Explain, by reference to the vertical forces, how the raindrop reaches a constant speed.

[3]

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- (c) During the first 3.0 s of motion, the raindrop falls a distance of 21 m and reaches a speed of 9.0 m s^{-1} . The mass of the raindrop is 34 mg. The temperature of the raindrop does not change.



- (i) Determine the energy transferred to the air during the first 3.0 s of motion. State your answer to an appropriate number of significant figures.

[3]

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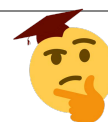
- (ii) Describe the energy change that takes place for $t > 3.0 \text{ s}$.

[1]

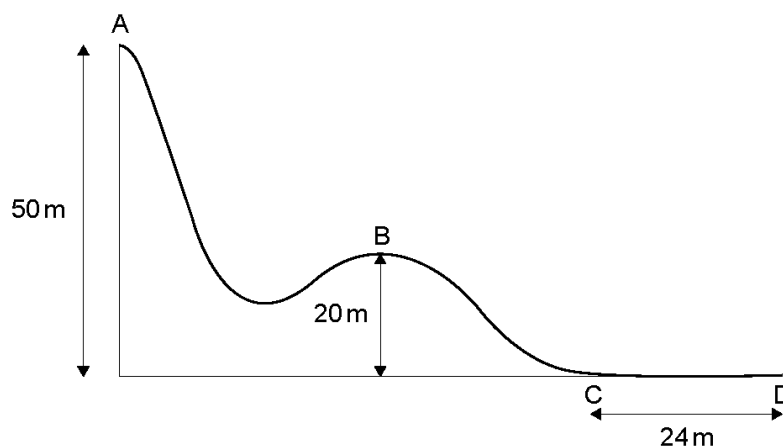
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1 - (PHYSI/21_HL_Summer_2017_Q1) - Mechanics, Thermal Physics



The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



- (a) A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

- (i) From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 ms^{-1} .

[2]

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- (ii) Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature.

[2]

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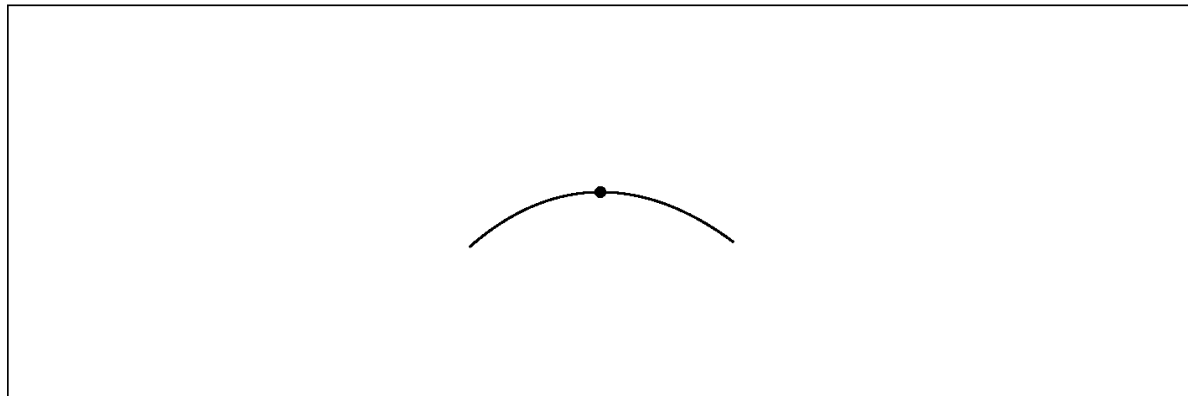
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- (b) (i) The dot on the following diagram represents the skier as she passes point B. Draw and label the vertical forces acting on the skier.

[2]



- (ii) The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B.

[3]

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- (c) The skier reaches point C with a speed of 8.2 ms^{-1} . She stops after a distance of 24 m at point D.

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

[3]

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- (d) At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 ms^{-1} .



- (i) Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer.

[2]

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- (ii) Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier.

[2]

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2 - (PHYSI/21_HL_Summer_2017_Q4) - *Electricity & Magnetism, Thermal Physics*

A heater in an electric shower has a power of 8.5 kW when connected to a 240 V electrical supply. It is connected to the electrical supply by a copper cable.

The following data are available:

Length of cable = 10 m
Cross-sectional area of cable = 6.0 mm^2
Resistivity of copper = $1.7 \times 10^{-8} \Omega \text{ m}$

(a) (i) Calculate the current in the copper cable. [1]

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(ii) Calculate the resistance of the cable. [2]

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(iii) Calculate the power dissipated in the cable. [1]

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- (b) Explain, in terms of electrons, what happens to the resistance of the cable as the temperature of the cable increases.

[3]



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- (c) The heater changes the temperature of the water by 35 K. The specific heat capacity of water is $4200 \text{ J kg}^{-1} \text{ K}^{-1}$.

Determine the rate at which water flows through the shower. State an appropriate unit for your answer.

[4]

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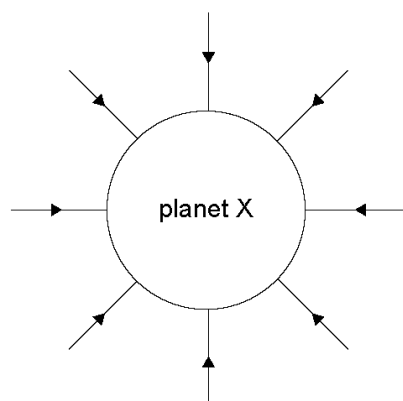
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3 – (PHYSI/21_HL_Summer_2017_Q6) – *Fields (ahl), Thermal Physics*



The diagram shows the gravitational field lines of planet X.

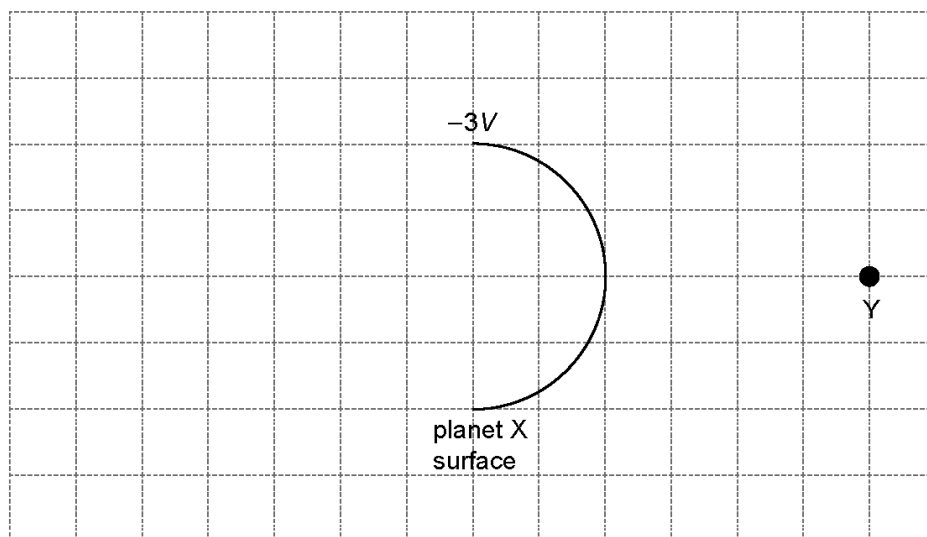


- (a) Outline how this diagram shows that the gravitational field strength of planet X decreases with distance from the surface.

[1]

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- (b) The diagram shows part of the surface of planet X. The gravitational potential at the surface of planet X is $-3V$ and the gravitational potential at point Y is $-V$.



Sketch on the grid the equipotential surface corresponding to a gravitational potential of $-2V$.

[2]

- (c) A meteorite, very far from planet X begins to fall to the surface with a negligibly small initial speed. The mass of planet X is 3.1×10^{21} kg and its radius is 1.2×10^6 m. The planet has no atmosphere. Calculate the speed at which the meteorite will hit the surface.

[3]



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- (d) At the instant of impact the meteorite which is made of ice has a temperature of 0°C . Assume that all the kinetic energy at impact gets transferred into internal energy in the meteorite. Calculate the percentage of the meteorite's mass that melts. The specific latent heat of fusion of ice is $3.3 \times 10^5 \text{ J kg}^{-1}$.

[2]

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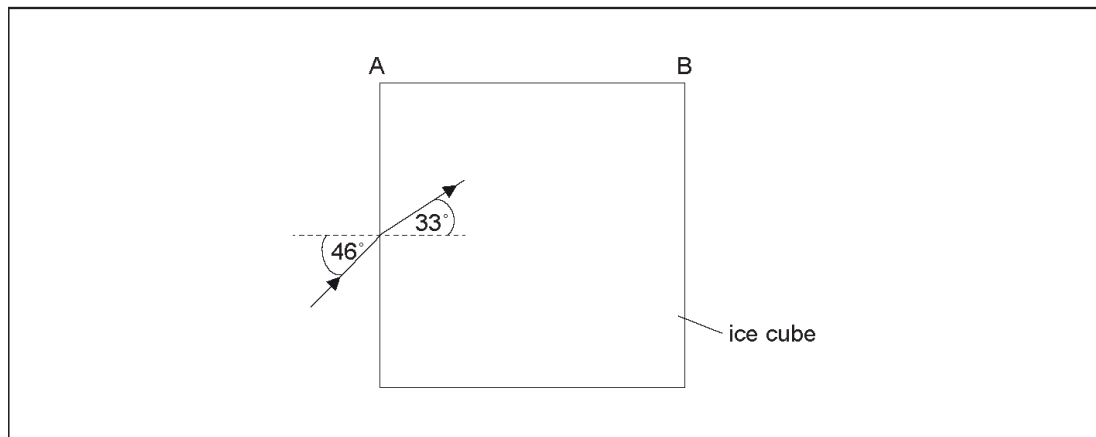
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4 - (PHYSI/20_HL_Winter_2017_Q5) - Thermal Physics, Oscillations & Waves



- (a) A large cube is formed from ice. A light ray is incident from a vacuum at an angle of 46° to the normal on one surface of the cube. The light ray is parallel to the plane of one of the sides of the cube. The angle of refraction inside the cube is 33° .



- (i) Calculate the speed of light inside the ice cube. [2]

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- (ii) Show that no light emerges from side AB. [3]

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- (iii) Sketch, on the diagram, the subsequent path of the light ray. [2]

- (b) Each side of the ice cube is 0.75 m in length. The initial temperature of the ice cube is -20°C .



- (i) Determine the energy required to melt all of the ice from -20°C to water at a temperature of 0°C .

[4]

Specific latent heat of fusion of ice = 330 kJ kg^{-1}
Specific heat capacity of ice = $2.1\text{ kJ kg}^{-1}\text{ K}^{-1}$
Density of ice = 920 kg m^{-3}

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- (ii) Outline the difference between the molecular structure of a solid and a liquid.

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5 - (PHYSI/21_HL_Summer_2018_Q2) - *Thermal Physics*

A closed box of fixed volume 0.15 m^3 contains 3.0 mol of an ideal monatomic gas.
The temperature of the gas is 290 K

- (a) Calculate the pressure of the gas. [1]

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- (b) When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K .
The specific heat capacity of the gas is $3.1\text{ kJ kg}^{-1}\text{ K}^{-1}$

- (i) Calculate, in kg , the mass of the gas. [1]

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- (ii) Determine, in kJ , the total kinetic energy of the particles of the gas. [3]

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- (c) Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure. [3]

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6 – (PHYSI/22_HL_Summer_2018_Q2) – *Thermal Physics*

- (a) An ideal monatomic gas is kept in a container of volume $2.1 \times 10^{-4} \text{ m}^3$, temperature 310 K and pressure $5.3 \times 10^5 \text{ Pa}$.

(i) State what is meant by an ideal gas. [1]

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(ii) Calculate the number of atoms in the gas. [1]

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(iii) Calculate, in J, the internal energy of the gas. [2]

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- (b) The volume of the gas in (a) is increased to $6.8 \times 10^{-4} \text{ m}^3$ at constant temperature.

(i) Calculate, in Pa, the new pressure of the gas. [1]

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(ii) Explain, in terms of molecular motion, this change in pressure. [2]

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7 - (PHYSI/20_HL_Winter_2018_Q9) - Thermal Physics



Liquid oxygen at its boiling point is stored in an insulated tank. Gaseous oxygen is produced from the tank when required using an electrical heater placed in the liquid.

The following data are available.

Mass of 1.0 mol of oxygen = 32 g
Specific latent heat of vaporization of oxygen = $2.1 \times 10^5 \text{ J kg}^{-1}$

- (a) Distinguish between the internal energy of the oxygen at the boiling point when it is in its liquid phase and when it is in its gas phase. [2]

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- (b) An oxygen flow rate of 0.25 mol s^{-1} is needed.

- (i) Calculate, in kW, the heater power required. [2]

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- (ii) Calculate the volume of the oxygen produced in one second when it is allowed to expand to a pressure of 0.11 MPa and to reach a temperature of -13°C . [2]

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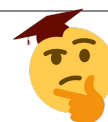
- (c) State **one** assumption of the kinetic model of an ideal gas that does not apply to oxygen.

[1]

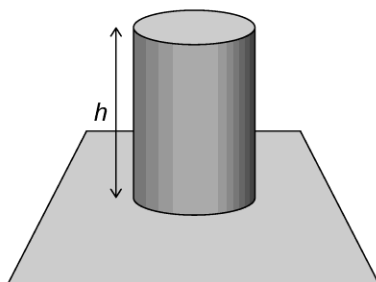


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8 - (PHYSI/21_HL_Summer_2019_Q4) - Thermal Physics



A solid cylinder of height h and density ρ rests on a flat surface.



- (a) Show that the pressure p_c exerted by the cylinder on the surface is given by $p_c = \rho gh$. [2]

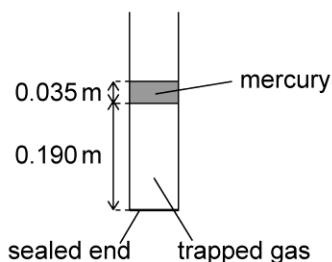
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- (b) A tube of constant circular cross-section, sealed at one end, contains an ideal gas trapped by a cylinder of mercury of length 0.035 m. The whole arrangement is in the Earth's atmosphere. The density of mercury is $1.36 \times 10^4 \text{ kg m}^{-3}$.



When the mercury is above the gas column the length of the gas column is 0.190 m.

- (i) Show that $(p_o + p_m) \times 0.190 = \frac{nRT}{A}$ where

p_o = atmospheric pressure

p_m = pressure due to the mercury column

T = temperature of the trapped gas

n = number of moles of the trapped gas

A = cross-sectional area of the tube.

[2]

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- (ii) The tube is slowly rotated until the gas column is above the mercury.

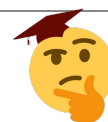
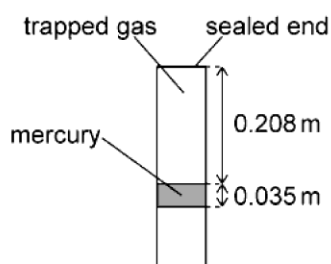


diagram not to scale



The length of the gas column is now 0.208 m. The temperature of the trapped gas does not change during the process.

Determine the atmospheric pressure. Give a suitable unit for your answer.

[4]

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- (iii) Outline why the gas particles in the tube hit the mercury surface less often after the tube has been rotated.

[1]

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9 – (PHYSI/22_HL_Summer_2019_Q2) – Thermal Physics



A container of volume $3.2 \times 10^{-6} \text{ m}^3$ is filled with helium gas at a pressure of $5.1 \times 10^5 \text{ Pa}$ and temperature 320 K. Assume that this sample of helium gas behaves as an ideal gas.

- (a) The mass of a helium atom is $6.6 \times 10^{-27} \text{ kg}$. Estimate the average speed of the helium atoms in the container.

[2]

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- (b) Show that the number of helium atoms in the container is 4×10^{20} .

[2]

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- (c) A helium atom has a volume of $4.9 \times 10^{-34} \text{ m}^3$.

- (i) Calculate the ratio $\frac{\text{volume of helium atoms}}{\text{volume of helium gas}}$.

[1]

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- (ii) Discuss, by reference to the kinetic model of an ideal gas and the answer to (c)(i), whether the assumption that helium behaves as an ideal gas is justified.

[2]

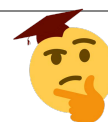
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10 – (PHYSI/20_HL_Winter_2019_Q2) – Thermal Physics



The air in a kitchen has pressure $1.0 \times 10^5 \text{ Pa}$ and temperature 22°C . A refrigerator of internal volume 0.36 m^3 is installed in the kitchen.

- (a) With the door open the air in the refrigerator is initially at the same temperature and pressure as the air in the kitchen. Calculate the number of molecules of air in the refrigerator.

[2]

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- (b) The refrigerator door is closed. The air in the refrigerator is cooled to 5.0°C and the number of air molecules in the refrigerator stays the same.

- (i) Determine the pressure of the air inside the refrigerator.

[2]

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- (ii) The door of the refrigerator has an area of 0.72 m^2 . Show that the minimum force needed to open the refrigerator door is about 4 kN .

[2]

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- (iii) Comment on the magnitude of the force in (b)(ii).

[2]

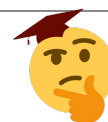
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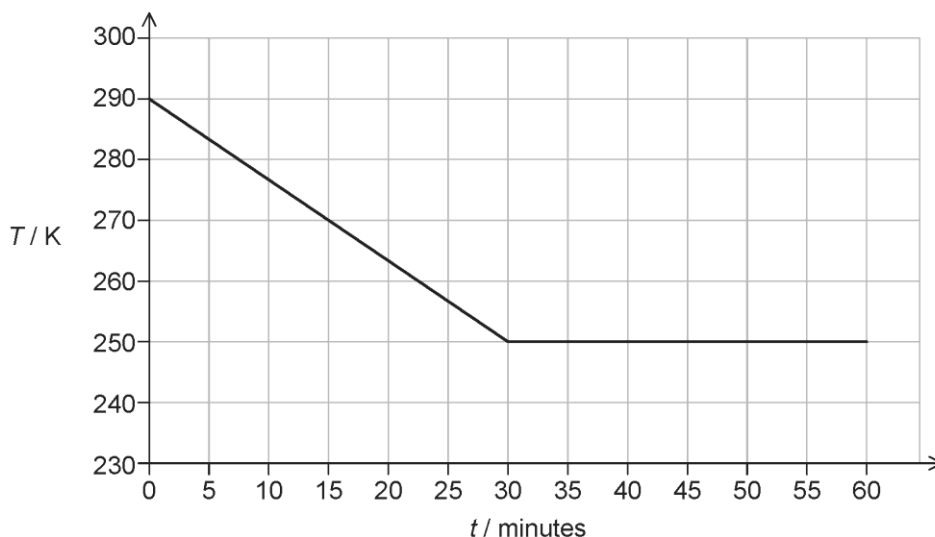
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11 – (PHYSI/20_HL_Winter_2020_Q3) – Thermal Physics



A sample of vegetable oil, initially in the liquid state, is placed in a freezer that transfers thermal energy from the sample at a constant rate. The graph shows how temperature T of the sample varies with time t .



The following data are available.

Mass of the sample = 0.32 kg

Specific latent heat of fusion of the oil = 130 kJ kg^{-1}

Rate of thermal energy transfer = 15 W

- (a) (i) Calculate the thermal energy transferred from the sample during the first 30 minutes.

[1]

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- (ii) Estimate the specific heat capacity of the oil in its liquid phase. State an appropriate unit for your answer.

[2]

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- (b) The sample begins to freeze during the thermal energy transfer. Explain, in terms of the molecular model of matter, why the temperature of the sample remains constant during freezing.

[3]



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- (c) Calculate the mass of the oil that remains unfrozen after 60 minutes.

[2]

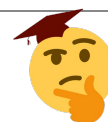
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12 – (PHYSI/21_HL_Summer_2021_Q3) – Thermal Physics, Electricity & Magnetism



A mass of 1.0 kg of water is brought to its boiling point of 100°C using an electric heater of power 1.6 kW.

- (a) (i) The molar mass of water is 18 g mol^{-1} . Estimate the average speed of the water molecules in the vapor produced. Assume the vapor behaves as an ideal gas. [2]

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- (ii) State **one** assumption of the kinetic model of an ideal gas. [1]

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- (b) A mass of 0.86 kg of water remains after it has boiled for 200 s.

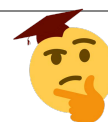
- (i) Estimate the specific latent heat of vaporization of water. State an appropriate unit for your answer. [2]

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- (ii) Explain why the temperature of water remains at 100°C during this time. [1]

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- (c) The heater is removed and a mass of 0.30 kg of pasta at -10°C is added to the boiling water.



Determine the equilibrium temperature of the pasta and water after the pasta is added. Other heat transfers are negligible.

Specific heat capacity of pasta = $1.8 \text{ kJ kg}^{-1} \text{ K}^{-1}$

Specific heat capacity of water = $4.2 \text{ kJ kg}^{-1} \text{ K}^{-1}$

[3]

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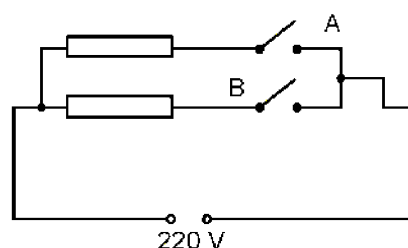
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- (d) The electric heater has two identical resistors connected in parallel.



The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

- (i) Show that each resistor has a resistance of about 30Ω .

[1]

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- (ii) Calculate the power transferred by the heater when both switches are closed.

[2]

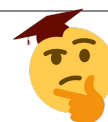
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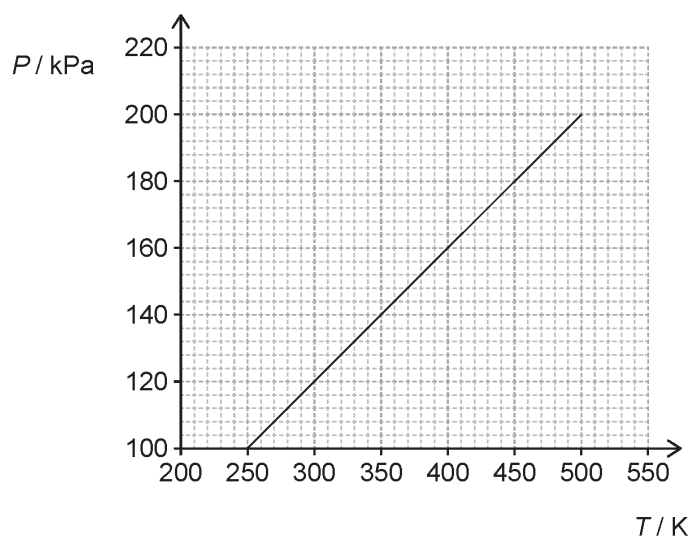
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13 – (PHYSI/22_HL_Summer_2021_Q2) – Thermal Physics



The graph shows the variation with temperature T of the pressure P of a fixed mass of helium gas trapped in a container with a fixed volume of $1.0 \times 10^{-3} \text{ m}^3$.



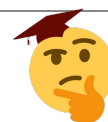
- (a) Deduce whether helium behaves as an ideal gas over the temperature range 250 K to 500 K. [2]

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- (b) Helium has a molar mass of 4.0 g. Calculate the mass of gas in the container. [2]

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- (c) A second container, of the same volume as the original container, contains twice as many helium atoms. The graph of the variation of P with T is determined for the gas in the second container.



Predict how the graph for the second container will differ from the graph for the first container.

[2]

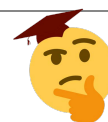
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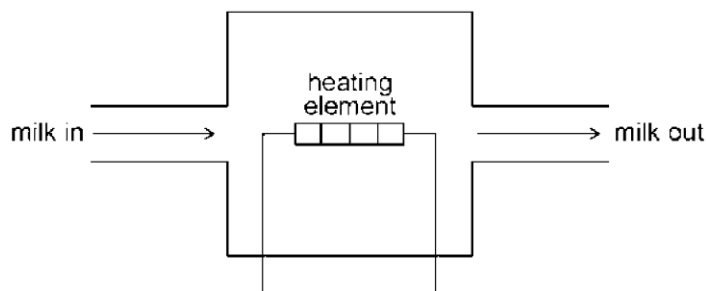
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14 – (PHYSI/21_HL_Summer_2022_Q2) – Thermal Physics



Cold milk enters a small sterilizing unit and flows over an electrical heating element.



The temperature of the milk is raised from 11°C to 84°C . A mass of 55 g of milk enters the sterilizing unit every second.

Specific heat capacity of milk = $3.9\text{ kJ kg}^{-1}\text{ K}^{-1}$

- (a) Estimate the power input to the heating element. State an appropriate unit for your answer.

[2]

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- (b) Outline whether your answer to (a) is likely to overestimate or underestimate the power input.

[2]

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- (c) Discuss, with reference to the molecules in the liquid, the difference between milk at 11°C and milk at 84°C .

[2]

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- (d) The milk flows out through an insulated metal pipe. The pipe is at a temperature of 84°C . A small section of the insulation has been removed from around the pipe.

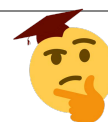
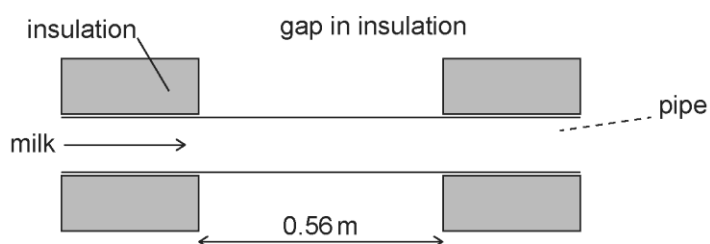


diagram not to scale



- (i) State how energy is transferred from the inside of the metal pipe to the outside of the metal pipe.

[1]

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- (ii) The missing section of insulation is 0.56 m long and the external radius of the pipe is 0.067 m . The emissivity of the pipe surface is 0.40 . Determine the energy lost every second from the pipe surface. Ignore any absorption of radiation by the pipe surface.

[3]

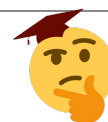
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- (iii) Describe **one** other method by which significant amounts of energy can be transferred from the pipe to the surroundings.

[2]

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15 – (PHYSI/22_HL_Summer_2022_Q2) – Thermal Physics



A fixed mass of an ideal gas is contained in a cylinder closed with a frictionless piston. The volume of the gas is $2.5 \times 10^{-3} \text{ m}^3$ when the temperature of the gas is 37°C and the pressure of the gas is $4.0 \times 10^5 \text{ Pa}$.

- (a) Calculate the number of gas particles in the cylinder. [2]

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- (b) Energy is now supplied to the gas and the piston moves to allow the gas to expand. The temperature is held constant.

Discuss, for this process, the changes that occur in the

- (i) density of the gas. [2]

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- (ii) internal energy of the gas. [2]

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16 – (PHYSI/20_HL_Winter_2022_Q2) – Thermal Physics



A solar heating panel is placed on the roof of a house in order to heat water in a storage tank. The rest of the roof is covered with tiles.

- (a) On a certain day, the intensity of the solar radiation that is incident perpendicular to the surface of the panel is 680 W m^{-2} .

The following data are available.

Mass of the water in the tank – 250 kg

Initial temperature of the water in the tank = 15°C

Specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$

Overall efficiency of the heating system = 0.30

Albedo of the roof tiles = 0.20

Emissivity of the roof tiles = 0.97

- (i) Determine the minimum area of the solar heating panel required to increase the temperature of all the water in the tank to 30°C during a time of 1.0 hour. [3]

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- (ii) Estimate, in $^\circ\text{C}$, the temperature of the roof tiles. [3]

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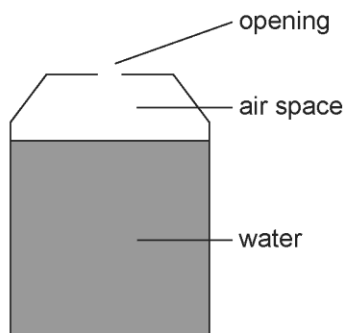
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- (b) There is an air space above the water in the storage tank with an opening to the atmosphere. Assume that air behaves like an ideal gas.



- (i) State **one** way in which a real gas differs from an ideal gas.

[1]

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The air space is always at constant atmospheric pressure and constant volume, as the water level is kept constant. The air-space temperature and water temperature are the same.

- (ii) The water is heated. Explain why the quantity of air in the storage tank decreases.

[2]

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- (c) Another method of harnessing solar energy involves the use of photovoltaic cells.

Outline **one** advantage of the output of a photovoltaic cell compared to the output of a solar heating panel.

[2]

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1 - (PHYSI/21_HL_Summer_2017_Q2) - Oscillations & Waves, Wave Phenomena (ahl)



- (a) Outline what is meant by the principle of superposition of waves.

[2]

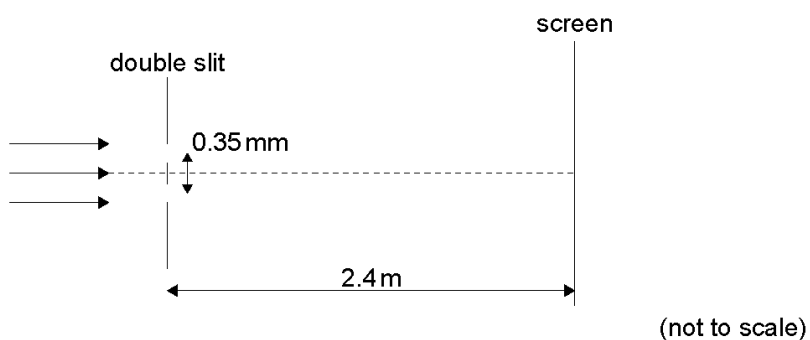
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- (b) Red laser light is incident on a double slit with a slit separation of 0.35 mm. A double-slit interference pattern is observed on a screen 2.4 m from the slits. The distance between successive maxima on the screen is 4.7 mm.



Calculate the wavelength of the light. Give your answer to an appropriate number of significant figures.

[3]

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- (c) Explain the change to the appearance of the interference pattern when the red-light laser is replaced by one that emits green light.

[2]



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- (d) One of the slits is now covered.

Describe the appearance of the pattern on the screen.

[2]

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2 - (PHYSI/21_HL_Summer_2017_Q7) - Oscillations & Waves, Measurements & Uncertainties

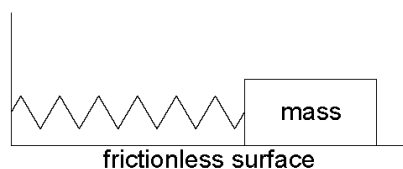


A student is investigating a method to measure the mass of a wooden block by timing the period of its oscillations on a spring.

- (a) Describe the conditions required for an object to perform simple harmonic motion (SHM). [2]

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- (b) A 0.52 kg mass performs simple harmonic motion with a period of 0.86 s when attached to the spring. A wooden block attached to the same spring oscillates with a period of 0.74 s.



Calculate the mass of the wooden block.

[2]

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- (c) In carrying out the experiment the student displaced the block horizontally by 4.8 cm from the equilibrium position. Determine the total energy in the oscillation of the wooden block.

[3]

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- (d) A second identical spring is placed in parallel and the experiment in (b) is repeated. Suggest how this change affects the fractional uncertainty in the mass of the block.

[3]



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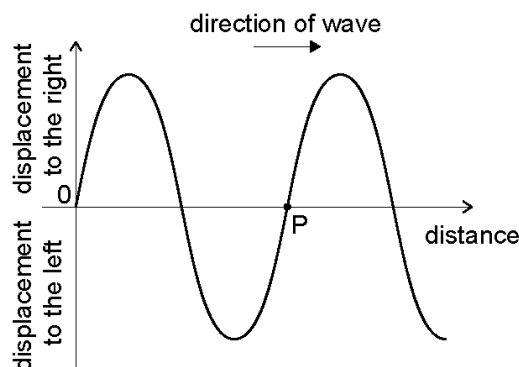
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- (e) With the block stationary a longitudinal wave is made to travel through the original spring from left to right. The diagram shows the variation with distance x of the displacement y of the coils of the spring at an instant of time.



A point on the graph has been labelled that represents a point P on the spring.

- (i) State the direction of motion of P on the spring.

[1]

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- (ii) Explain whether P is at the centre of a compression or the centre of a rarefaction.

[2]

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3 - (PHYSI/22_HL_Summer_2017_Q2) - Oscillations & Waves, Energy Production



- (a) Outline the conditions necessary for simple harmonic motion (SHM) to occur.

[2]

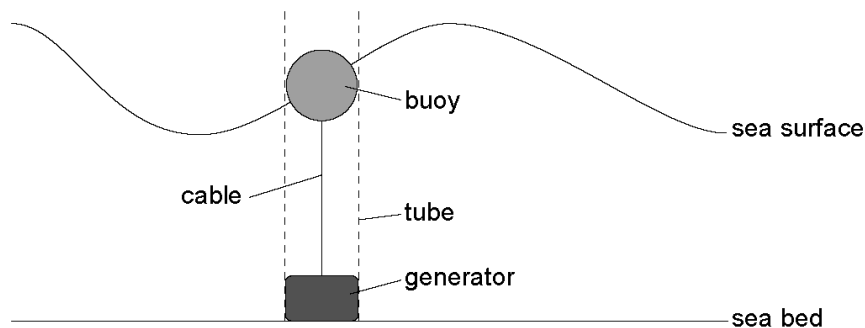
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- (b) A buoy, floating in a vertical tube, generates energy from the movement of water waves on the surface of the sea. When the buoy moves up, a cable turns a generator on the sea bed producing power. When the buoy moves down, the cable is wound in by a mechanism in the generator and no power is produced.



The motion of the buoy can be assumed to be simple harmonic.

- (i) A wave of amplitude 4.3 m and wavelength 35 m, moves with a speed of 3.4 m s^{-1} . Calculate the maximum vertical speed of the buoy.

[3]

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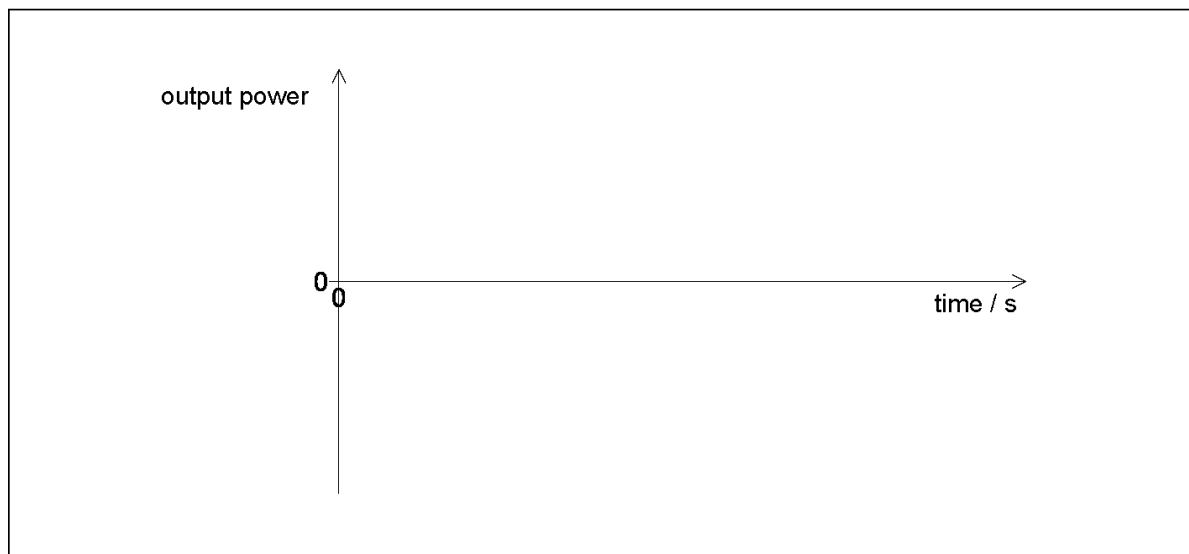
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- (ii) Sketch a graph to show the variation with time of the generator output power.
Label the time axis with a suitable scale.

[2]



(c) Water can be used in other ways to generate energy.



- (i) Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system.

[2]

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- (ii) The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which water arrives at the turbines. Assume that there is no energy loss in the system.

[2]

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- (iii) The hydroelectric system has four 250 MW generators. Determine the maximum time for which the hydroelectric system can maintain full output from the stored energy when a mass of 1.5×10^{10} kg of water passes through the turbines.

[2]

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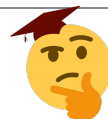
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- (iv) Not all the stored energy can be retrieved because of energy losses in the system.
Explain two such losses.

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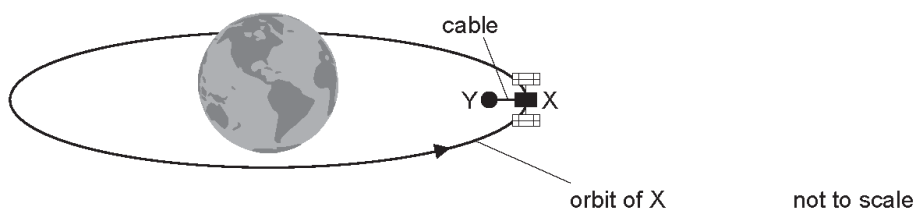


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4 - (PHYSI/20_HL_Winter_2017_Q2) - Circular Motion & Gravitation, Oscillations & Waves, Fields (ahl)



There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



- (a) Satellite X orbits 6600 km from the centre of the Earth.

$$\text{Mass of the Earth} = 6.0 \times 10^{24} \text{ kg}$$

Show that the orbital speed of satellite X is about 8 km s^{-1} . [2]

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- (b) Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

- (i) the orbital times for X and Y are different. [1]

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- (ii) satellite Y requires a propulsion system. [2]

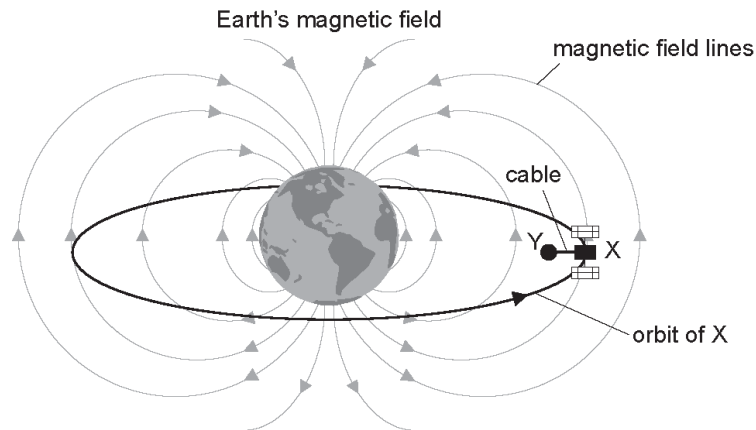
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- (c) The cable between the satellites cuts the magnetic field lines of the Earth at right angles.



Explain why satellite X becomes positively charged.

[3]

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- (d) Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y.

[3]

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- (e) The magnetic field strength of the Earth is $31 \mu\text{T}$ at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]



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- (f) The cable acts as a spring. Satellite Y has a mass m of $3.5 \times 10^2 \text{ kg}$. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period T of 5.2 s.

- (i) Estimate the value of k in the following expression.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X. [3]

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- (ii) Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. [2]

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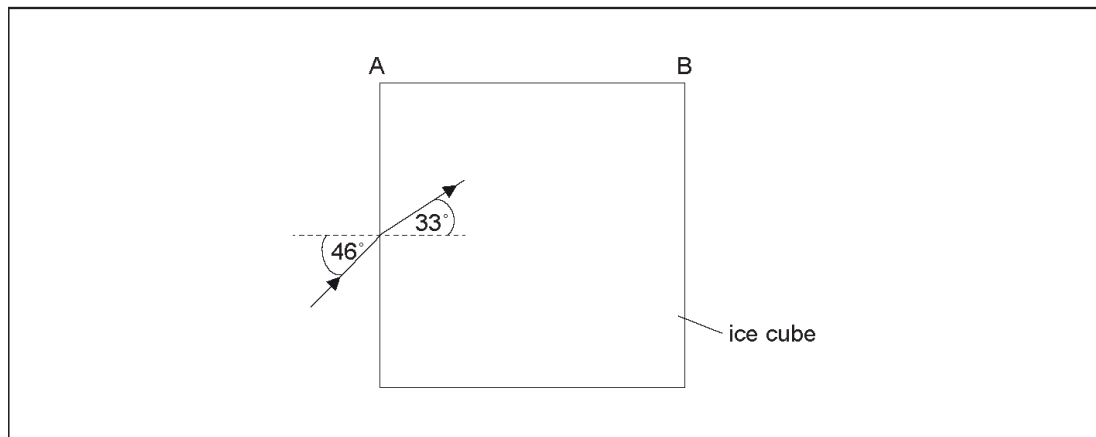
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5 - (PHYSI/20_HL_Winter_2017_Q5) - Thermal Physics, Oscillations & Waves



- (a) A large cube is formed from ice. A light ray is incident from a vacuum at an angle of 46° to the normal on one surface of the cube. The light ray is parallel to the plane of one of the sides of the cube. The angle of refraction inside the cube is 33° .



- (i) Calculate the speed of light inside the ice cube. [2]

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- (ii) Show that no light emerges from side AB. [3]

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- (iii) Sketch, on the diagram, the subsequent path of the light ray. [2]

- (b) Each side of the ice cube is 0.75 m in length. The initial temperature of the ice cube is -20°C .



- (i) Determine the energy required to melt all of the ice from -20°C to water at a temperature of 0°C .

[4]

Specific latent heat of fusion of ice = 330 kJ kg^{-1}
Specific heat capacity of ice = $2.1\text{ kJ kg}^{-1}\text{ K}^{-1}$
Density of ice = 920 kg m^{-3}

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- (ii) Outline the difference between the molecular structure of a solid and a liquid.

[1]

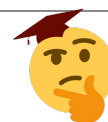
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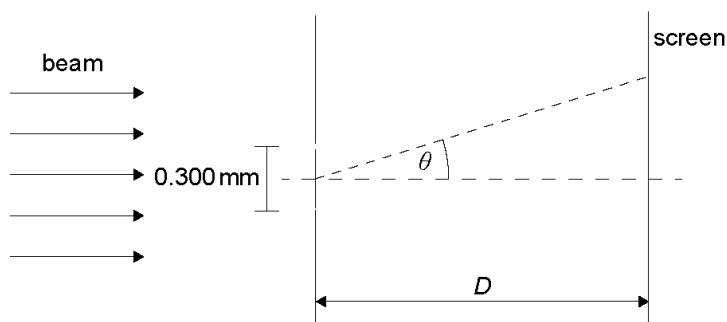
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6 – (PHYSI/21_HL_Summer_2018_Q3) – Oscillations & Waves, Wave Phenomena (ahl)



A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

- (a) The beam is incident normally on a double slit. The distance between the slits is 0.300 mm . A screen is at a distance D from the slits. The diffraction angle θ is labelled.



- (i) A series of dark and bright fringes appears on the screen. Explain how a dark fringe is formed.

[3]

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- (ii) Outline why the beam has to be coherent in order for the fringes to be visible.

[1]

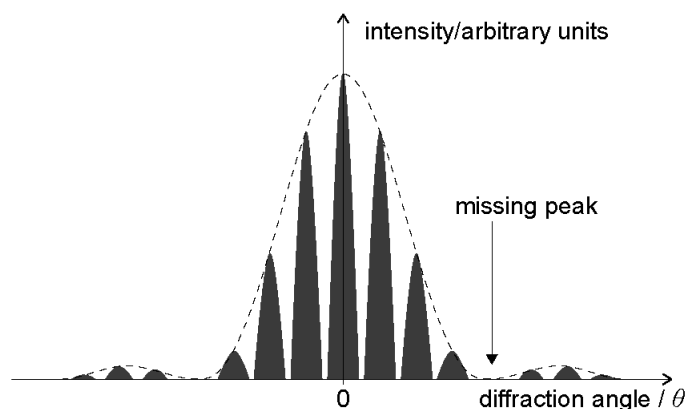
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- (iii) The wavelength of the beam as observed on Earth is 633.0 nm . The separation between a dark and a bright fringe on the screen is 4.50 mm . Calculate D .

[2]

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- (b) The graph of variation of intensity with diffraction angle for this experiment is shown.



- (i) Calculate the angular separation between the central peak and the missing peak in the double-slit interference intensity pattern. State your answer to an appropriate number of significant figures.

[3]

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- (ii) Deduce, in mm, the width of one slit.

[2]

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- (c) The wavelength of the light in the beam when emitted by the galaxy was 621.4 nm.



Explain, without further calculation, what can be deduced about the relative motion of the galaxy and the Earth.

[2]

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- (d) The air between the slits and the screen is replaced with water. The refractive index of water is 1.33.

- (i) Calculate the wavelength of the light in water.

[1]

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- (ii) State **two** ways in which the intensity pattern on the screen changes.

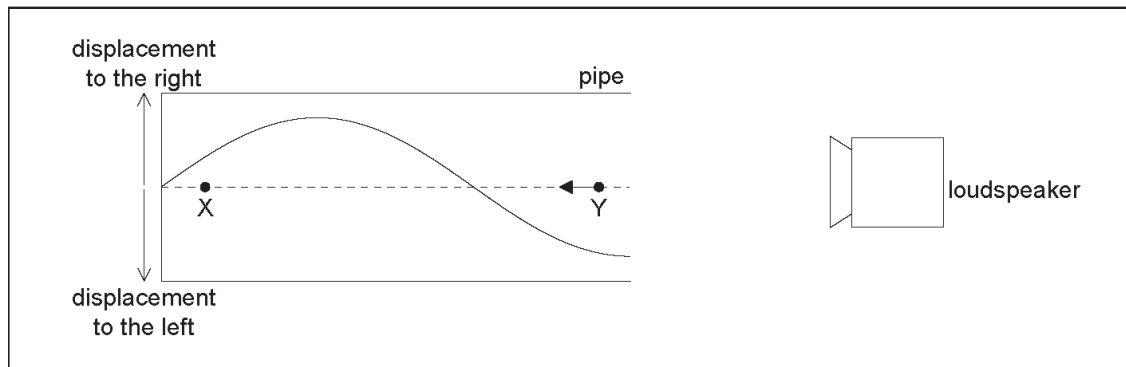
[2]

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7 – (PHYSI/22_HL_Summer_2018_Q3) – Oscillations & Waves



- (a) A loudspeaker emits sound towards the open end of a pipe. The other end is closed. A standing wave is formed in the pipe. The diagram represents the displacement of molecules of air in the pipe at an instant of time.



- (i) Outline how the standing wave is formed.

[1]

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X and Y represent the equilibrium positions of two air molecules in the pipe. The arrow represents the velocity of the molecule at Y.

- (ii) Draw an arrow on the diagram to represent the direction of motion of the molecule at X.

[1]

- (iii) Label a position N that is a node of the standing wave.

[1]

- (iv) The speed of sound is 340 m s^{-1} and the length of the pipe is 0.30 m . Calculate, in Hz, the frequency of the sound.

[2]

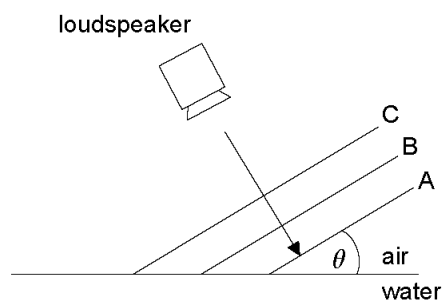
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- (b) The loudspeaker in (a) now emits sound towards an air–water boundary. A, B and C are parallel wavefronts emitted by the loudspeaker. The parts of wavefronts A and B in water are not shown. Wavefront C has not yet entered the water.



- (i) The speed of sound in air is 340 m s^{-1} and in water it is 1500 m s^{-1} . The wavefronts make an angle θ with the surface of the water. Determine the maximum angle, θ_{max} , at which the sound can enter water. Give your answer to the correct number of significant figures.

[2]

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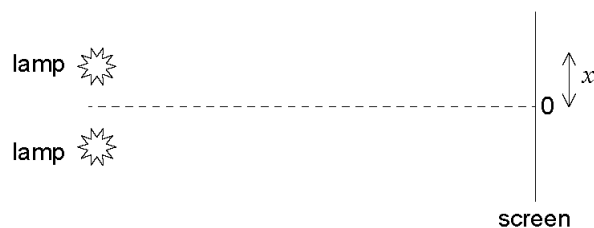
- (ii) Draw lines on the diagram to complete wavefronts A and B in water for $\theta < \theta_{\text{max}}$.

[2]

8 – (PHYSI/22_HL_Summer_2018_Q5) – Oscillations & Waves, Wave Phenomena (ahl)



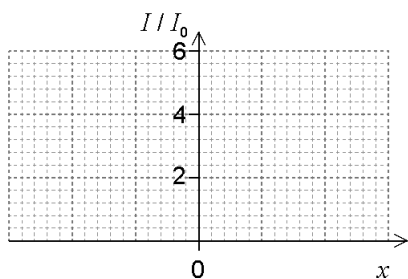
- (a) Monochromatic light from two identical lamps arrives on a screen.



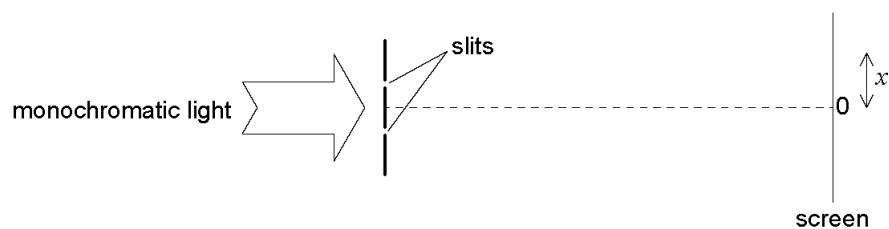
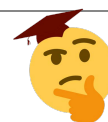
The intensity of light on the screen from each lamp separately is I_0 .

On the axes, sketch a graph to show the variation with distance x on the screen of the intensity I of light on the screen.

[1]



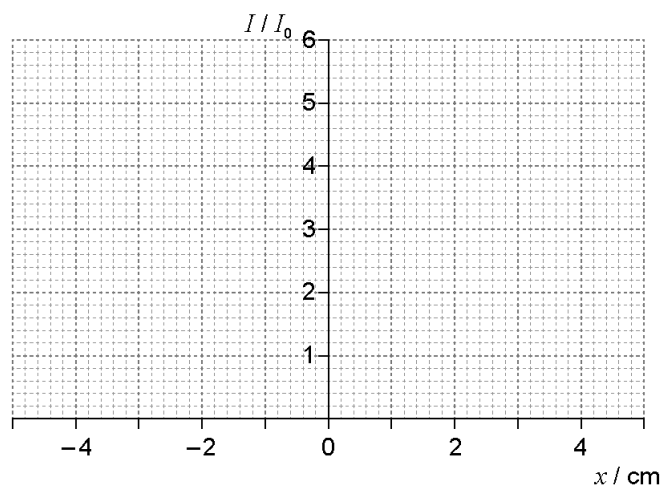
- (b) Monochromatic light from a single source is incident on two thin, parallel slits.



The following data are available.

Slit separation	= 0.12 mm
Wavelength	= 680 nm
Distance to screen	= 3.5 m

The intensity I of light at the screen from each slit separately is I_0 . Sketch, on the axes, a graph to show the variation with distance x on the screen of the intensity of light on the screen for this arrangement. [3]



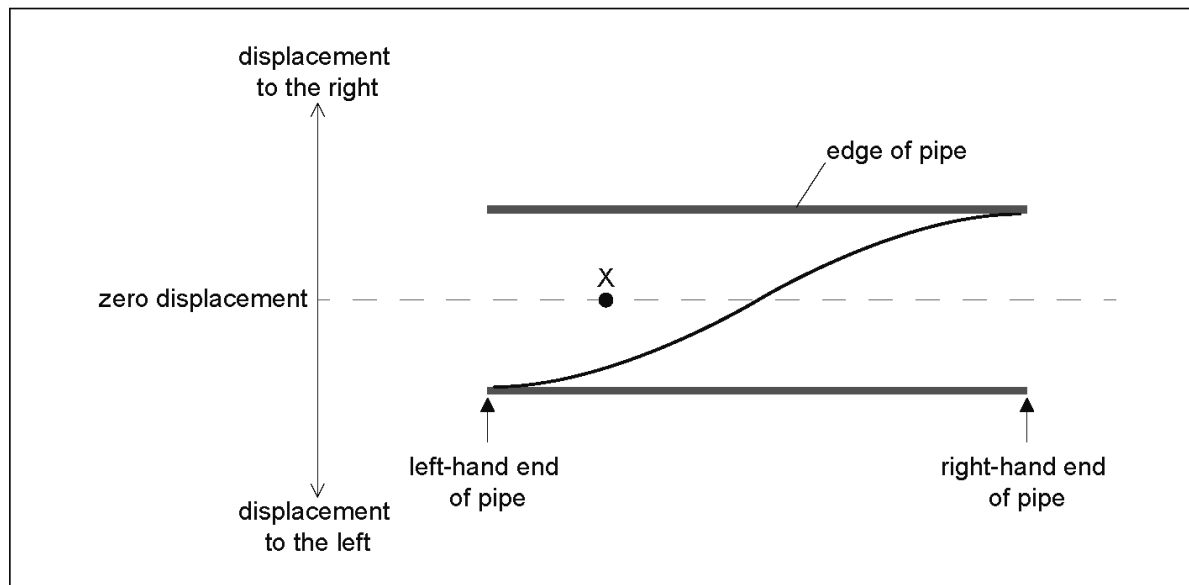
- (c) The slit separation is increased. Outline one change observed on the screen. [1]

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9 – (PHYSI/20_HL_Winter_2018_Q4) – Oscillations & Waves



A pipe is open at both ends. A first-harmonic standing wave is set up in the pipe. The diagram shows the variation of displacement of air molecules in the pipe with distance along the pipe at time $t = 0$. The frequency of the first harmonic is f .



- (a) (i) Sketch, on the diagram, the variation of displacement of the air molecules with distance along the pipe when $t = \frac{3}{4f}$. [1]
- (ii) An air molecule is situated at point X in the pipe at $t = 0$. Describe the motion of this air molecule during one complete cycle of the standing wave beginning from $t = 0$. [2]

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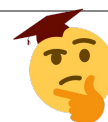
- (b) The speed of sound c for longitudinal waves in air is given by

$$c = \sqrt{\frac{K}{\rho}}$$

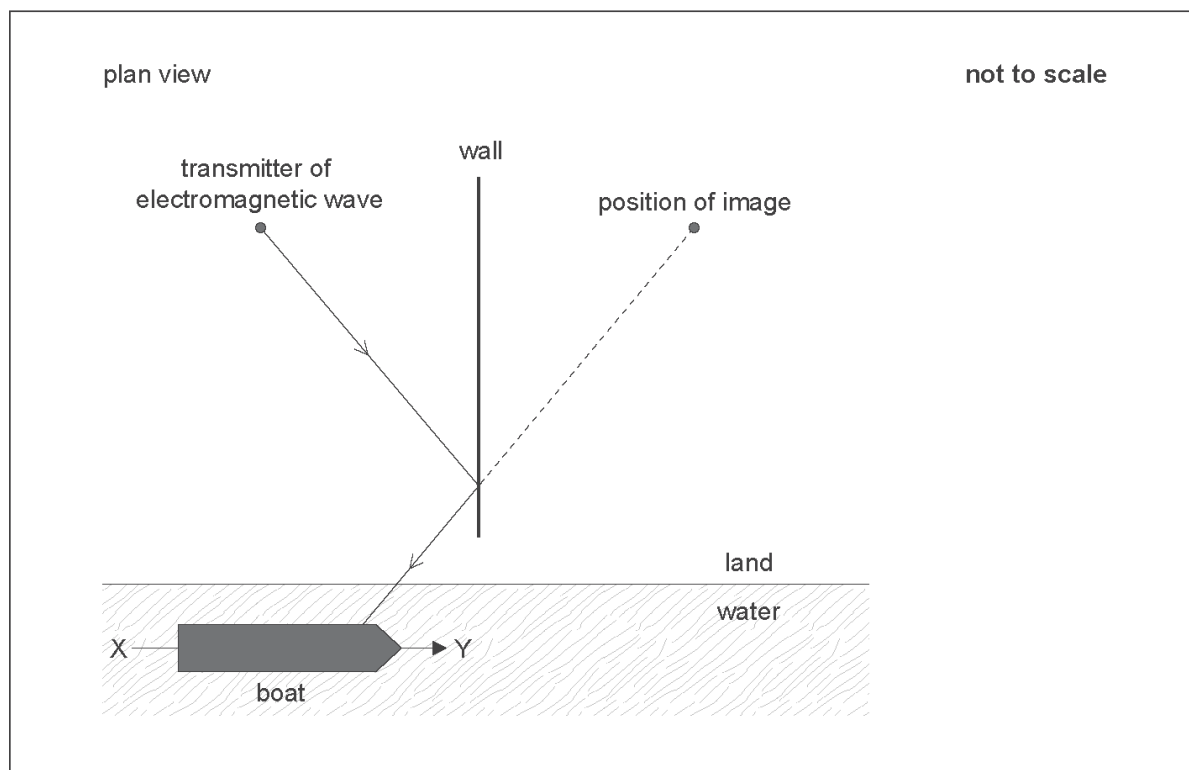
where ρ is the density of the air and K is a constant.

A student measures f to be 120 Hz when the length of the pipe is 1.4 m. The density of the air in the pipe is 1.3 kg m^{-3} . Determine the value of K for air. State your answer with the appropriate fundamental (SI) unit.

[4]



- (c) A transmitter of electromagnetic waves is next to a long straight vertical wall that acts as a plane mirror to the waves. An observer on a boat detects the waves both directly and as an image from the other side of the wall. The diagram shows one ray from the transmitter reflected at the wall and the position of the image.



- (i) Demonstrate, using a second ray, that the image appears to come from the position indicated. [1]
- (ii) Outline why the observer detects a series of increases and decreases in the intensity of the received signal as the boat moves along the line XY. [2]

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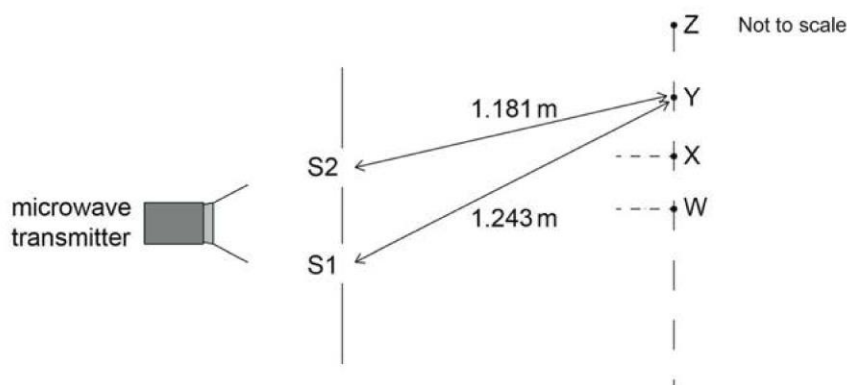
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10 – (PHYSI/21_HL_Summer_2019_Q3) – Oscillations & Waves



A beam of microwaves is incident normally on a pair of identical narrow slits S1 and S2.



When a microwave receiver is initially placed at W which is equidistant from the slits, a maximum in intensity is observed. The receiver is then moved towards Z along a line parallel to the slits. Intensity maxima are observed at X and Y with one minimum between them. W, X and Y are consecutive maxima.

(a) Explain why intensity maxima are observed at X and Y.

[2]

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The distance from S1 to Y is 1.243 m and the distance from S2 to Y is 1.181 m.

(b) Determine the frequency of the microwaves.

[3]

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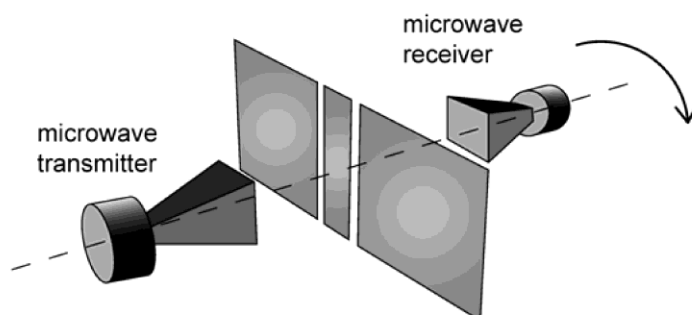
- (c) Outline **one** reason why the maxima observed at W, X and Y will have different intensities from each other.

[1]



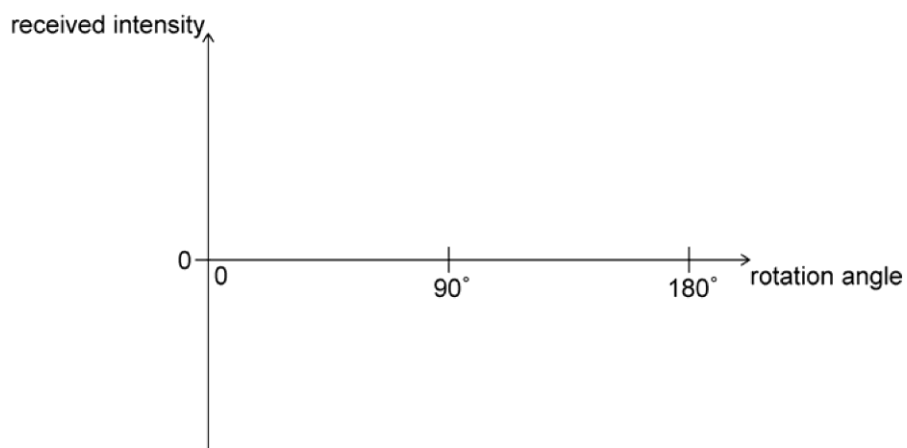
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- (d) The microwaves emitted by the transmitter are horizontally polarized. The microwave receiver contains a polarizing filter. When the receiver is at position W it detects a maximum intensity.

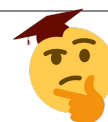


The receiver is then rotated through 180° about the horizontal dotted line passing through the microwave transmitter. Sketch a graph on the axes provided to show the variation of received intensity with rotation angle.

[2]



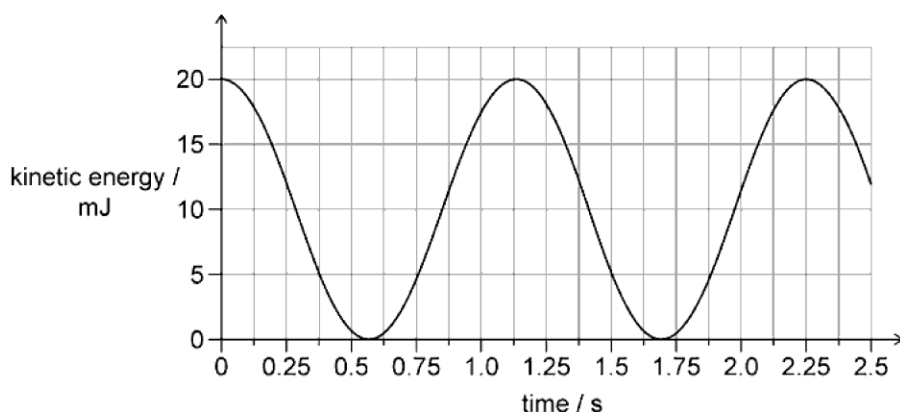
11 – (PHYSI/21_HL_Summer_2019_Q6) – Mechanics, Oscillations & Waves



A small metal pendulum bob is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible.

The pendulum begins to oscillate. Assume that the motion of the system is simple harmonic, and in one vertical plane.

The graph shows the variation of kinetic energy of the pendulum bob with time.



- (a) (i) Calculate, in m, the length of the thread. State your answer to an appropriate number of significant figures.

[3]

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- (ii) Label on the graph with the letter X a point where the speed of the pendulum is half that of its initial speed.

[1]

- (iii) The mass of the pendulum bob is 75 g. Show that the maximum speed of the bob is about 0.7 ms^{-1} .

[2]

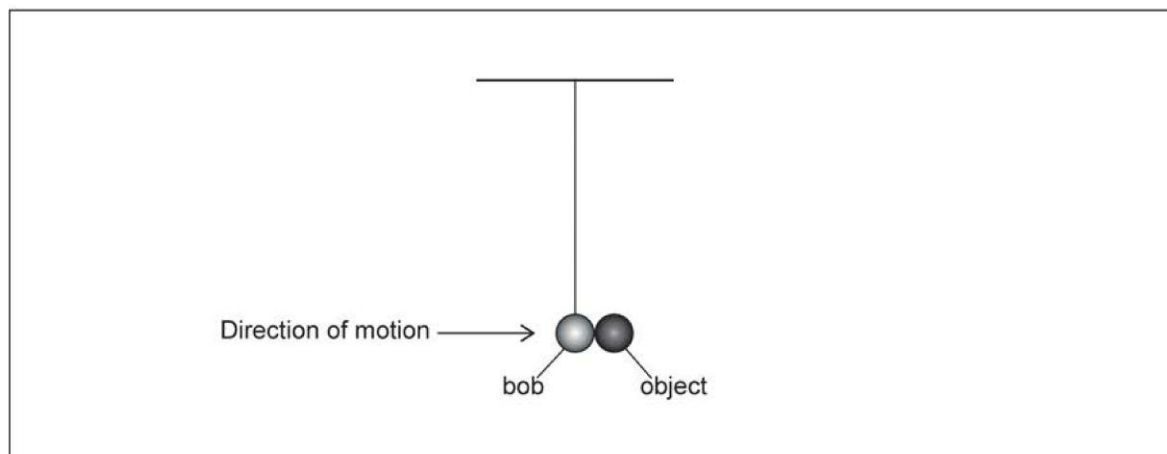
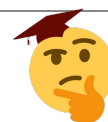
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- (b) When the 75 g bob is moving horizontally at 0.80 m s^{-1} , it collides with a small stationary object also of mass 75 g. The object and the bob stick together.



- (i) Calculate the speed of the combined masses immediately after the collision. [1]

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- (ii) Show that the collision is inelastic. [3]

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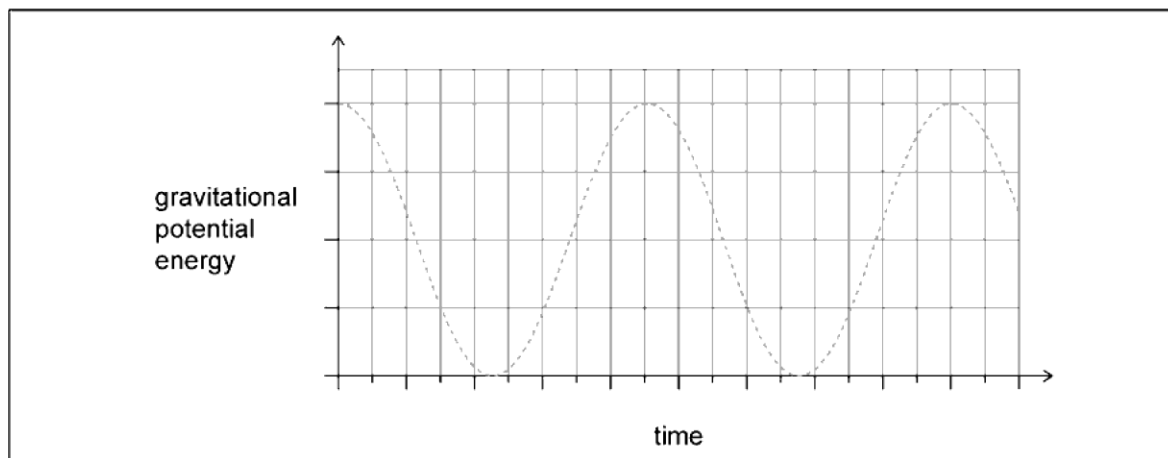
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- (iii) Sketch, on the axes, a graph to show the variation of gravitational potential energy with time for the bob and the object after the collision. The data from the graph used in (a) is shown as a dashed line for reference.

[2]



- (iv) The speed after the collision of the bob and the object was measured using a sensor. This sensor emits a sound of frequency f and this sound is reflected from the moving bob. The sound is then detected by the sensor as frequency f' .

Explain why f and f' are different.

[3]

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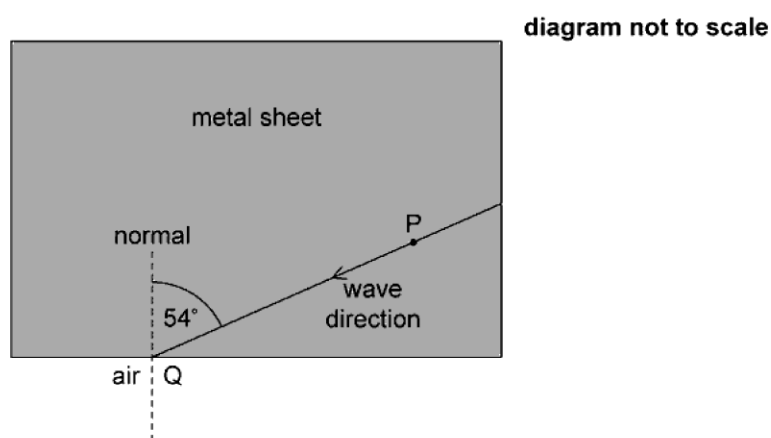
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12 – (PHYSI/22_HL_Summer_2019_Q3) – Oscillations & Waves



The diagram shows the direction of a sound wave travelling in a metal sheet.



- (a) Particle P in the metal sheet performs simple harmonic oscillations. When the displacement of P is $3.2\mu\text{m}$ the magnitude of its acceleration is 7.9ms^{-2} . Calculate the magnitude of the acceleration of P when its displacement is $2.3\mu\text{m}$. [2]

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- (b) The wave is incident at point Q on the metal–air boundary. The wave makes an angle of 54° with the normal at Q. The speed of sound in the metal is 6010ms^{-1} and the speed of sound in air is 340ms^{-1} . Calculate the angle between the normal at Q and the direction of the wave in air. [2]

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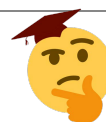
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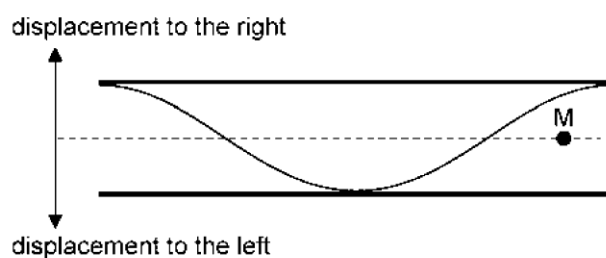
- (c) The frequency of the sound wave in the metal is 250 Hz. Determine the wavelength of the wave in air.

[1]



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- (d) The sound wave in air in (c) enters a pipe that is open at both ends. The diagram shows the displacement, at a particular time T , of the standing wave that is set up in the pipe.



A particular air molecule has its equilibrium position at the point labelled M.

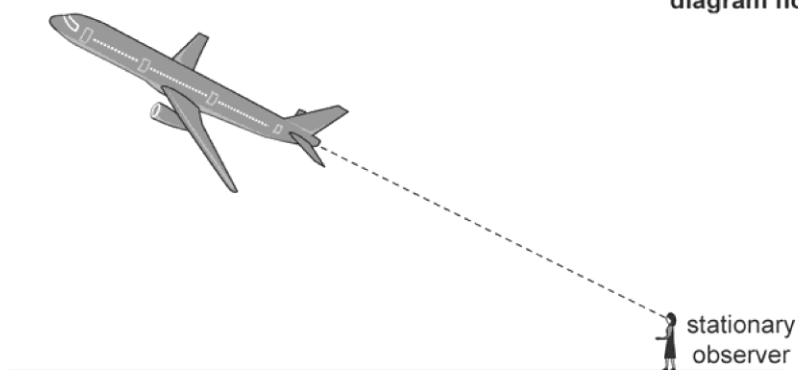
On the diagram, at time T ,

- (i) draw an arrow to indicate the acceleration of this molecule. [1]
- (ii) label with the letter C a point in the pipe that is at the centre of a compression. [1]

- (e) Sound of frequency $f = 2500\text{ Hz}$ is emitted from an aircraft that moves with speed $v = 280\text{ m s}^{-1}$ away from a stationary observer. The speed of sound in still air is $c = 340\text{ m s}^{-1}$.



diagram not to scale



Calculate the

- (i) frequency heard by the observer.

[2]

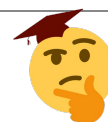
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- (ii) wavelength measured by the observer.

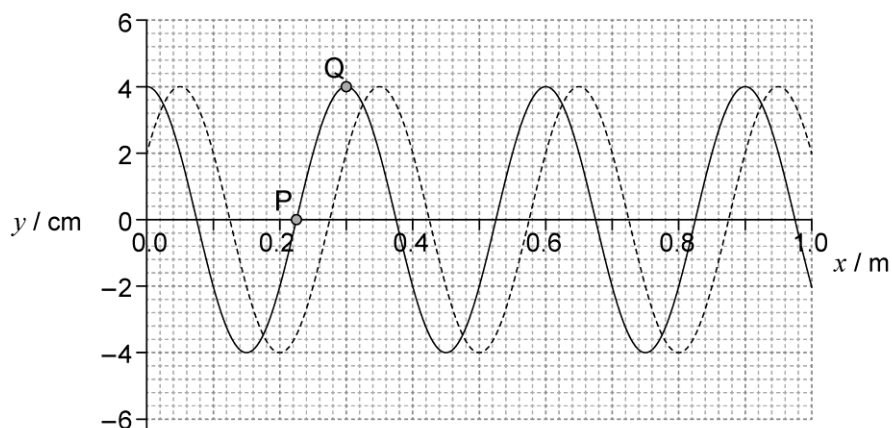
[1]

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13 – (PHYSI/20_HL_Winter_2019_Q3) – Oscillations & Waves



The solid line in the graph shows the variation with distance x of the displacement y of a travelling wave at $t = 0$. The dotted line shows the wave 0.20 ms later. The period of the wave is longer than 0.20 ms .



- (a) (i) Calculate, in ms^{-1} , the speed for this wave. [1]

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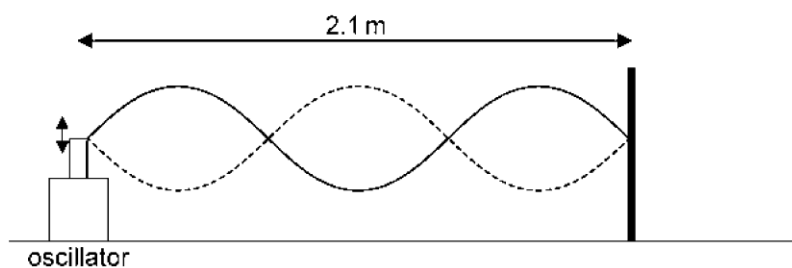
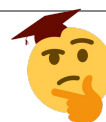
- (ii) Calculate, in Hz, the frequency for this wave. [2]

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- (b) The graph also shows the displacement of two particles, P and Q, in the medium at $t = 0$. State and explain which particle has the larger magnitude of acceleration at $t = 0$. [2]

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- (c) One end of a string is attached to an oscillator and the other is fixed to a wall. When the frequency of the oscillator is 360 Hz the standing wave shown is formed on the string.



Point X (not shown) is a point on the string at a distance of 10 cm from the oscillator.

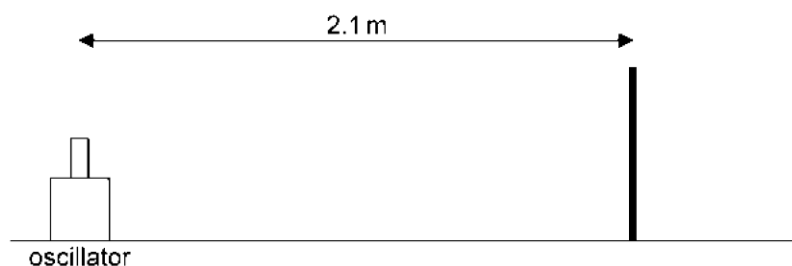
- (i) State the number of all other points on the string that have the same amplitude and phase as X.

[1]

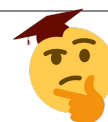
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- (ii) The frequency of the oscillator is reduced to 120 Hz. On the diagram, draw the standing wave that will be formed on the string.

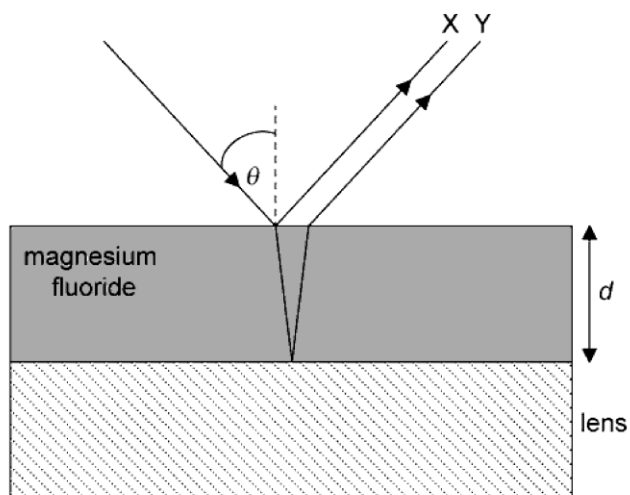
[1]



14 – (PHYSI/20_HL_Winter_2019_Q10) – Oscillations & Waves, Wave Phenomena (ahl)



The lens of an optical system is coated with a thin film of magnesium fluoride of thickness d . Monochromatic light of wavelength 656 nm in air is incident on the lens. The angle of incidence is θ . Two reflected rays, X and Y, are shown.



The following refractive indices are available.

Air	= 1.00
Magnesium fluoride	= 1.38
Lens	= 1.58

(a) Predict whether reflected ray X undergoes a phase change.

[2]

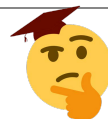
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(b) The thickness of the magnesium fluoride film is d . For the case of normal incidence ($\theta = 0$),



(i) state, in terms of d , the path difference between the reflected rays X and Y. [1]

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(ii) calculate the smallest value of d that will result in destructive interference between ray X and ray Y. [2]

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(iii) discuss a practical advantage of this arrangement. [2]

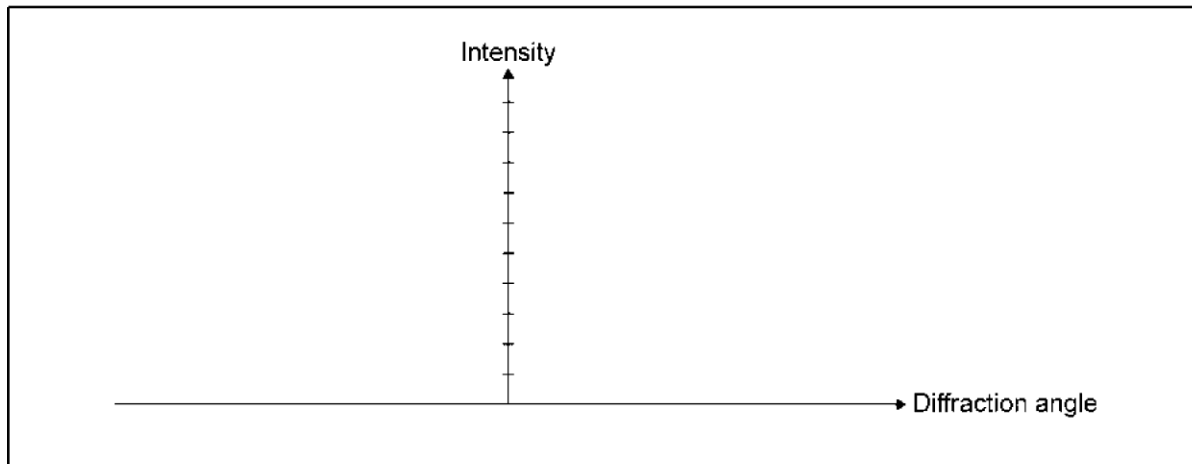
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- (c) Light from a point source is incident on the pupil of the eye of an observer. The diameter of the pupil is 2.8 mm.



- (i) Draw, on the axes, the variation with diffraction angle of the intensity of light incident on the retina of the observer.

[2]



- (ii) Estimate, in rad, the smallest angular separation of two distinct point sources of light of wavelength 656 nm that can be resolved by the eye of this observer.

[2]

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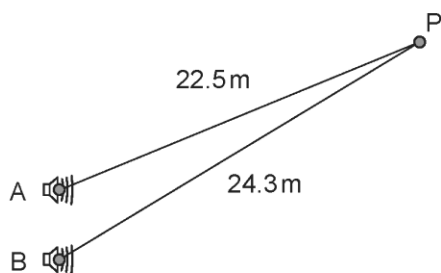
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15 – (PHYSI/20_HL_Winter_2020_Q4) – *Oscillations & Waves, Wave Phenomena (ahl)*



Two loudspeakers, A and B, are driven in phase and with the same amplitude at a frequency of 850 Hz. Point P is located 22.5 m from A and 24.3 m from B. The speed of sound is 340 m s^{-1} .



(a) Deduce that a minimum intensity of sound is heard at P.

[4]

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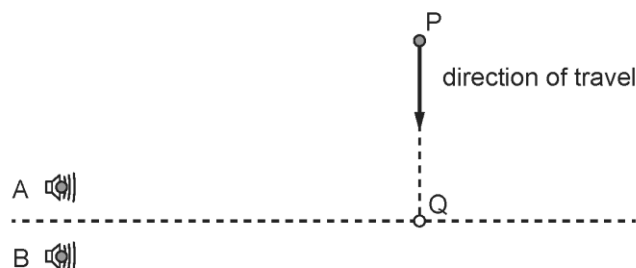
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- (b) A microphone moves along the line from P to Q. PQ is normal to the line midway between the loudspeakers.



The intensity of sound is detected by the microphone. Predict the variation of detected intensity as the microphone moves from P to Q.

[2]

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- (c) When both loudspeakers are operating, the intensity of sound recorded at Q is I_0 . Loudspeaker B is now disconnected. Loudspeaker A continues to emit sound with unchanged amplitude and frequency. The intensity of sound recorded at Q changes to I_A .

Estimate $\frac{I_A}{I_0}$.

[2]

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- (d) In another experiment, loudspeaker A is stationary and emits sound with a frequency of 850 Hz. The microphone is moving directly away from the loudspeaker with a constant speed v . The frequency of sound recorded by the microphone is 845 Hz.



- (i) Explain why the frequency recorded by the microphone is lower than the frequency emitted by the loudspeaker.

[2]

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- (ii) Calculate v .

[2]

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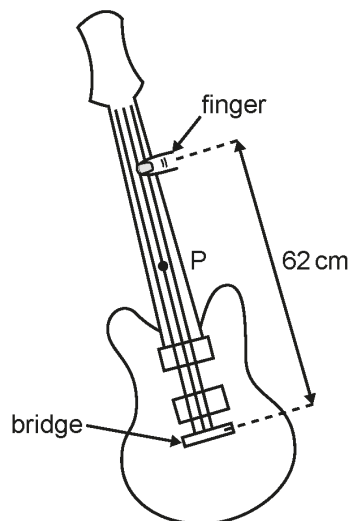
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16 – (PHYSI/21_HL_Summer_2021_Q8) – *Oscillations & Waves*

On a guitar, the strings played vibrate between two fixed points. The frequency of vibration is modified by changing the string length using a finger. The different strings have different wave speeds. When a string is plucked, a standing wave forms between the bridge and the finger.



(a) Outline how a standing wave is produced on the string.

[2]

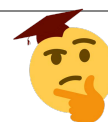
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- (b) The string is displaced 0.4 cm at point P to sound the guitar. Point P on the string vibrates with simple harmonic motion (shm) in its first harmonic with a frequency of 195 Hz. The sounding length of the string is 62 cm.



- (i) Show that the speed of the wave on the string is about 240 m s^{-1} .

[2]

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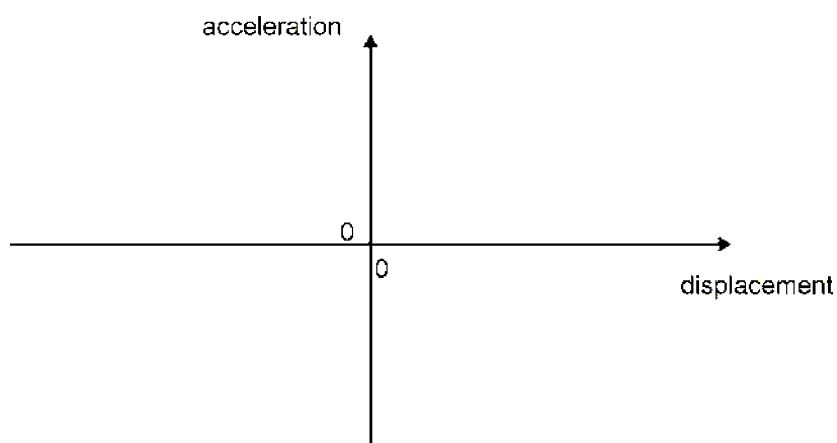
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- (ii) Sketch a graph to show how the acceleration of point P varies with its displacement from the rest position.

[1]



- (iii) Calculate, in m s^{-1} , the maximum velocity of vibration of point P when it is vibrating with a frequency of 195 Hz.

[2]

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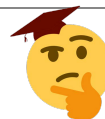
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(iv) Calculate, in terms of g , the maximum acceleration of P.

[2]



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(v) Estimate the displacement needed to double the energy of the string.

[2]

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(c) The string is made to vibrate in its third harmonic. State the distance between consecutive nodes.

[1]

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17 – (PHYSI/22_HL_Summer_2021_Q7) – Oscillations & Waves, Electromagnetic Induction (ahl)



- (a) The primary coil of a transformer is connected to a 110V alternating current (ac) supply. The secondary coil of the transformer is connected to a 15V garden lighting system that consists of 8 lamps connected in parallel. Each lamp is rated at 35W when working at its normal brightness. Root mean square (rms) values are used throughout this question.

- (i) The primary coil has 3300 turns. Calculate the number of turns on the secondary coil. [1]

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- (ii) Determine the total resistance of the lamps when they are working normally. [2]

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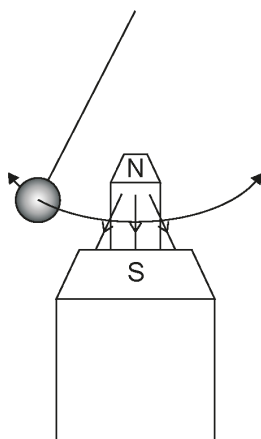
- (iii) Calculate the current in the primary of the transformer assuming that it is ideal. [2]

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- (iv) Flux leakage is one reason why a transformer may not be ideal. Explain the effect of flux leakage on the transformer. [2]

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- (b) A pendulum with a metal bob comes to rest after 200 swings. The same pendulum, released from the same position, now swings at 90° to the direction of a strong magnetic field and comes to rest after 20 swings.



Explain why the pendulum comes to rest after a smaller number of swings.

[4]

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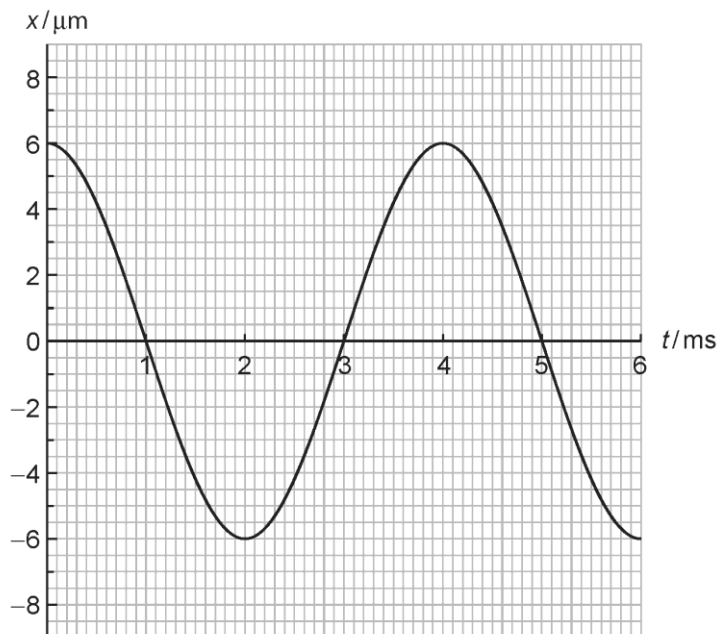
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18 – (PHYSI/20_HL_Winter_2021_Q2) – Oscillations & Waves



A longitudinal wave travels in a medium with speed 340 m s^{-1} . The graph shows the variation with time t of the displacement x of a particle P in the medium. Positive displacements on the graph correspond to displacements to the right for particle P.



(a) Calculate the wavelength of the wave.

[2]

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(b) Determine, for particle P, the magnitude and direction of the acceleration at $t = 2.0 \text{ ms}$

[3]

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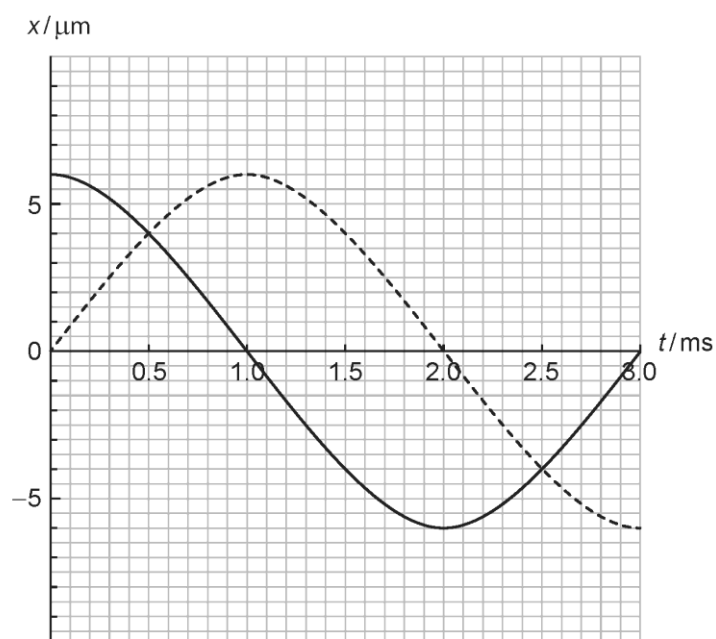
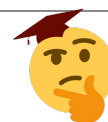
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- (c) Another wave travels in the medium. The graph shows the variation with time t of the displacement of each wave at the position of P.



- (i) State the phase difference between the two waves.

[1]

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- (ii) Identify a time at which the displacement of P is zero.

[1]

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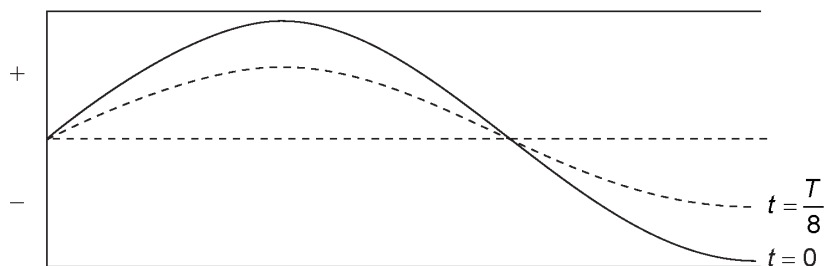
- (iii) Estimate the amplitude of the resultant wave.

[1]

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- (d) A standing sound wave is established in a tube that is closed at one end and open at the other end. The period of the wave is T . The diagram represents the standing wave at $t = 0$ and at $t = \frac{T}{8}$. The wavelength of the wave is 1.20 m. Positive displacements mean displacements to the right.



- (i) Calculate the length of the tube.

[1]

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- (ii) A particle in the tube has its equilibrium position at the open end of the tube.

State and explain the direction of the velocity of this particle at time $t = \frac{T}{8}$

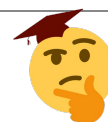
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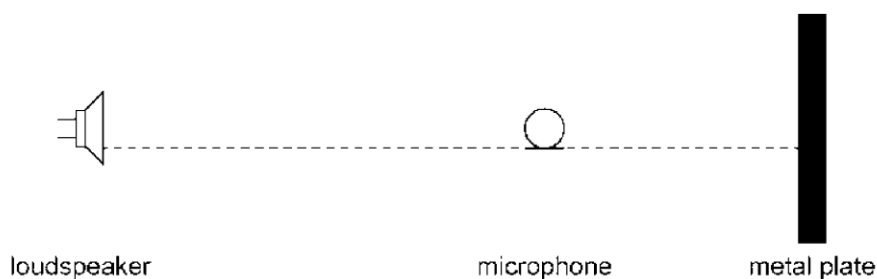
- (iii) Draw on the diagram the standing wave at time $t = \frac{T}{4}$

[1]

19 – (PHYSI/22_HL_Summer_2022_Q3) – Oscillations & Waves



A loudspeaker emits sound waves of frequency f towards a metal plate that reflects the waves. A small microphone is moved along the line from the metal plate to the loudspeaker. The intensity of sound detected at the microphone as it moves varies regularly between maximum and minimum values.



The speed of sound in air is 340 m s^{-1} .

(a) (i) Explain the variation in intensity.

[3]

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(ii) Adjacent minima are separated by a distance of 0.12 m . Calculate f .

[2]

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- (b) The metal plate is replaced by a wooden plate that reflects a lower intensity sound wave than the metal plate.



State and explain the differences between the sound intensities detected by the same microphone with the metal plate and the wooden plate.

[3]

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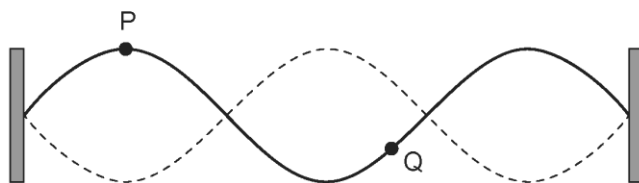
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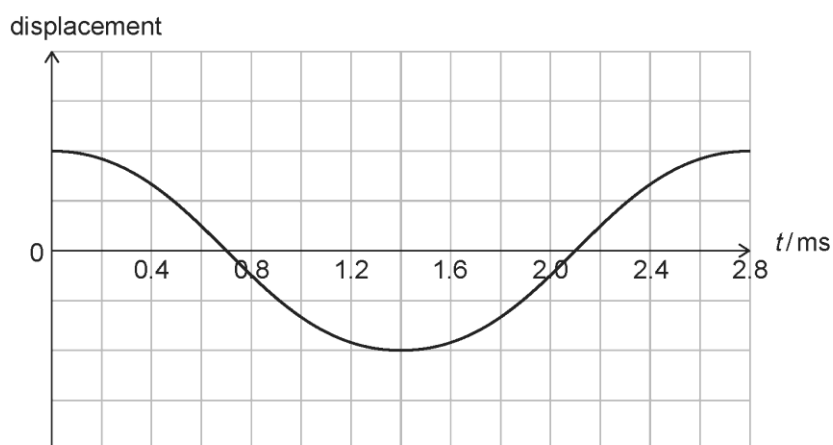
20 – (PHYSI/20_HL_Winter_2022_Q3) – Oscillations & Waves



A string of length 0.80 m is fixed at both ends. The diagram shows a standing wave formed on the string. P and Q are two particles on the string.



(a) The variation with time t of the displacement of particle P is shown.



(i) Draw, on the axes, a graph to show the variation with t of the displacement of particle Q. [2]

(ii) Calculate the speed of waves on the string. [2]

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- (b) It is suggested that the speed c of waves in the string is related to the tension force T in the string according to the equation $T = ac^2$, where a is a constant.



- (i) Determine the fundamental SI unit for a .

[2]

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- (ii) The tension force on the string is doubled. Describe the effect, if any, of this change on the frequency of the standing wave.

[2]

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(c) The standing wave on the string creates a travelling sound wave in the surrounding air.

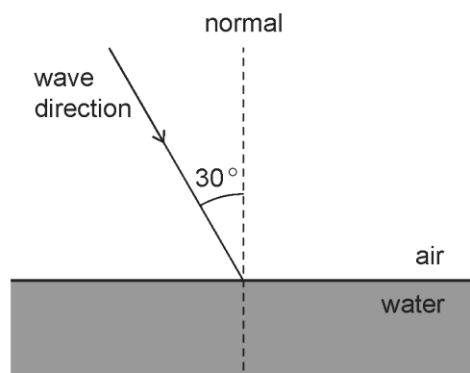
(i) Outline **one** difference between a standing wave and a travelling wave.

[1]



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The sound wave is incident on a surface of water. The wave makes an angle of 30° with the normal to the surface.



(ii) The speed of sound in air is 340 m s^{-1} and in water it is 1500 m s^{-1} .

Discuss whether the sound wave can enter the water.

[2]

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1 - (PHYSI/21_HL_Summer_2017_Q3) - *Energy Production, Electricity & Magnetism*



Two renewable energy sources are solar and wind.

- (a) Describe the difference between photovoltaic cells and solar heating panels.

[1]

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- (b) A solar farm is made up of photovoltaic cells of area $25\,000\text{ m}^2$. The average solar intensity falling on the farm is 240 W m^{-2} and the average power output of the farm is 1.6 MW . Calculate the efficiency of the photovoltaic cells.

[2]

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- (c) An alternative generation method is the use of wind turbines.

The following data are available:

Length of turbine blade = 17 m
Density of air = 1.3 kg m^{-3}
Average wind speed = 7.5 ms^{-1}

- (i) Determine the minimum number of turbines needed to generate the same power as the solar farm.

[3]

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- (ii) Explain **two** reasons why the number of turbines required is likely to be greater than your answer to (c)(i).

[2]



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2 - (PHYSI/21_HL_Summer_2017_Q4) - *Electricity & Magnetism, Thermal Physics*

A heater in an electric shower has a power of 8.5 kW when connected to a 240 V electrical supply. It is connected to the electrical supply by a copper cable.

The following data are available:

Length of cable = 10 m
Cross-sectional area of cable = 6.0 mm^2
Resistivity of copper = $1.7 \times 10^{-8} \Omega \text{ m}$

(a) (i) Calculate the current in the copper cable. [1]

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(ii) Calculate the resistance of the cable. [2]

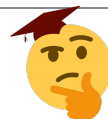
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(iii) Calculate the power dissipated in the cable. [1]

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- (b) Explain, in terms of electrons, what happens to the resistance of the cable as the temperature of the cable increases.

[3]



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- (c) The heater changes the temperature of the water by 35 K. The specific heat capacity of water is $4200 \text{ J kg}^{-1} \text{ K}^{-1}$.

Determine the rate at which water flows through the shower. State an appropriate unit for your answer.

[4]

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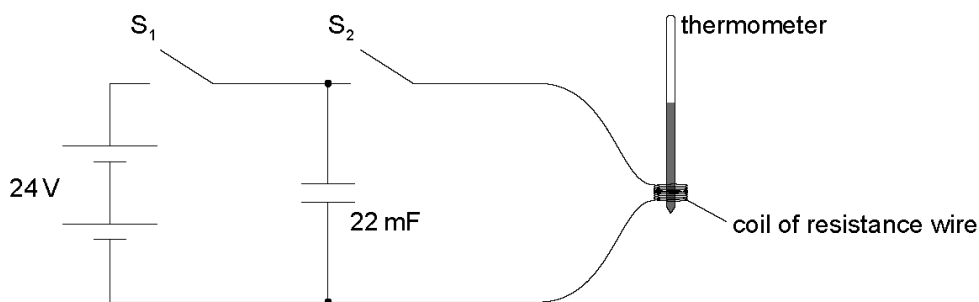
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3 - (PHYSI/22_HL_Summer_2017_Q3) - Electromagnetic Induction (ahl), Electricity & Magnetism



The electrical circuit shown is used to investigate the temperature change in a wire that is wrapped around a mercury-in-glass thermometer.



A power supply of emf (electromotive force) 24 V and of negligible internal resistance is connected to a capacitor and to a coil of resistance wire using an arrangement of two switches. Switch S_1 is closed and, a few seconds later, opened. Then switch S_2 is closed.

- (a) The capacitance of the capacitor is 22 mF. Calculate the energy stored in the capacitor when it is fully charged.

[1]

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- (b) The resistance of the wire is $8.0\ \Omega$. Determine the time taken for the capacitor to discharge through the resistance wire. Assume that the capacitor is completely discharged when the potential difference across it has fallen to 0.24 V.

[3]

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- (c) (i) The mass of the resistance wire is 0.61 g and its observed temperature rise is 28 K. Estimate the specific heat capacity of the wire. Include an appropriate unit for your answer.

[2]



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- (ii) Suggest one other energy loss in the experiment and the effect it will have on the value for the specific heat capacity of the wire.

[2]

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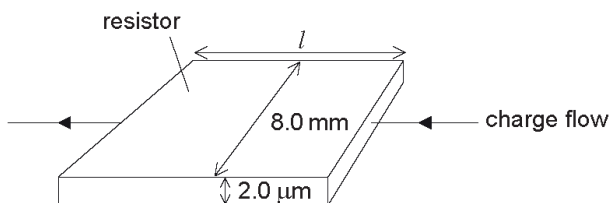
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4 – (PHYSI/20_HL_Winter_2017_Q4) – Electricity & Magnetism



Electrical resistors can be made by forming a thin film of carbon on a layer of an insulating material.

- (a) A carbon film resistor is made from a film of width 8.0 mm and of thickness $2.0\ \mu\text{m}$. The diagram shows the direction of charge flow through the resistor.



not to scale

- (i) The resistance of the carbon film is $82\ \Omega$. The resistivity of carbon is $4.1 \times 10^{-5}\ \Omega\text{ m}$. Calculate the length l of the film.

[1]

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- (ii) The film must dissipate a power less than 1500 W from each square metre of its surface to avoid damage. Calculate the maximum allowable current for the resistor.

[2]

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- (iii) State why knowledge of quantities such as resistivity is useful to scientists.

[1]

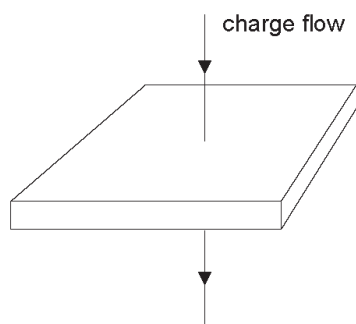
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- (b) The current direction is now changed so that charge flows vertically through the film.



not to scale

Deduce, without calculation, the change in the resistance.

[2]

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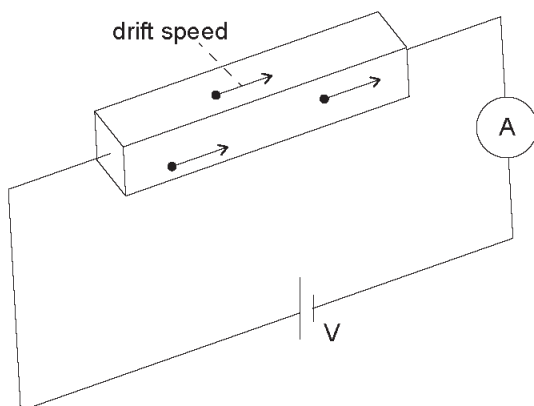
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5 - (PHYSI/21_HL_Summer_2018_Q4) - Electricity & Magnetism



An ohmic conductor is connected to an ideal ammeter and to a power supply of output voltage V .



The following data are available for the conductor:

density of free electrons $= 8.5 \times 10^{22} \text{ cm}^{-3}$
resistivity $\rho = 1.7 \times 10^{-8} \Omega \text{ m}$
dimensions $w \times h \times l = 0.020 \text{ cm} \times 0.020 \text{ cm} \times 10 \text{ cm}$.

The ammeter reading is 2.0 A.

(a) Calculate the resistance of the conductor.

[2]

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(b) Calculate the drift speed v of the electrons in the conductor in cm s^{-1} .

[2]

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- (c) The electric field E inside the sample can be approximated as the uniform electric field between two parallel plates.



- (i) Determine the electric field strength E .

[2]

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- (ii) Show that $\frac{v}{E} = \frac{1}{ne\rho}$.

[3]

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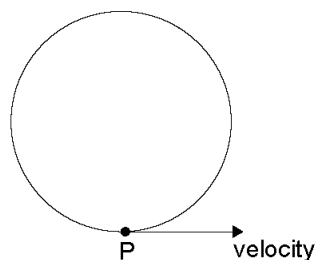
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6 - (PHYSI/21_HL_Summer_2018_Q5) - *Electricity & Magnetism, Circular Motion & Gravitation*



An electron moves in circular motion in a uniform magnetic field.



The velocity of the electron at point P is $6.8 \times 10^5 \text{ ms}^{-1}$ in the direction shown.
The magnitude of the magnetic field is 8.5 T.

- (a) State the direction of the magnetic field. [1]

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- (b) Calculate, in N, the magnitude of the magnetic force acting on the electron. [1]

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- (c) Explain why the electron moves

- (i) at constant speed. [1]

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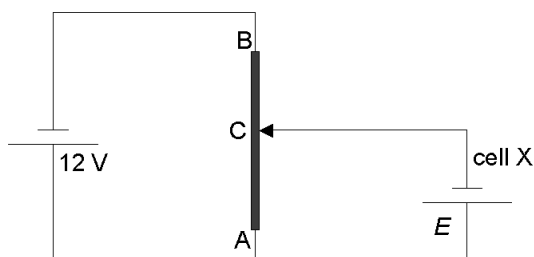
- (ii) on a circular path. [2]

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7 - (PHYSI/22_HL_Summer_2018_Q4) - Electricity & Magnetism



The diagram shows a potential divider circuit used to measure the emf E of a cell X. Both cells have negligible internal resistance.



- (a) State what is meant by the emf of a cell. [2]

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- (b) AB is a wire of uniform cross-section and length 1.0 m. The resistance of wire AB is $80\ \Omega$. When the length of AC is 0.35 m the current in cell X is zero.

- (i) Show that the resistance of the wire AC is $28\ \Omega$. [2]

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- (ii) Determine E . [2]

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- (c) Cell X is replaced by a second cell of identical emf E but with internal resistance $2.0\ \Omega$.
Comment on the length of AC for which the current in the second cell is zero.

[2]

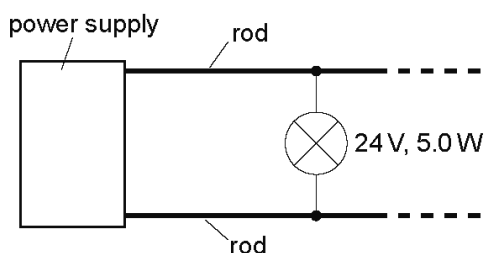


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8 - (PHYSI/20_HL_Winter_2018_Q2) - Electricity & Magnetism



A lighting system consists of two long metal rods with a potential difference maintained between them. Identical lamps can be connected between the rods as required.



The following data are available for the lamps when at their working temperature.

Lamp specifications	24 V, 5.0 W
Power supply root mean square (rms) emf	24 V
Power supply maximum rms current	8.0 A
Length of each rod	12.5 m
Resistivity of rod metal	$7.2 \times 10^{-7} \Omega \text{ m}$

- (a) Each rod is to have a resistance no greater than 0.10Ω . Calculate, in m, the minimum radius of each rod. Give your answer to an appropriate number of significant figures. [3]

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- (b) Calculate the maximum number of lamps that can be connected between the rods. Neglect the resistance of the rods. [2]

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- (c) One advantage of this system is that if one lamp fails then the other lamps in the circuit remain lit. Outline one other electrical advantage of this system compared to one in which the lamps are connected in series.

[1]



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- (d) A step-down transformer is used to transfer energy to the two rods. The primary coil of this transformer is connected to an alternating mains supply that has an emf of root mean square (rms) magnitude 240 V. The transformer is 95 % efficient.

- (i) Outline how eddy currents reduce transformer efficiency.

[2]

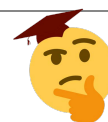
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- (ii) Determine the peak current in the primary coil when operating with the maximum number of lamps.

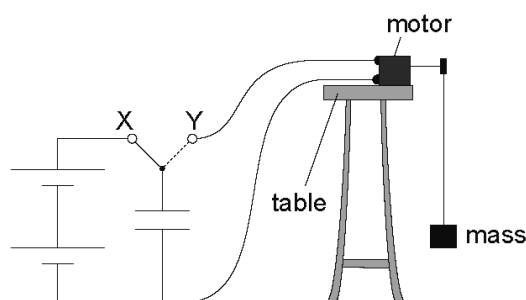
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9 - (PHYSI/20_HL_Winter_2018_Q7) - Electricity & Magnetism



A small electric motor is used with a 12 mF capacitor and a battery in a school experiment.



When the switch is connected to X, the capacitor is charged using the battery. When the switch is connected to Y, the capacitor fully discharges through the electric motor that raises a small mass.

- (a) The battery has an emf of 7.5 V. Determine the charge that flows through the motor when the mass is raised.

[1]

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- (b) The motor can transfer one-third of the electrical energy stored in the capacitor into gravitational potential energy of the mass. Determine the maximum height through which a mass of 45 g can be raised.

[2]

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- (c) An additional identical capacitor is connected in series with the first capacitor and the charging and discharging processes are repeated. Comment on the effect this change has on the height and time taken to raise the 45 g mass.

[3]



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10 – (PHYSI/21_HL_Summer_2019_Q1) – *Mechanics, Electricity & Magnetism*

A girl rides a bicycle that is powered by an electric motor. A battery transfers energy to the electric motor. The emf of the battery is 16 V and it can deliver a charge of 43 kC when discharging completely from a full charge.

- (a) The maximum speed of the girl on a horizontal road is 7.0 m s^{-1} with energy from the battery alone. The maximum distance that the girl can travel under these conditions is 20 km.

- (i) Show that the time taken for the battery to discharge is about $3 \times 10^3 \text{ s}$. [1]

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- (ii) Deduce that the average power output of the battery is about 240 W. [2]

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- (iii) Friction and air resistance act on the bicycle and the girl when they move. Assume that all the energy is transferred from the battery to the electric motor. Determine the total average resistive force that acts on the bicycle and the girl. [2]

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- (b) The bicycle and the girl have a total mass of 66 kg. The girl rides up a slope that is at an angle of 3.0° to the horizontal.



- (i) Calculate the component of weight for the bicycle and girl acting down the slope. [1]

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- (ii) The battery continues to give an output power of 240 W. Assume that the resistive forces are the same as in (a)(iii).

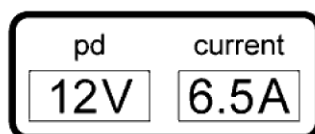
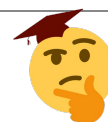
Calculate the maximum speed of the bicycle and the girl up the slope. [2]

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- (c) On another journey up the slope, the girl carries an additional mass. Explain whether carrying this mass will change the maximum distance that the bicycle can travel along the slope. [2]

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- (d) The bicycle has a meter that displays the current and the terminal potential difference (pd) for the battery when the motor is running. The diagram shows the meter readings at one instant. The emf of the cell is 16V.



Determine the internal resistance of the battery.

[2]

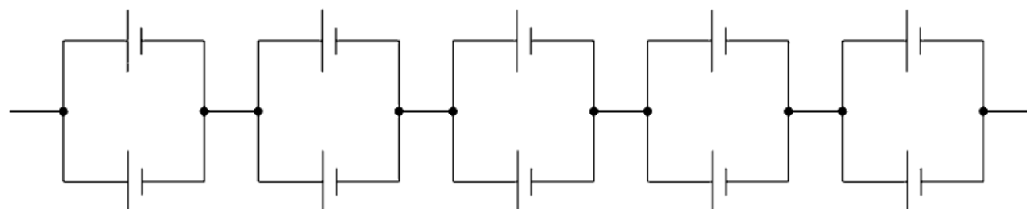
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- (e) The battery is made from an arrangement of 10 identical cells as shown.



Calculate

- (i) the emf of **one** cell.

[1]

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- (ii) the internal resistance of **one** cell.

[2]

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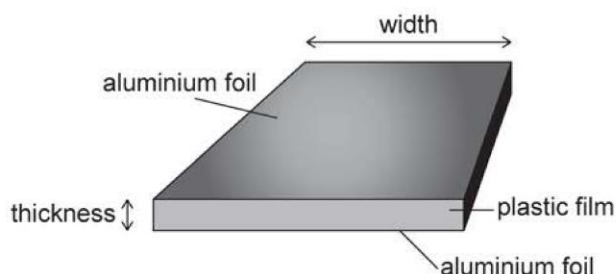
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11 – (PHYSI/21_HL_Summer_2019_Q8) – *Electromagnetic Induction (ahl), Electricity & Magnetism*



A student makes a parallel-plate capacitor of capacitance 68 nF from aluminium foil and plastic film by inserting one sheet of plastic film between two sheets of aluminium foil.

diagram not to scale



The aluminium foil and the plastic film are 450 mm wide.

The plastic film has a thickness of 55 μm and a permittivity of $2.5 \times 10^{-11} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$.

- (a) (i) Calculate the total length of aluminium foil that the student will require. [3]

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- (ii) The plastic film begins to conduct when the electric field strength in it exceeds 1.5 MN C^{-1} . Calculate the maximum charge that can be stored on the capacitor. [2]

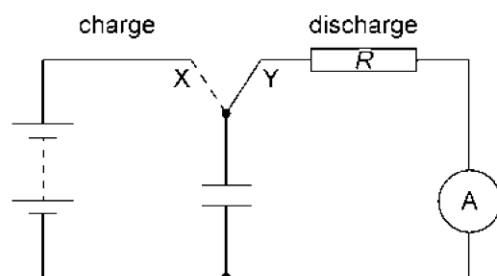
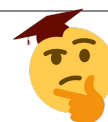
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- (b) The student uses a switch to charge and discharge the capacitor using the circuit shown. The ammeter is ideal.



The emf of the battery is 12 V.

- (i) The resistor R in the circuit has a resistance of $1.2 \text{ k}\Omega$. Calculate the time taken for the charge on the capacitor to fall to 50 % of its fully charged value.

[3]

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- (ii) The ammeter is replaced by a coil. Explain why there will be an induced emf in the coil while the capacitor is discharging.

[2]

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- (iii) Suggest **one** change to the discharge circuit, apart from changes to the coil, that will increase the maximum induced emf in the coil.

[2]

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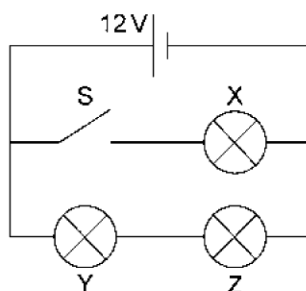
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12 – (PHYSI/22_HL_Summer_2019_Q4) – Electricity & Magnetism



Three identical light bulbs, X, Y and Z, each of resistance $4.0\,\Omega$ are connected to a cell of emf $12\,\text{V}$. The cell has negligible internal resistance.



- (a) The switch S is initially open. Calculate the total power dissipated in the circuit. [2]

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- (b) The switch is now closed.

- (i) State, without calculation, why the current in the cell will increase. [1]

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- (ii) Deduce the ratio $\frac{\text{power dissipated in Y with S open}}{\text{power dissipated in Y with S closed}}$. [2]

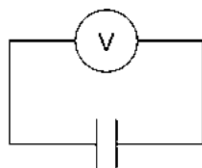
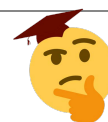
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- (c) The cell is used to charge a parallel-plate capacitor in a vacuum. The fully charged capacitor is then connected to an ideal voltmeter.



The capacitance of the capacitor is $6.0\mu\text{F}$ and the reading of the voltmeter is 12V .

Calculate the energy stored in the capacitor.

[1]

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- (d) When fully charged the space between the plates of the capacitor is filled with a dielectric with double the permittivity of a vacuum.

(i) Calculate the change in the energy stored in the capacitor.

[3]

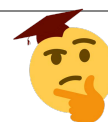
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(ii) Suggest, in terms of conservation of energy, the cause for the above change.

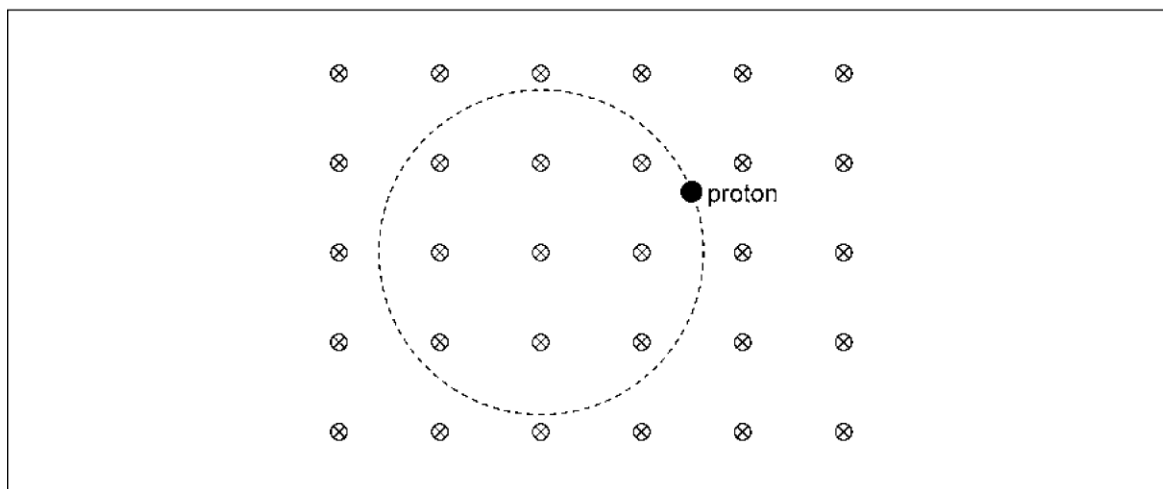
[1]

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13 – (PHYSI/22_HL_Summer_2019_Q5) – Electricity & Magnetism, Circular Motion & Gravitation



A proton moves along a circular path in a region of a uniform magnetic field. The magnetic field is directed into the plane of the page.



- (a) Label with arrows on the diagram the
- (i) magnetic force F on the proton. [1]
 - (ii) velocity vector v of the proton. [1]
- (b) The speed of the proton is $2.16 \times 10^6 \text{ m s}^{-1}$ and the magnetic field strength is 0.042 T . For this proton,
- (i) determine, in m, the radius of the circular path. Give your answer to an appropriate number of significant figures. [3]

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- (ii) calculate, in s, the time for one full revolution. [2]

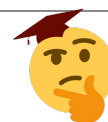
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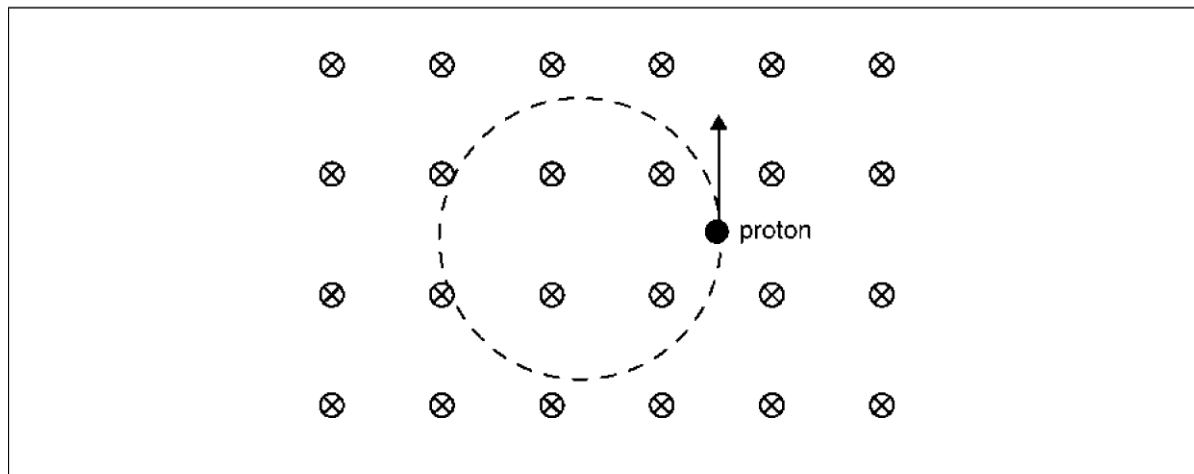
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14 – (PHYSI/20_HL_Winter_2019_Q4) – Electricity & Magnetism, Circular Motion & Gravitation



A proton is moving in a region of uniform magnetic field. The magnetic field is directed into the plane of the paper. The arrow shows the velocity of the proton at one instant and the dotted circle gives the path followed by the proton.



(a) Explain why the path of the proton is a circle.

[2]

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(b) The speed of the proton is $2.0 \times 10^6 \text{ m s}^{-1}$ and the magnetic field strength B is 0.35 T .

(i) Show that the radius of the path is about 6 cm .

[2]

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(ii) Calculate the time for **one** complete revolution.

[2]



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(c) Explain why the kinetic energy of the proton is constant.

[2]

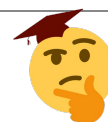
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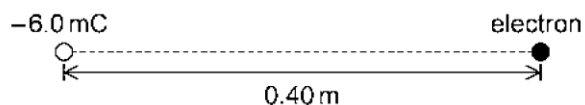
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15 – (PHYSI/20_HL_Winter_2019_Q5) – Electricity & Magnetism



An electron is placed at a distance of 0.40 m from a fixed point charge of -6.0 mC .



- (a) Show that the electric field strength due to the point charge at the position of the electron is $3.4 \times 10^8 \text{ NC}^{-1}$.

[2]

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- (b) (i) Calculate the magnitude of the initial acceleration of the electron.

[2]

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- (ii) Describe the subsequent motion of the electron.

[3]

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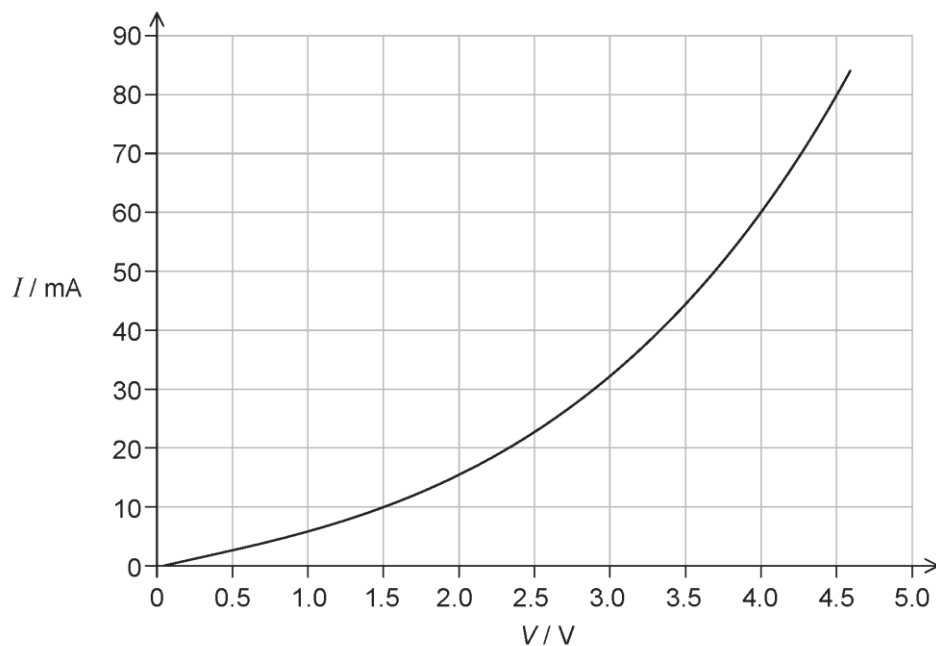
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16 – (PHYSI/20_HL_Winter_2020_Q5) – Electricity & Magnetism



The graph shows how current I varies with potential difference V across a component X.

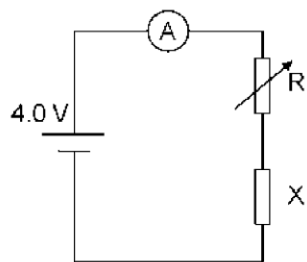


(a) Outline why component X is considered non-ohmic.

[1]

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- (b) Component X and a cell of negligible internal resistance are placed in a circuit. A variable resistor R is connected in series with component X. The ammeter reads 20 mA.



- (i) Determine the resistance of the variable resistor.

[3]

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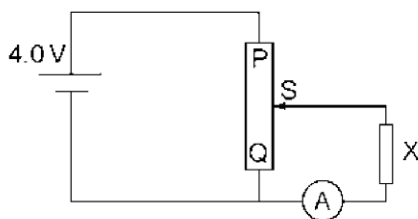
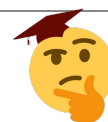
- (ii) Calculate the power dissipated in the circuit.

[1]

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- (c) Component X and the cell are now placed in a potential divider circuit.



- (i) State the range of current that the ammeter can measure as the slider S of the potential divider is moved from Q to P.

[1]

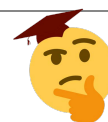
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- (ii) Slider S of the potential divider is positioned so that the ammeter reads 20 mA. Explain, without further calculation, any difference in the power transferred by the potential divider arrangement over the arrangement in (b).

[3]

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17 – (PHYSI/21_HL_Summer_2021_Q3) – Thermal Physics, Electricity & Magnetism



A mass of 1.0 kg of water is brought to its boiling point of 100°C using an electric heater of power 1.6 kW.

- (a) (i) The molar mass of water is 18 g mol^{-1} . Estimate the average speed of the water molecules in the vapor produced. Assume the vapor behaves as an ideal gas. [2]

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- (ii) State **one** assumption of the kinetic model of an ideal gas. [1]

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- (b) A mass of 0.86 kg of water remains after it has boiled for 200 s.

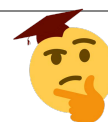
- (i) Estimate the specific latent heat of vaporization of water. State an appropriate unit for your answer. [2]

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- (ii) Explain why the temperature of water remains at 100°C during this time. [1]

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- (c) The heater is removed and a mass of 0.30 kg of pasta at -10°C is added to the boiling water.



Determine the equilibrium temperature of the pasta and water after the pasta is added. Other heat transfers are negligible.

Specific heat capacity of pasta = $1.8 \text{ kJ kg}^{-1} \text{ K}^{-1}$

Specific heat capacity of water = $4.2 \text{ kJ kg}^{-1} \text{ K}^{-1}$

[3]

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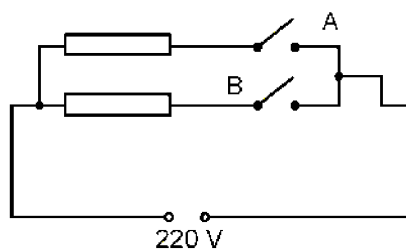
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- (d) The electric heater has two identical resistors connected in parallel.



The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

- (i) Show that each resistor has a resistance of about 30Ω .

[1]

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- (ii) Calculate the power transferred by the heater when both switches are closed.

[2]

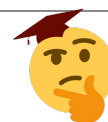
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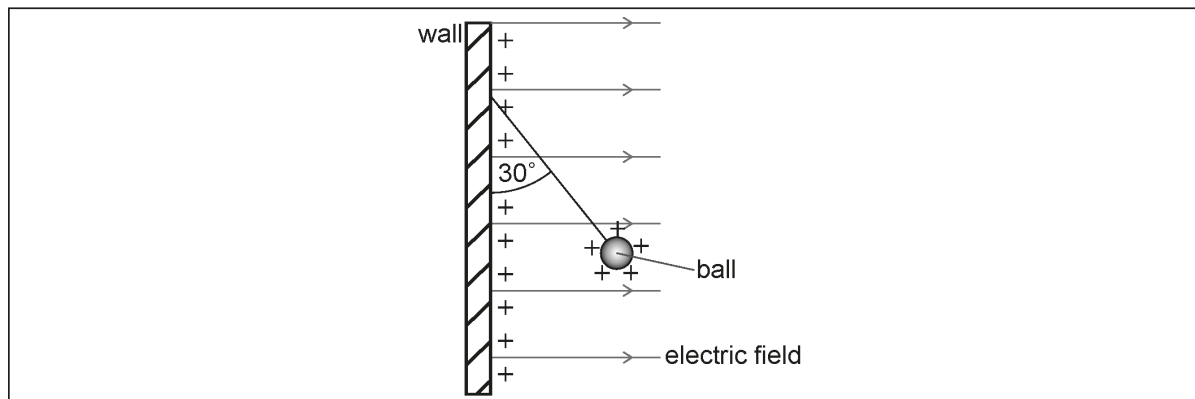
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18 - (PHYSI/22_HL_Summer_2021_Q3) - Electricity & Magnetism



A vertical wall carries a uniform positive charge on its surface. This produces a uniform horizontal electric field perpendicular to the wall. A small, positively-charged ball is suspended in equilibrium from the vertical wall by a thread of negligible mass.



- (a) The charge per unit area on the surface of the wall is σ . It can be shown that the electric field strength E due to the charge on the wall is given by the equation

$$E = \frac{\sigma}{2\epsilon_0}.$$

Demonstrate that the units of the quantities in this equation are consistent.

[2]

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- (b) (i) The thread makes an angle of 30° with the vertical wall. The ball has a mass of 0.025 kg.

Determine the horizontal force that acts on the ball.

[3]

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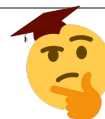
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(ii) The charge on the ball is $1.2 \times 10^{-6} \text{ C}$. Determine σ .

[2]



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(c) The thread breaks. Explain the initial subsequent motion of the ball.

[3]

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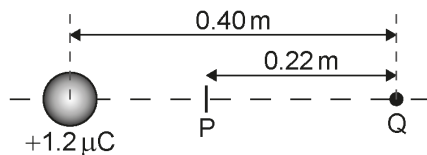
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- (d) The centre of the ball, still carrying a charge of $1.2 \times 10^{-6} \text{ C}$, is now placed 0.40 m from a point charge Q. The charge on the ball acts as a point charge at the centre of the ball.



P is the point on the line joining the charges where the electric field strength is zero.
The distance PQ is 0.22 m.



- (i) Calculate the charge on Q. State your answer to an appropriate number of significant figures.

[3]

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- (ii) Outline, without calculation, whether or not the electric potential at P is zero.

[2]

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19 - (PHYSI/22_HL_Summer_2021_Q5) - Electricity & Magnetism

(a) Describe **two** ways in which standing waves differ from travelling waves.

[2]

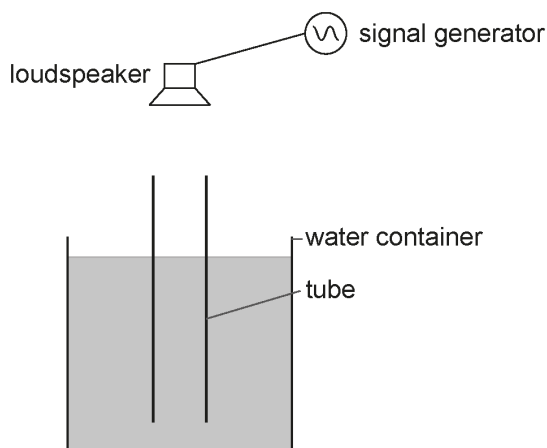
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(b) A vertical tube, open at both ends, is completely immersed in a container of water. A loudspeaker above the container connected to a signal generator emits sound. As the tube is raised the loudness of the sound heard reaches a maximum because a standing wave has formed in the tube.



(i) Outline how a standing wave forms in the tube.

[2]

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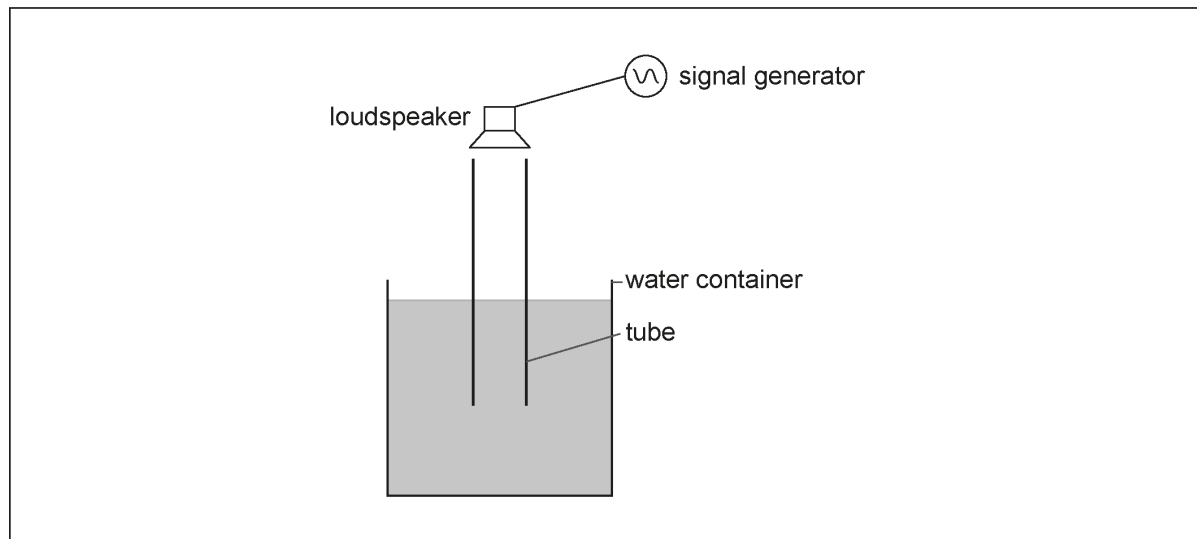
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- (ii) The tube is raised until the loudness of the sound reaches a maximum for a **second time**.



Draw, on the following diagram, the position of the nodes in the tube when the second maximum is heard.

[1]



- (iii) Between the first and second positions of maximum loudness, the tube is raised through 0.37 m. The speed of sound in the air in the tube is 320 m s^{-1} . Determine the frequency of the sound emitted by the loudspeaker.

[2]

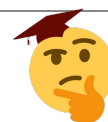
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20 – (PHYSI/22_HL_Summer_2021_Q6) – Electricity & Magnetism, Energy Production



A photovoltaic cell is supplying energy to an external circuit. The photovoltaic cell can be modelled as a practical electrical cell with internal resistance.

The intensity of solar radiation incident on the photovoltaic cell at a particular time is at a maximum for the place where the cell is positioned.

The following data are available for this particular time:

Operating current = 0.90 A
Output potential difference to external circuit = 14.5 V
Output emf of photovoltaic cell = 21.0 V
Area of panel = 350 mm × 450 mm

- (a) Explain why the output potential difference to the external circuit and the output emf of the photovoltaic cell are different. [2]

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- (b) Calculate the internal resistance of the photovoltaic cell for the maximum intensity condition using the model for the cell. [3]

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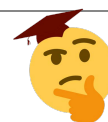
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- (c) The maximum intensity of sunlight incident on the photovoltaic cell at the place on the Earth's surface is 680 W m^{-2} .



A measure of the efficiency of a photovoltaic cell is the ratio

$$\frac{\text{energy available every second to the external circuit}}{\text{energy arriving every second at the photovoltaic cell surface}}$$

Determine the efficiency of this photovoltaic cell when the intensity incident upon it is at a maximum.

[3]

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- (d) State **two** reasons why future energy demands will be increasingly reliant on sources such as photovoltaic cells.

[2]

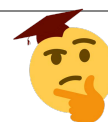
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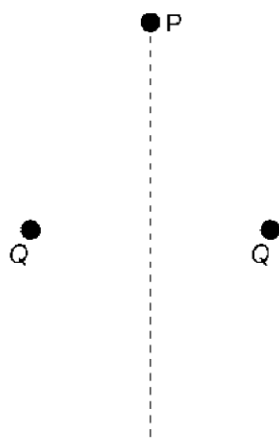
Reason 2:

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21 – (PHYSI/20_HL_Winter_2021_Q3) – Electricity & Magnetism



Two equal positive fixed point charges $Q = +44\text{ }\mu\text{C}$ and point P are at the vertices of an equilateral triangle of side 0.48 m .



- (a) (i) Show that the magnitude of the resultant electric field at P is 3 MN C^{-1} [2]

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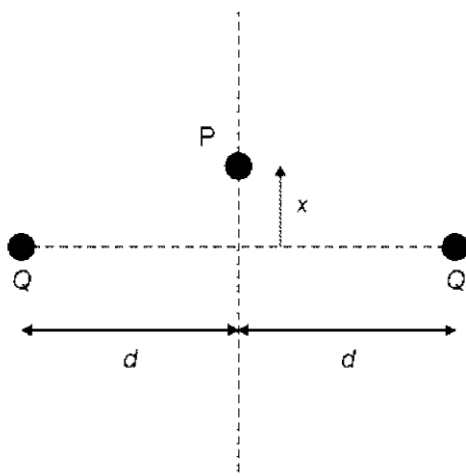
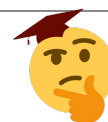
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- (ii) State the direction of the resultant electric field at P. [1]

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- (b) Point P is now moved closer to the charges.



A point charge $q = -2.0\mu\text{C}$ and mass 0.25 kg is placed at P. When x is small compared to d , the magnitude of the net force on q is $F \approx 115x$.

- (i) Explain why q will perform simple harmonic oscillations when it is released. [2]

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- (ii) Calculate the period of oscillations of q . [2]

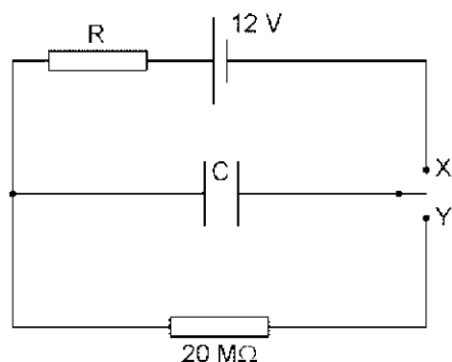
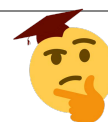
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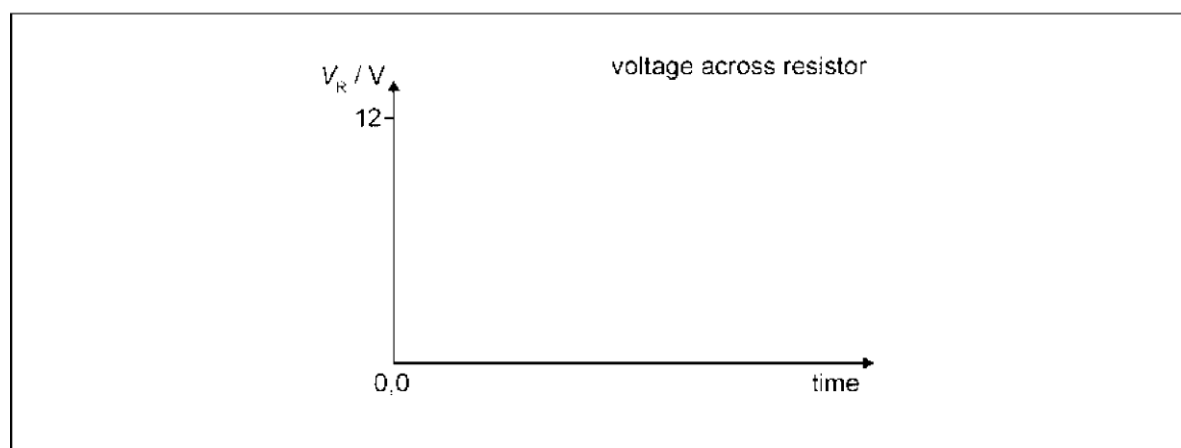
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- (c) An uncharged parallel plate capacitor C is connected to a cell of emf 12 V , a resistor R and another resistor of resistance $20\text{ M}\Omega$.



- (i) At $t = 0$, the switch is connected to X. On the axes, draw a sketch graph to show the variation with time of the voltage V_R across R . [2]



- (ii) The switch is then connected to Y and C discharges through the $20\text{ M}\Omega$ resistor. The voltage V_C drops to 50% of its initial value in 5.0 s . Determine the capacitance of C . [2]

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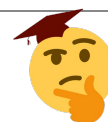
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22 – (PHYSI/20_HL_Winter_2021_Q7) – Electricity & Magnetism

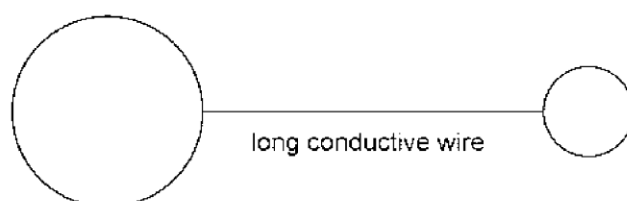


A conducting sphere has radius 48 cm. The electric potential on the surface of the sphere is $3.4 \times 10^5 \text{ V}$.

- (a) Show that the charge on the surface of the sphere is $+18 \mu\text{C}$. [1]

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- (b) The sphere is connected by a long conducting wire to a second conducting sphere of radius 24 cm. The second sphere is initially uncharged.



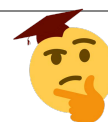
- (i) Describe, in terms of electron flow, how the smaller sphere becomes charged. [1]

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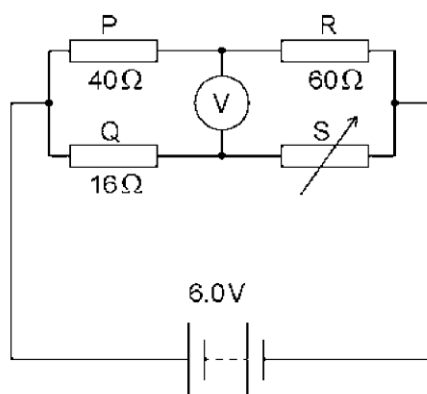
- (ii) Predict the charge on each sphere. [3]

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23 – (PHYSI/21_HL_Summer_2022_Q4) – Electricity & Magnetism



A power supply is connected to three resistors P, Q and R of fixed value and to an ideal voltmeter. A variable resistor S, formed from a solid cylinder of conducting putty, is also connected in the circuit. Conducting putty is a material that can be moulded so that the resistance of S can be changed by re-shaping it.



The resistance values of P, Q and R are 40Ω , 16Ω and 60Ω respectively. The emf of the power supply is 6.0V and its internal resistance is negligible.

(a) Calculate the potential difference across P.

[2]

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(b) The voltmeter reads zero. Determine the resistance of S.

[3]

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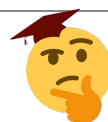
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(c) All the putty is reshaped into a solid cylinder that is four times longer than the original length.



(i) Deduce the resistance of this new cylinder when it has been reshaped.

[3]

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(ii) Outline, without calculation, the change in the total power dissipated in Q and the new cylinder after it has been reshaped.

[2]

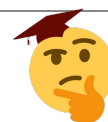
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24 – (PHYSI/22_HL_Summer_2022_Q4) – Electricity & Magnetism



- (a) Identify the laws of conservation that are represented by Kirchhoff's circuit laws.

[2]

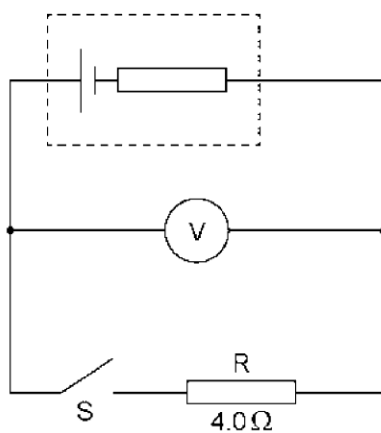
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- (b) A cell is connected to an ideal voltmeter, a switch S and a resistor R. The resistance of R is $4.0\ \Omega$.



When S is open the reading on the voltmeter is 12 V. When S is closed the voltmeter reads 8.0 V.

- (i) State the emf of the cell.

[1]

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- (ii) Deduce the internal resistance of the cell.

[2]

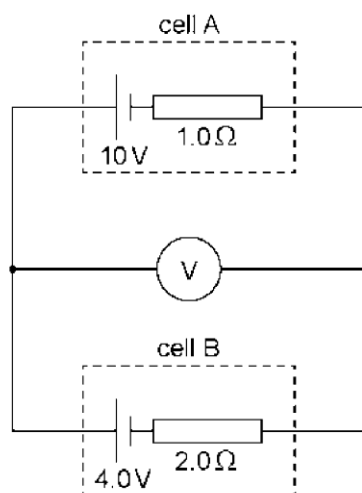
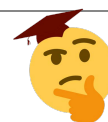
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- (c) The voltmeter is used in another circuit that contains two secondary cells.



Cell A has an emf of 10V and an internal resistance of 1.0Ω . Cell B has an emf of 4.0V and an internal resistance of 2.0Ω .

- (i) Calculate the reading on the voltmeter.

[3]

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- (ii) Comment on the implications of your answer to (c)(i) for cell B.

[1]

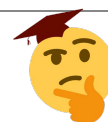
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(d) Electricity can be generated using renewable resources.

(i) Outline why electricity is a secondary energy source.

[1]



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(ii) Some fuel sources are renewable. Outline what is meant by renewable.

[1]

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(e) (i) A fully charged cell of emf 6.0V delivers a constant current of 5.0A for a time of 0.25 hour until it is completely discharged.

The cell is then re-charged by a rectangular solar panel of dimensions $0.40\text{ m} \times 0.15\text{ m}$ at a place where the maximum intensity of sunlight is 380 W m^{-2} .

The overall efficiency of the re-charging process is 18%.

Calculate the minimum time required to re-charge the cell fully.

[3]

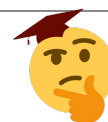
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(ii) Outline why research into solar cell technology is important to society.

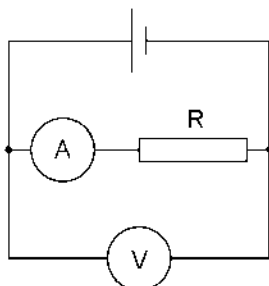
[1]

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25 – (PHYSI/20_HL_Winter_2022_Q5) – Electricity & Magnetism



Resistor R is connected in a circuit with a cell that has internal resistance.



The ammeter and the voltmeter are ideal.

- (a) State what is meant by an ideal voltmeter. [1]

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- (b) The resistance of R is $50.0\ \Omega$. The voltmeter reads 1.47 V .

- (i) Calculate, in mA, the current in the resistor. [1]

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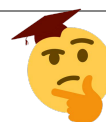
Resistor R is replaced by another of resistance $10.0\ \Omega$. The ammeter now reads 139 mA .

- (ii) Show that the internal resistance of the cell is about $0.7\ \Omega$. [2]

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(iii) Calculate the emf of the cell.

[2]



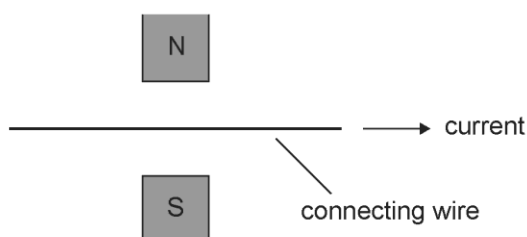
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One of the connecting wires is placed in a magnetic field. The direction of the current in the wire is shown.



(c) (i) Explain, by reference to charge carriers in the wire, how the magnetic force on the wire arises.

[2]

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(ii) Identify the direction of the magnetic force on the wire.

[1]

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1 - (PHYSI/22_HL_Summer_2017_Q8) - Circular Motion & Gravitation



The gravitational potential due to the Sun at its surface is $-1.9 \times 10^{11} \text{ J kg}^{-1}$. The following data are available.

Mass of Earth $= 6.0 \times 10^{24} \text{ kg}$
Distance from Earth to Sun $= 1.5 \times 10^{11} \text{ m}$
Radius of Sun $= 7.0 \times 10^8 \text{ m}$

- (a) Outline why the gravitational potential is negative. [2]

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- (b) (i) The gravitational potential due to the Sun at a distance r from its centre is V_s .
Show that

$$rV_s = \text{constant.} \quad [1]$$

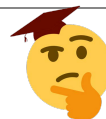
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- (ii) Calculate the gravitational potential energy of the Earth in its orbit around the Sun.
Give your answer to an appropriate number of significant figures. [2]

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- (iii) Calculate the total energy of the Earth in its orbit.

[2]



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- (iv) An asteroid strikes the Earth and causes the orbital speed of the Earth to suddenly decrease. Suggest the ways in which the orbit of the Earth will change. [2]

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- (c) Outline, in terms of the force acting on it, why the Earth remains in a circular orbit around the Sun.

[2]

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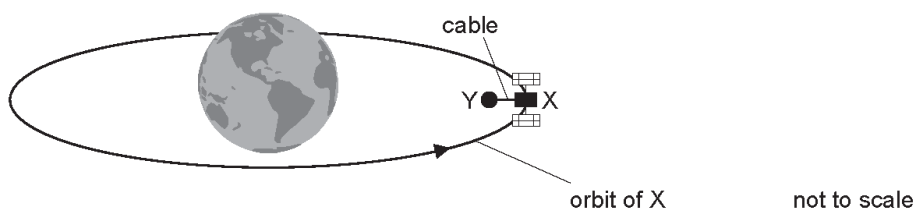
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2 - (PHYSI/20_HL_Winter_2017_Q2) - Circular Motion & Gravitation, Oscillations & Waves, Fields (ahl)



There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



- (a) Satellite X orbits 6600 km from the centre of the Earth.

$$\text{Mass of the Earth} = 6.0 \times 10^{24} \text{ kg}$$

Show that the orbital speed of satellite X is about 8 km s^{-1} . [2]

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- (b) Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

- (i) the orbital times for X and Y are different. [1]

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- (ii) satellite Y requires a propulsion system. [2]

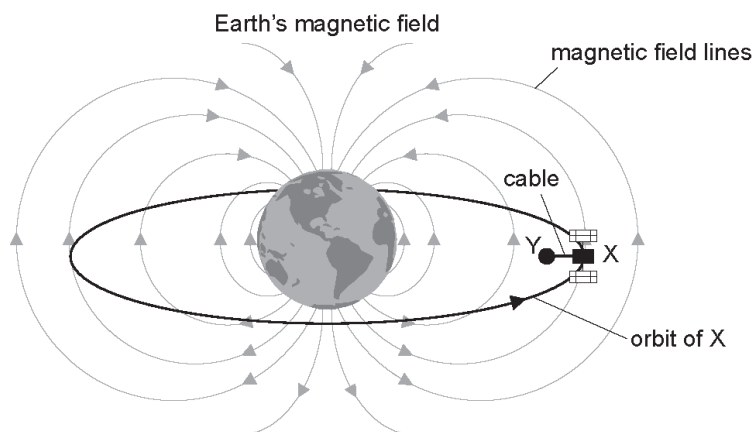
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- (c) The cable between the satellites cuts the magnetic field lines of the Earth at right angles.



Explain why satellite X becomes positively charged.

[3]

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- (d) Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y.

[3]

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- (e) The magnetic field strength of the Earth is $31 \mu\text{T}$ at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]



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- (f) The cable acts as a spring. Satellite Y has a mass m of $3.5 \times 10^2 \text{ kg}$. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period T of 5.2 s.

- (i) Estimate the value of k in the following expression.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X. [3]

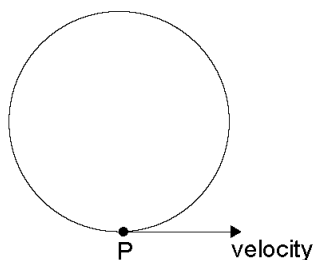
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- (ii) Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. [2]

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3 – (PHYSI/21_HL_Summer_2018_Q5) – *Electricity & Magnetism, Circular Motion & Gravitation*

An electron moves in circular motion in a uniform magnetic field.



The velocity of the electron at point P is $6.8 \times 10^5 \text{ ms}^{-1}$ in the direction shown.
The magnitude of the magnetic field is 8.5 T.

- (a) State the direction of the magnetic field. [1]

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- (b) Calculate, in N, the magnitude of the magnetic force acting on the electron. [1]

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- (c) Explain why the electron moves

- (i) at constant speed. [1]

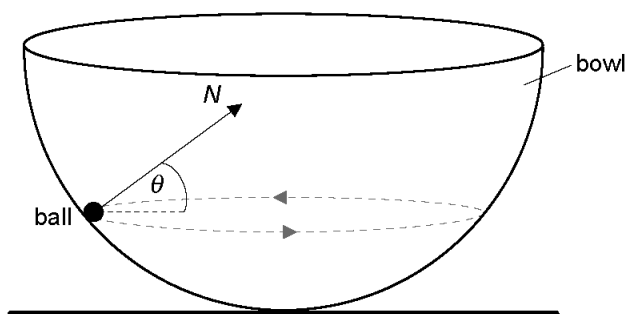
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- (ii) on a circular path. [2]

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4 - (PHYSI/22_HL_Summer_2018_Q1) - *Mechanics, Circular Motion & Gravitation*

- (a) A small ball of mass m is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.

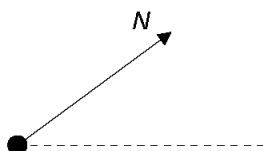


The normal reaction force N makes an angle θ to the horizontal.

- (i) State the direction of the resultant force on the ball. [1]

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- (ii) On the diagram, construct an arrow of the correct length to represent the weight of the ball. [2]



- (iii) Show that the magnitude of the net force F on the ball is given by the following equation.

[3]



$$F = \frac{mg}{\tan \theta}$$

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- (b) The radius of the bowl is 8.0 m and $\theta = 22^\circ$. Determine the speed of the ball.

[4]

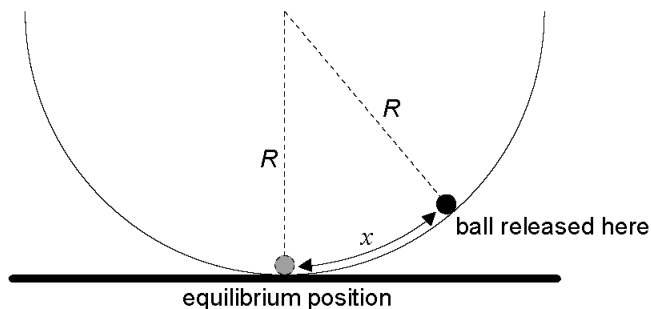
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- (c) Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl.

[2]

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- (d) The ball is now displaced through a small distance x from the bottom of the bowl and is then released from rest.



The magnitude of the force on the ball towards the equilibrium position is given by

$$\frac{mgx}{R}$$

where R is the radius of the bowl.

- (i) Outline why the ball will perform simple harmonic oscillations about the equilibrium position.

[1]

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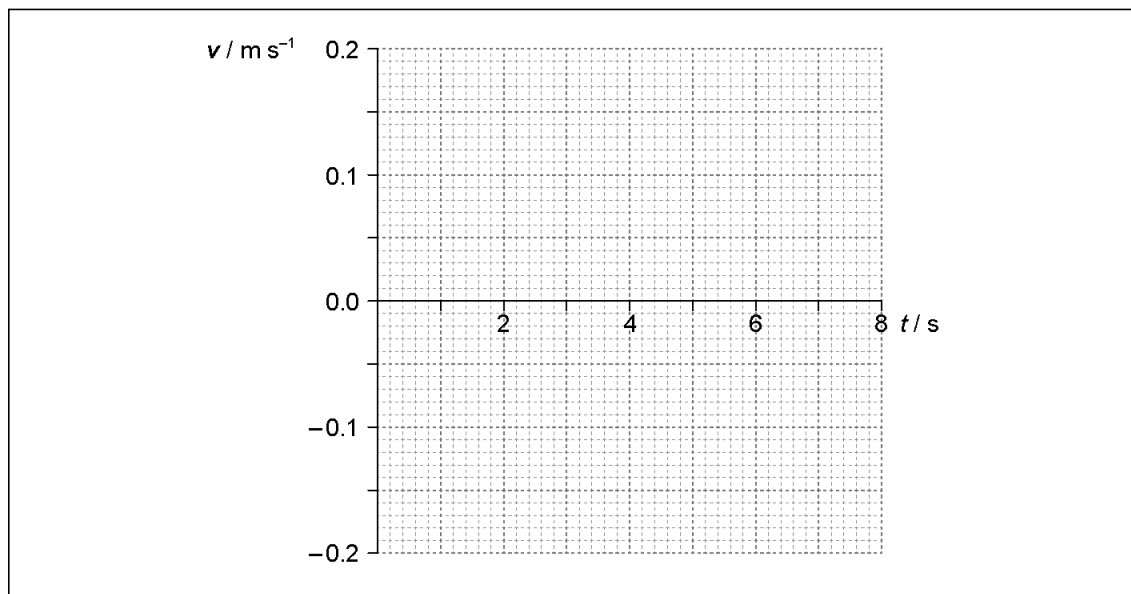
- (ii) Show that the period of oscillation of the ball is about 6 s.

[2]

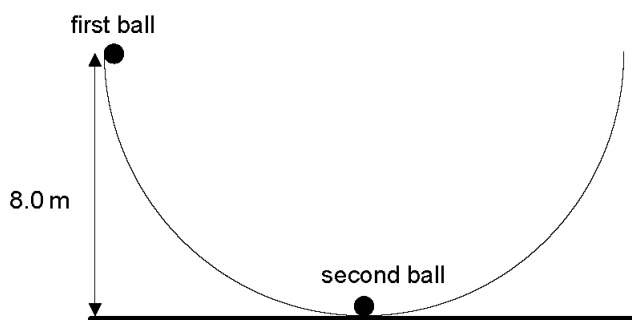
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- (iii) The amplitude of oscillation is 0.12 m. On the axes, draw a graph to show the variation with time t of the velocity v of the ball during one period.

[3]



- (e) A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m.



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Calculate, in m, the maximum height reached by the two balls.

[3]

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5 - (PHYSI/22_HL_Summer_2018_Q6) - *Circular Motion & Gravitation, Fields (ahl)*

- (a) A planet has radius R . At a distance h above the surface of the planet the gravitational field strength is g and the gravitational potential is V .

- (i) State what is meant by gravitational field strength. [1]

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- (ii) Show that $V = -g(R + h)$. [2]

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- (iii) Draw a graph, on the axes, to show the variation of the gravitational potential V of the planet with height h above the surface of the planet. [2]



- (b) A planet has a radius of 3.1×10^6 m. At a point P a distance 2.4×10^7 m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1} . Calculate the gravitational potential at point P, include an appropriate unit for your answer.

[1]



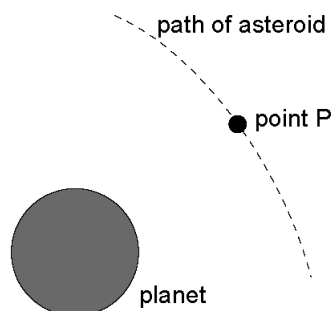
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- (c) The diagram shows the path of an asteroid as it moves past the planet.



When the asteroid was far away from the planet it had negligible speed.
Estimate the speed of the asteroid at point P as defined in (b).

[3]

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- (d) The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the planet when the asteroid is at point P.

[2]

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6 - (PHYSI/20_HL_Winter_2018_Q8) - *Circular Motion & Gravitation*

There is a proposal to place a satellite in orbit around planet Mars.

- (a) (i) Outline what is meant by gravitational field strength at a point.

[2]

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- (ii) Newton's law of gravitation applies to point masses. Suggest why the law can be applied to a satellite orbiting Mars.

[2]

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- (b) The satellite is to have an orbital time T equal to the length of a day on Mars. It can be shown that

$$T^2 = kR^3$$

where R is the orbital radius of the satellite and k is a constant.

- (i) Mars has a mass of 6.4×10^{23} kg. Show that, for Mars, k is about $9 \times 10^{-13} \text{ s}^2 \text{ m}^{-3}$. [3]

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- (ii) The time taken for Mars to revolve on its axis is 8.9×10^4 s. Calculate, in m s^{-1} , the orbital speed of the satellite. [2]

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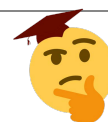
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- (c) The ratio $\frac{\text{distance of Mars from the Sun}}{\text{distance of Earth from the Sun}} = 1.5$.



- (i) Show that the intensity of solar radiation at the orbit of Mars is about 600 W m^{-2} . [2]

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- (ii) Determine, in K, the mean surface temperature of Mars. Assume that Mars acts as a black body. [2]

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- (iii) The atmosphere of Mars is composed mainly of carbon dioxide and has a pressure less than 1 % of that on Earth. Outline why the mean temperature of Earth is strongly affected by gases in its atmosphere but that of Mars is not. [3]

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7 – (PHYSI/21_HL_Summer_2019_Q5) – *Circular Motion & Gravitation*

(a) The moon Phobos moves around the planet Mars in a circular orbit.

(i) Outline the origin of the force that acts on Phobos.

[1]

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(ii) Outline why this force does no work on Phobos.

[1]

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(b) The orbital period T of a moon orbiting a planet of mass M is given by

$$\frac{R^3}{T^2} = kM$$

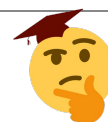
where R is the average distance between the centre of the planet and the centre of the moon.

(i) Show that $k = \frac{G}{4\pi^2}$

[3]

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- (ii) The following data for the Mars–Phobos system and the Earth–Moon system are available:



Mass of Earth = 5.97×10^{24} kg

The Earth–Moon distance is 41 times the Mars–Phobos distance.

The orbital period of the Moon is 86 times the orbital period of Phobos.

Calculate, in kg, the mass of Mars.

[2]

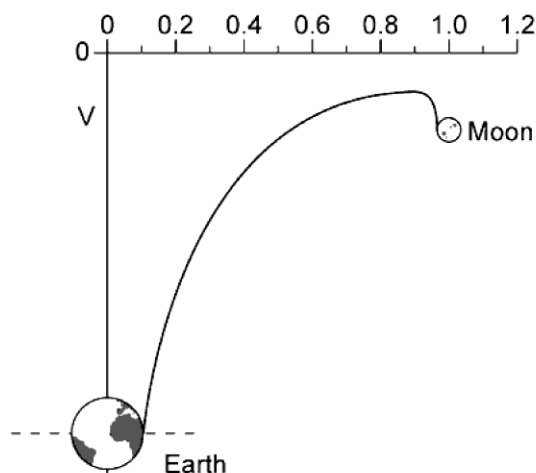
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- (c) The graph shows the variation of the gravitational potential between the Earth and Moon with distance from the centre of the Earth. The distance from the Earth is expressed as a fraction of the total distance between the centre of the Earth and the centre of the Moon.



Determine, using the graph, the mass of the Moon.

[3]

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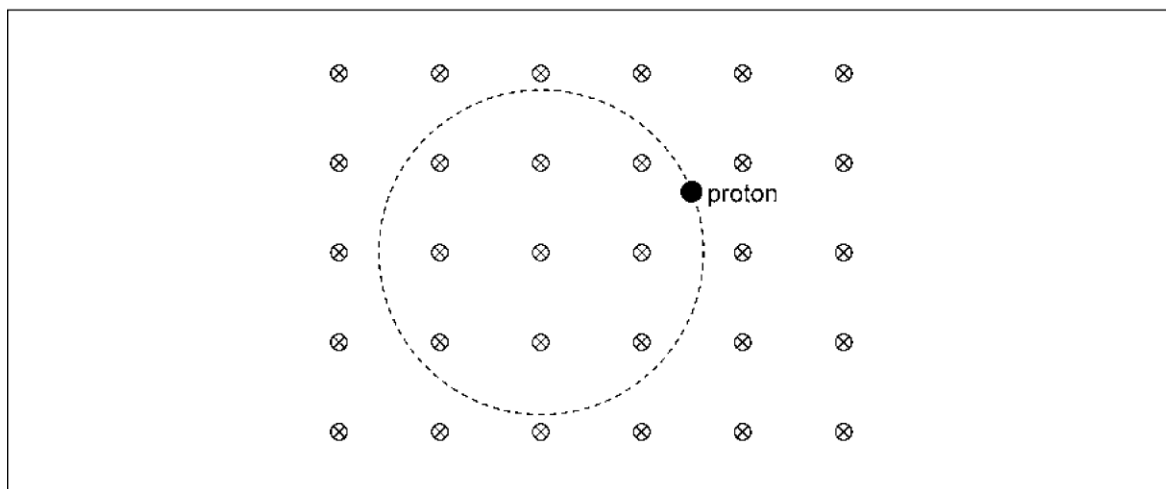
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8 – (PHYSI/22_HL_Summer_2019_Q5) – Electricity & Magnetism, Circular Motion & Gravitation



A proton moves along a circular path in a region of a uniform magnetic field. The magnetic field is directed into the plane of the page.



- (a) Label with arrows on the diagram the
- (i) magnetic force F on the proton. [1]
 - (ii) velocity vector v of the proton. [1]
- (b) The speed of the proton is $2.16 \times 10^6 \text{ m s}^{-1}$ and the magnetic field strength is 0.042 T . For this proton,
- (i) determine, in m, the radius of the circular path. Give your answer to an appropriate number of significant figures. [3]

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- (ii) calculate, in s, the time for one full revolution. [2]

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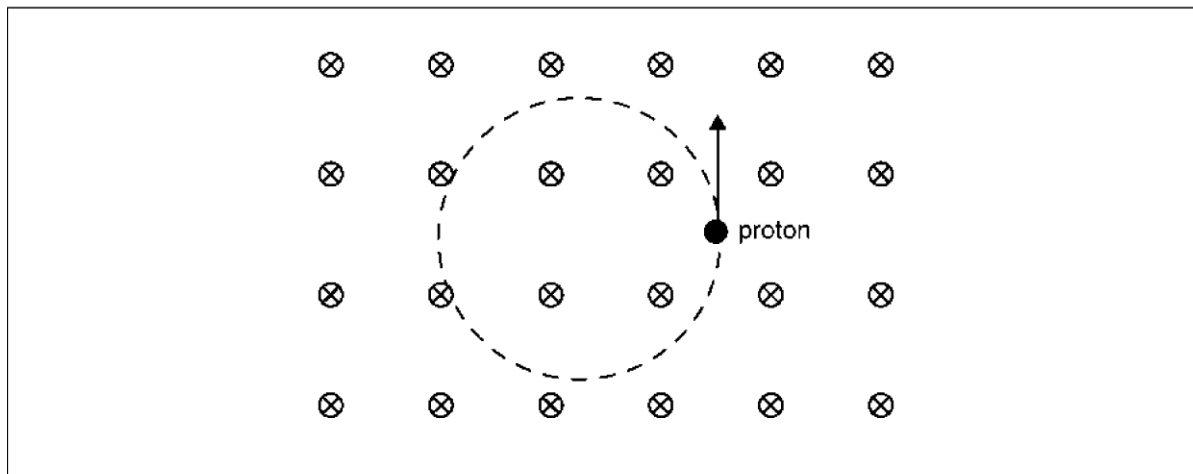
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9 - (PHYSI/20_HL_Winter_2019_Q4) - Electricity & Magnetism, Circular Motion & Gravitation



A proton is moving in a region of uniform magnetic field. The magnetic field is directed into the plane of the paper. The arrow shows the velocity of the proton at one instant and the dotted circle gives the path followed by the proton.



(a) Explain why the path of the proton is a circle.

[2]

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(b) The speed of the proton is $2.0 \times 10^6 \text{ m s}^{-1}$ and the magnetic field strength B is 0.35 T .

(i) Show that the radius of the path is about 6 cm .

[2]

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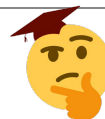
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(ii) Calculate the time for **one** complete revolution.

[2]



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(c) Explain why the kinetic energy of the proton is constant.

[2]

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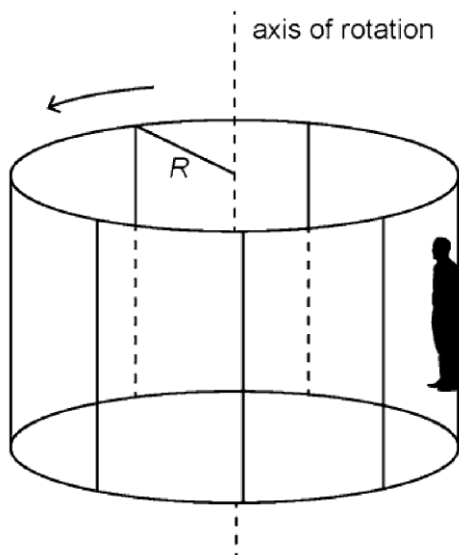
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10 - (PHYSI/20_HL_Winter_2020_Q2) - Circular Motion & Gravitation



The Rotor is an amusement park ride that can be modelled as a vertical cylinder of inner radius R rotating about its axis. When the cylinder rotates sufficiently fast, the floor drops out and the passengers stay motionless against the inner surface of the cylinder. The diagram shows a person taking the Rotor ride. The floor of the Rotor has been lowered away from the person.



(a) Draw and label the free-body diagram for the person.

[2]



- (b) The person must not slide down the wall. Show that the minimum angular velocity ω of the cylinder for this situation is



$$\omega = \sqrt{\frac{g}{\mu R}}$$

where μ is the coefficient of static friction between the person and the cylinder.

[2]

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- (c) The coefficient of static friction between the person and the cylinder is 0.40. The radius of the cylinder is 3.5 m. The cylinder makes 28 revolutions per minute. Deduce whether the person will slide down the inner surface of the cylinder.

[3]

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11 – (PHYSI/21_HL_Summer_2021_Q2) – *Circular Motion & Gravitation, Fields (ahl)*



A planet is in a circular orbit around a star. The speed of the planet is constant. The following data are given:

$$\text{Mass of planet} = 8.0 \times 10^{24} \text{ kg}$$

$$\text{Mass of star} = 3.2 \times 10^{30} \text{ kg}$$

$$\text{Distance from the star to the planet } R = 4.4 \times 10^{10} \text{ m.}$$

(a) Explain why a centripetal force is needed for the planet to be in a circular orbit. [2]

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(b) Calculate the value of the centripetal force. [1]

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- (c) A spacecraft is to be launched from the surface of the planet to escape from the star system. The radius of the planet is $9.1 \times 10^3 \text{ km}$.



- (i) Show that the gravitational potential due to the planet and the star at the surface of the planet is about $-5 \times 10^9 \text{ J kg}^{-1}$.

[3]

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- (ii) Estimate the escape speed of the spacecraft from the planet–star system.

[2]

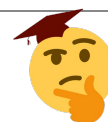
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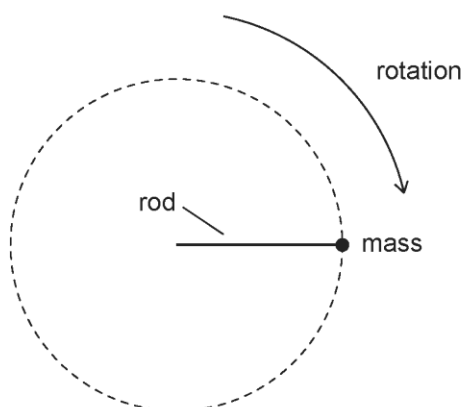
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12 – (PHYSI/20_HL_Winter_2022_Q4) – Circular Motion & Gravitation



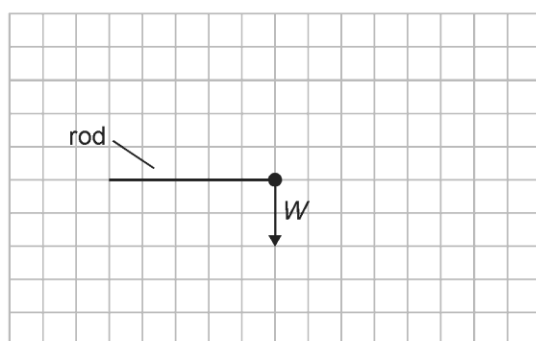
A mass is attached to one end of a rod and made to rotate with constant speed in a vertical circle.



- (a) The scale diagram shows the weight W of the mass at an instant when the rod is horizontal.

Draw, on the scale diagram, an arrow to represent the force exerted on the mass by the rod.

[2]



- (b) Explain why the magnitude of the force exerted on the mass by the rod is not constant.

[3]

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1 - (PHYSI/21_HL_Summer_2017_Q5) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



(a) State the quark structures of a meson and a baryon.

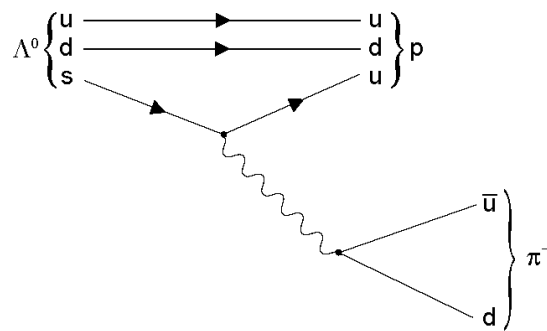
[2]

Meson:

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Baryon:

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(b) A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.

(i) Explain which interaction is responsible for this decay.

[2]

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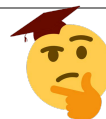
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(ii) Draw arrow heads on the lines representing $\bar{u}$ and d in the π^- .

[1]

(iii) Identify the exchange particle in this decay.

[1]



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(c) Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators.

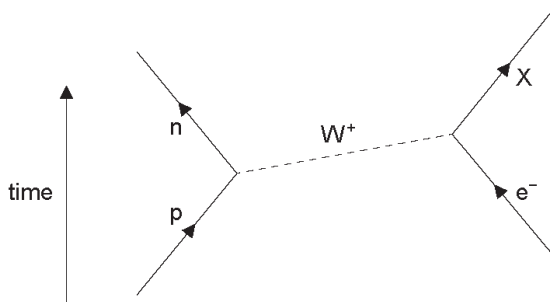
[1]

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2 - (PHYSI/20_HL_Winter_2017_Q3) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl), Measurements & Uncertainties



(a) The Feynman diagram shows electron capture.



(i) State and explain the nature of the particle labelled X.

[3]

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(ii) Distinguish between hadrons and leptons.

[2]

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(b) Particles can be used in scattering experiments to estimate nuclear sizes.



(i) Outline how these experiments are carried out.

[2]

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(ii) Outline why the particles must be accelerated to high energies in scattering experiments.

[3]

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(c) State and explain **one** example of a scientific analogy.

[2]

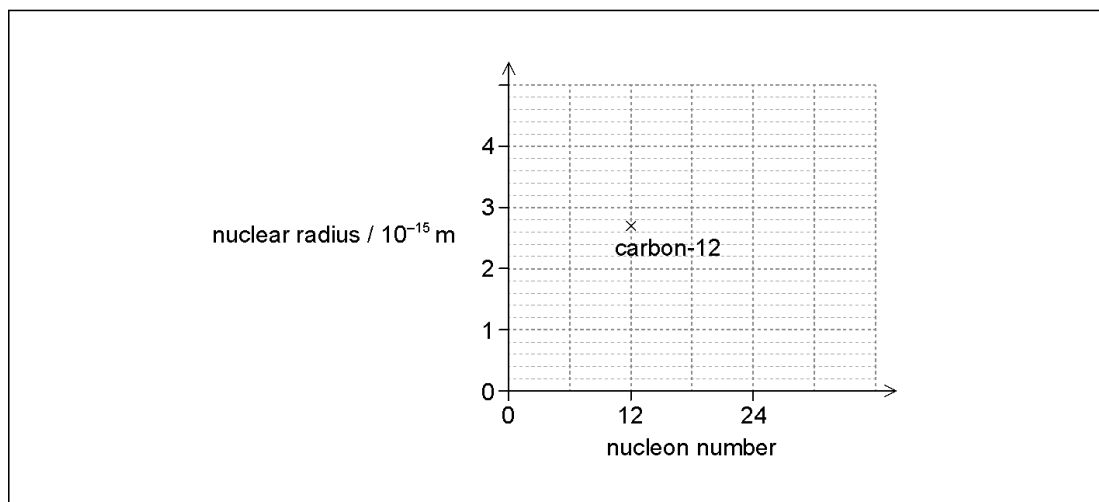
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- (d) Electron diffraction experiments indicate that the nuclear radius of carbon-12 ($^{12}_6\text{C}$) is $2.7 \times 10^{-15} \text{ m}$. The graph shows the variation of nuclear radius with nucleon number. The nuclear radius of the carbon-12 is shown on the graph.



- (i) Determine the radius of the magnesium-24 ($^{24}_{12}\text{Mg}$) nucleus. [2]

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- (ii) Plot the position of magnesium-24 on the graph. [1]

- (iii) Draw a line on the graph, to show the variation of nuclear radius with nucleon number. [2]

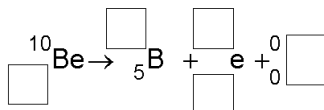
3 - (PHYSI/21_HL_Summer_2018_Q6) - Atomic, nuclear & Particle Physics



The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus (β^-) decay to form a stable boron (B) nuclide.

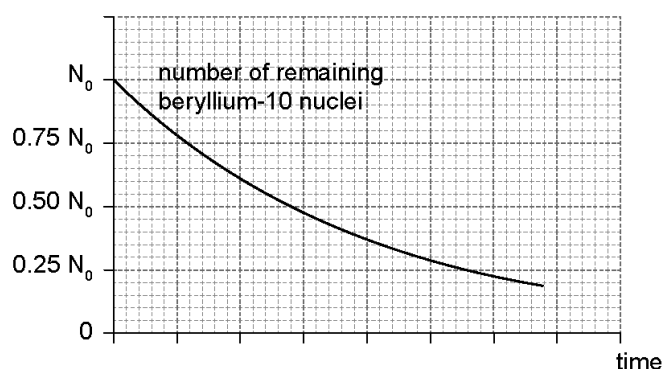
(a) Identify the missing information for this decay.

[2]



(b) The initial number of nuclei in a pure sample of beryllium-10 is N_0 . The graph shows how the number of remaining **beryllium** nuclei in the sample varies with time.

number of nuclei



(i) On the graph, sketch how the number of **boron** nuclei in the sample varies with time.

[2]

(ii) After 4.3×10^6 years,

$$\frac{\text{number of produced boron nuclei}}{\text{number of remaining beryllium nuclei}} = 7.$$

Show that the half-life of beryllium-10 is 1.4×10^6 years.

[3]

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- (iii) Beryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6×10^{11} atoms of beryllium-10. The present activity of the sample is 8.0×10^{-3} Bq.



Determine, in years, the age of the sample.

[3]

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- (c) An ice sample is moved to a laboratory for analysis. The temperature of the sample is -20°C .

- (i) State what is meant by thermal radiation.

[1]

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- (ii) Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body.

[2]

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- (iii) Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample.

[2]



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- (iv) The temperature in the laboratory is higher than the temperature of the ice sample. Describe **one** other energy transfer that occurs between the ice sample and the laboratory.

[2]

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- (v) Derive the units of intensity in terms of fundamental SI units.

[2]

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4 - (PHYSI/22_HL_Summer_2018_Q9) - *Quantum & Nuclear Physics (ahl), Atomic,nuclear & Particle Physics*



- (a) Rutherford constructed a model of the atom based on the results of the alpha particle scattering experiment. Describe this model. [2]

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- (b) Bohr modified the Rutherford model by introducing the condition $mvr = n \frac{h}{2\pi}$. Outline the reason for this modification. [3]

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- (c) (i) Show that the speed v of an electron in the hydrogen atom is related to the radius r of the orbit by the expression

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

where k is the Coulomb constant.

[1]



- (ii) Using the answer in (b) and (c)(i), deduce that the radius r of the electron's orbit in the ground state of hydrogen is given by the following expression.

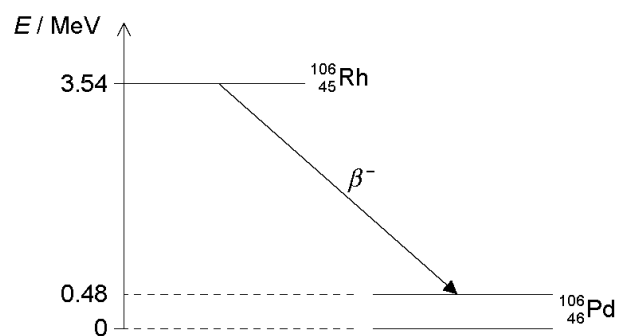
[2]

$$r = \frac{h^2}{4\pi^2 k m_e e^2}$$

- (iii) Calculate the electron's orbital radius in (c)(ii).

[1]

- (d) Rhodium-106 ($^{106}_{45}\text{Rh}$) decays into palladium-106 ($^{106}_{46}\text{Pd}$) by beta minus (β^-) decay. The diagram shows some of the nuclear energy levels of rhodium-106 and palladium-106. The arrow represents the β^- decay.



- (i) Explain what may be deduced about the energy of the electron in the β^- decay. [3]

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- (ii) Suggest why the β^- decay is followed by the emission of a gamma ray photon. [1]

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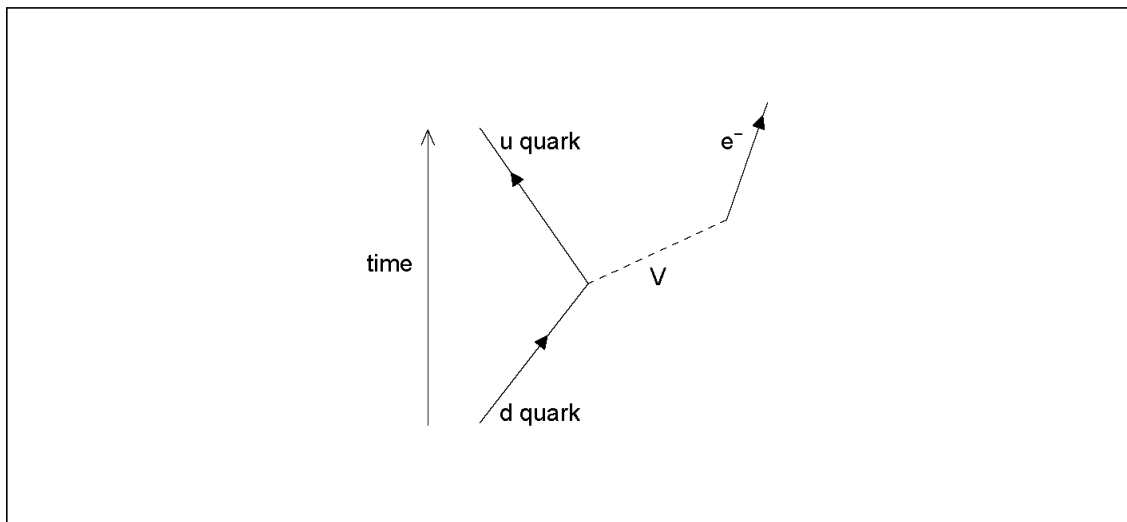
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- (iii) Calculate the wavelength of the gamma ray photon in (d)(ii). [2]

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(e) β^- decay is described by the following incomplete Feynman diagram.

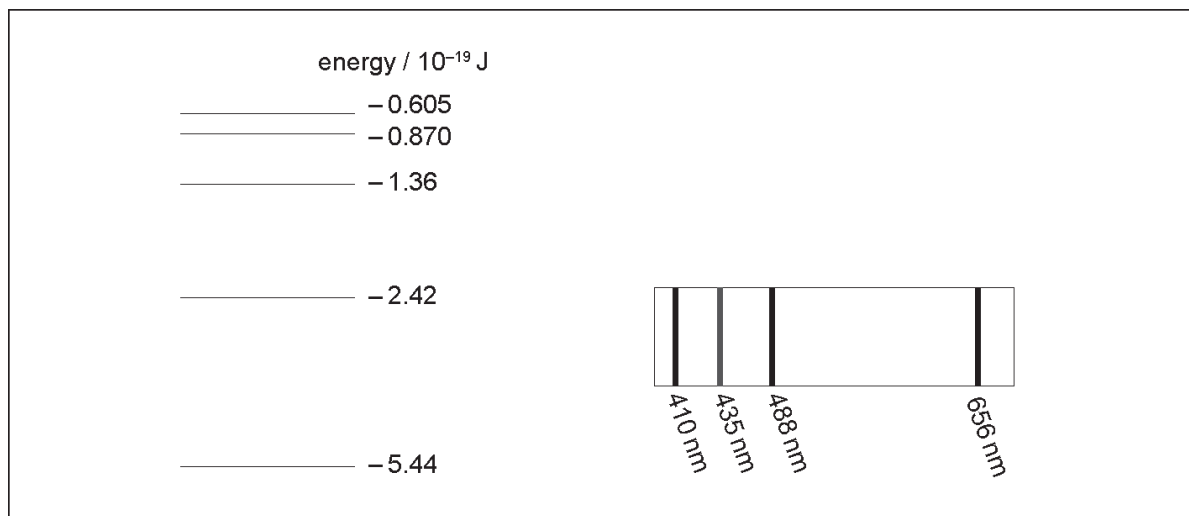


- (i) Draw a labelled arrow to complete the Feynman diagram. [1]
- (ii) Identify particle V. [1]

5 - (PHYSI/20_HL_Winter_2018_Q5) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



- (a) The diagram shows the position of the principal lines in the visible spectrum of atomic hydrogen and some of the corresponding energy levels of the hydrogen atom.



- (i) Determine the energy of a photon of blue light (435nm) emitted in the hydrogen spectrum.

[3]

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- (ii) Identify, with an arrow labelled B on the diagram, the transition in the hydrogen spectrum that gives rise to the photon with the energy in (a)(i).

[1]

- (iii) Explain your answer to (a)(ii).

[2]

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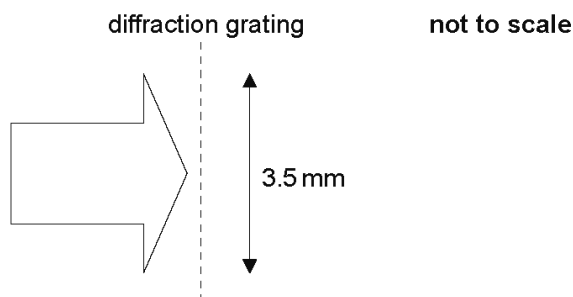
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- (b) A low-pressure hydrogen discharge lamp contains a small amount of deuterium gas in addition to the hydrogen gas. The deuterium spectrum contains a red line with a wavelength very close to that of the hydrogen red line. The wavelengths for the principal lines in the visible spectra of deuterium and hydrogen are given in the table.



	Hydrogen wavelength / nm	Deuterium wavelength / nm
Red line	656.288	656.107
Violet line	410.180	410.048

Light from the discharge lamp is normally incident on a diffraction grating.



- (i) The light illuminates a width of 3.5 mm of the grating. The deuterium and hydrogen red lines can just be resolved in the second-order spectrum of the diffraction grating. Show that the grating spacing of the diffraction grating is about 2×10^{-6} m.

[2]

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- (ii) Calculate the angle between the first-order line of the red light in the hydrogen spectrum and the second-order line of the violet light in the hydrogen spectrum.

[3]



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- (iii) The light source is changed so that white light is incident on the diffraction grating. Outline the appearance of the diffraction pattern formed with white light.

[3]

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6 – (PHYSI/20_HL_Winter_2018_Q6) – Atomic, nuclear & Particle Physics



- (a) (i) State how the density of a nucleus varies with the number of nucleons in the nucleus.

[1]

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- (ii) Show that the nuclear radius of phosphorus-31 ($^{31}_{15}\text{P}$) is about 4 fm.

[1]

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- (b) $^{32}_{15}\text{P}$ is formed when a nucleus of deuterium (^2_1H) collides with a nucleus of $^{31}_{15}\text{P}$.
The radius of a deuterium nucleus is 1.5 fm.

- (i) State the maximum distance between the centres of the nuclei for which the production of $^{32}_{15}\text{P}$ is likely to occur.

[1]

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- (ii) Determine, in J, the minimum initial kinetic energy that the deuterium nucleus must have in order to produce $^{32}_{15}\text{P}$. Assume that the phosphorus nucleus is stationary throughout the interaction and that only electrostatic forces act.

[2]

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- (c) $^{32}_{15}\text{P}$ undergoes beta-minus (β^-) decay. Explain why the energy gained by the emitted beta particles in this decay is not the same for every beta particle.

[2]



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- (d) (i) State what is meant by decay constant.

[2]

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- (ii) In a fresh pure sample of $^{32}_{15}\text{P}$ the activity of the sample is 24 Bq. After one week the activity has become 17 Bq. Calculate, in s^{-1} , the decay constant of $^{32}_{15}\text{P}$.

[3]

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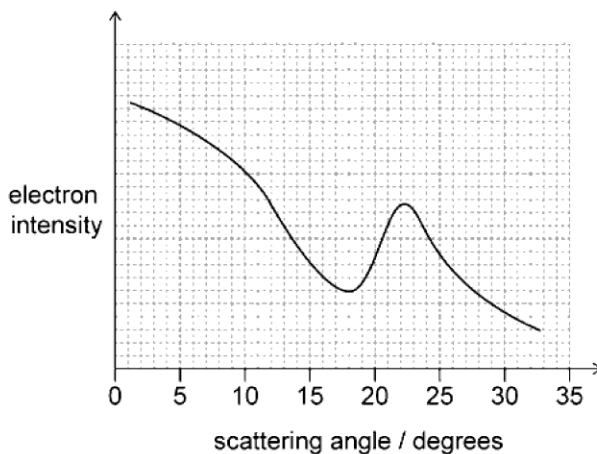
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7 - (PHYSI/21_HL_Summer_2019_Q2) - Atomic,nuclear & Particle Physics



- (a) A beam of electrons each of de Broglie wavelength $2.4 \times 10^{-15} \text{ m}$ is incident on a thin film of silicon-30 ($^{30}_{14}\text{Si}$). The variation in the electron intensity of the beam with scattering angle is shown.



- (i) Use the graph to show that the nuclear radius of silicon-30 is about 4 fm. [3]

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- (ii) Estimate, using the result from (a)(i), the nuclear radius of thorium-232 ($^{232}_{90}\text{Th}$). [2]

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- (iii) Suggest **one** reason why a beam of electrons is better for investigating the size of a nucleus than a beam of alpha particles of the same energy.

[1]



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- (iv) Outline why deviations from Rutherford scattering are observed when high-energy alpha particles are incident on nuclei.

[2]

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(b) Silicon-30 ($^{30}_{14}\text{Si}$) can be formed from phosphorus-30 ($^{30}_{15}\text{P}$) by a process of beta-plus decay.



(i) Write down the nuclear equation that represents this reaction.

[2]

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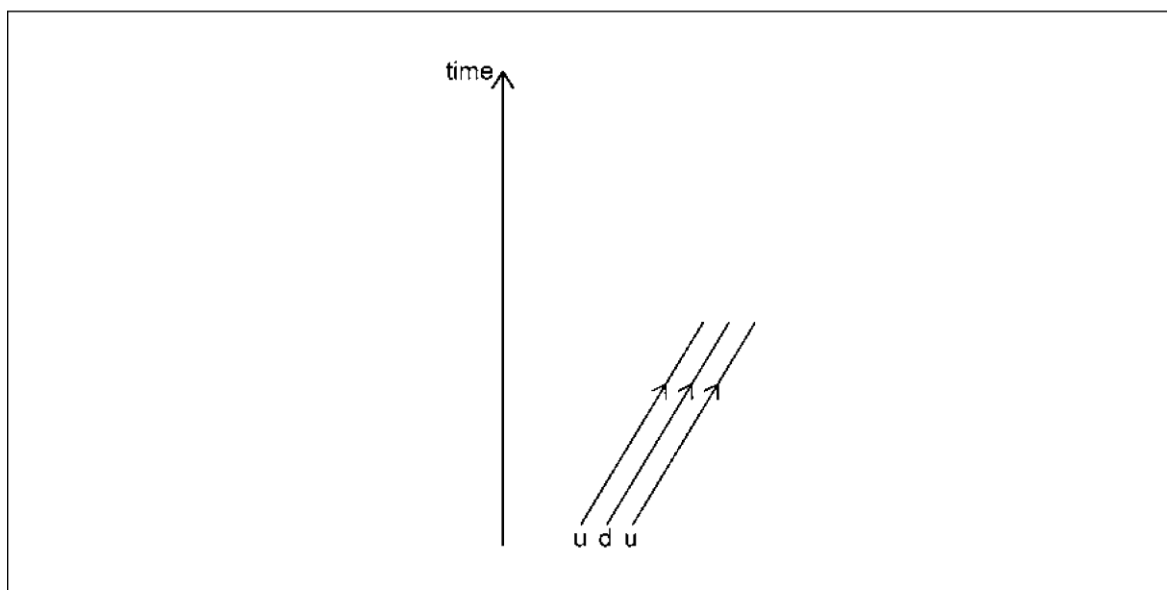
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(ii) Sketch the Feynman diagram that represents this reaction. The diagram has been started for you.

[3]



(iii) Energy is transferred to a hadron in an attempt to separate its quarks. Describe the implications of quark confinement for this situation.

[2]

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- (c) The Standard Model was accepted by many scientists before the observation of the Higgs boson was made.



Outline why it is important to continue research into a topic once a scientific model has been accepted by the scientific community.

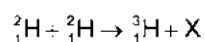
[1]

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8 - (PHYSI/22_HL_Summer_2019_Q6) - Atomic,nuclear & Particle Physics



Deuterium, ${}^2_1\text{H}$, undergoes fusion according to the following reaction.



- (a) Identify particle X. [1]

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- (b) The following data are available for binding energies per nucleon.

$${}^2_1\text{H} = 1.12\text{MeV}$$

$${}^3_1\text{H} = 2.78\text{MeV}$$

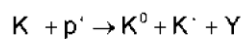
- (i) Determine, in MeV, the energy released. [2]

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- (ii) Suggest why, for the fusion reaction above to take place, the temperature of deuterium must be very high. [2]

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- (c) Particle Y is produced in the collision of a proton with a K^- in the following reaction.



The quark content of some of the particles involved are

$$K^- = \bar{u}s \quad K^0 = d\bar{s}$$

Identify, for particle Y, the

- (i) charge.

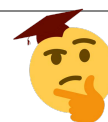
[1]

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- (ii) strangeness.

[1]

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9 - (PHYSI/20_HL_Winter_2019_Q7) - Atomic, nuclear & Particle Physics



- (a) Radioactive decay is said to be "random" and "spontaneous". Outline what is meant by each of these terms. [2]

Random:

Spontaneous:

- (b) A stationary nucleus of uranium-238 undergoes alpha decay to form thorium-234.

The following data are available.

Energy released in decay	4.27 MeV
Binding energy per nucleon for helium	7.07 MeV
Binding energy per nucleon for thorium	7.60 MeV

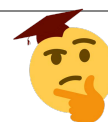
- (i) Calculate the binding energy per nucleon for uranium-238. [3]

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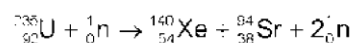
- (ii) Calculate the ratio $\frac{\text{kinetic energy of alpha particle}}{\text{kinetic energy of thorium nucleus}}$. [2]

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10 – (PHYSI/20_HL_Winter_2020_Q6) – Atomic,nuclear & Particle Physics, Energy Production



- (a) One possible fission reaction of uranium-235 (U-235) is



The following data are available.

Mass of one atom of U-235 = 235 u

Binding energy per nucleon for U-235 = 7.59 MeV

Binding energy per nucleon for Xe-140 = 8.29 MeV

Binding energy per nucleon for Sr-94 = 8.59 MeV

- (i) State what is meant by binding energy of a nucleus. [1]

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- (ii) Outline why quantities such as atomic mass and nuclear binding energy are often expressed in non-SI units. [1]

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- (iii) Show that the energy released in the reaction is about 180 MeV. [1]

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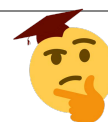
- (b) A nuclear power station uses U-235 as fuel. Assume that every fission reaction of U-235 gives rise to 180 MeV of energy.

- (i) Estimate, in J kg^{-1} , the specific energy of U-235. [2]

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- (ii) The power station has a useful power output of 1.2 GW and an efficiency of 36 %. Determine the mass of U-235 that undergoes fission in one day.

[2]



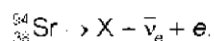
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- (iii) The specific energy of fossil fuel is typically 30 MJ kg^{-1} . Suggest, with reference to your answer to (b)(i), one advantage of U-235 compared with fossil fuels in a power station.

[1]

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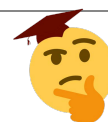
- (c) A sample of waste produced by the reactor contains 1.0 kg of strontium-94 (Sr-94). Sr-94 is radioactive and undergoes beta-minus (β^-) decay into a daughter nuclide X. The reaction for this decay is



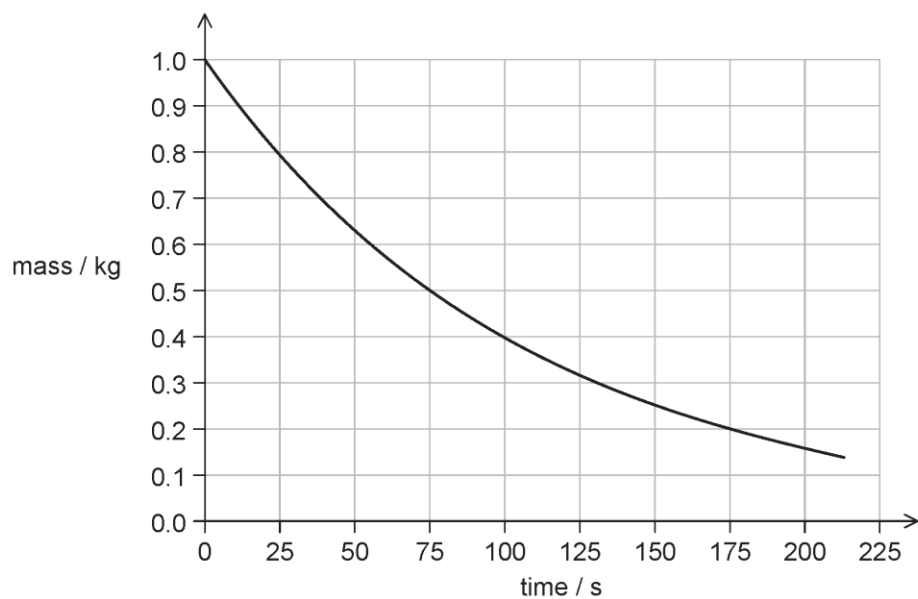
- (i) Write down the proton number of nuclide X.

[1]

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The graph shows the variation with time of the mass of Sr-94 remaining in the sample.



(ii) State the half-life of Sr-94.

[1]

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(iii) Calculate the mass of Sr-94 remaining in the sample after 10 minutes.

[2]

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11 - (PHYSI/20_HL_Winter_2020_Q10) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



The de Broglie wavelength λ of a particle accelerated close to the speed of light is approximately

$$\lambda \approx \frac{hc}{E}$$

where E is the energy of the particle.

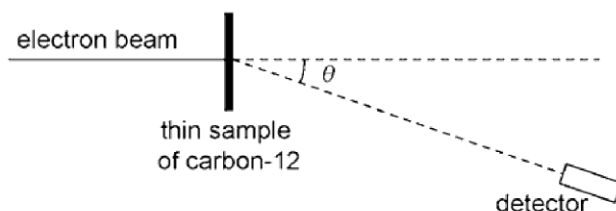
A beam of electrons of energy $4.2 \times 10^8 \text{ eV}$ is produced in an accelerator.

- (a) Show that the wavelength of an electron in the beam is about $3 \times 10^{-15} \text{ m}$.

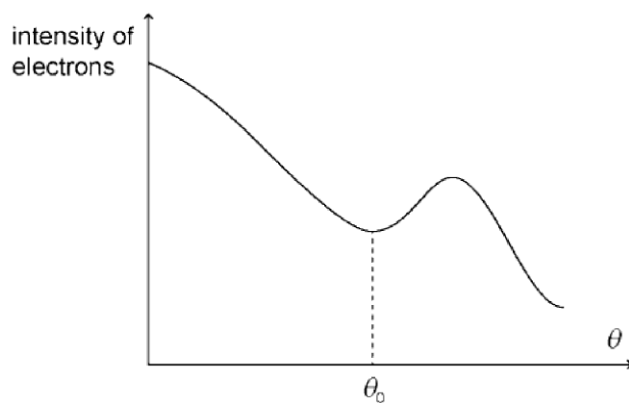
[1]

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- (b) The electron beam is used to study the nuclear radius of carbon-12. The beam is directed from the left at a thin sample of carbon-12. A detector is placed at an angle θ relative to the direction of the incident beam.

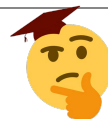


The graph shows the variation of the intensity of electrons with θ . There is a minimum of intensity for $\theta = \theta_0$.



- (i) Discuss how the results of the experiment provide evidence for matter waves.

[2]



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- (ii) The accepted value of the diameter of the carbon-12 nucleus is 4.94×10^{-15} m. Estimate the angle θ_0 at which the minimum of the intensity is formed.

[2]

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- (iii) Outline why electrons with energy of approximately 10^7 eV would be unsuitable for the investigation of nuclear radii.

[2]

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- (c) Experiments with many nuclides suggest that the radius of a nucleus is proportional to $A^{\frac{1}{3}}$, where A is the number of nucleons in the nucleus. Show that the density of a nucleus remains approximately the same for all nuclei.

[2]

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12 - (PHYSI/21_HL_Summer_2021_Q7) - Atomic,nuclear & Particle Physics



Radioactive uranium-238 ($^{238}_{92}\text{U}$) produces a series of decays ending with a stable nuclide of lead. The nuclides in the series decay by either alpha (α) or beta-minus (β^-) processes.

- (a) Uranium-238 decays into a nuclide of thorium-234 (Th).

Write down the complete equation for this radioactive decay.

[1]



- (b) Thallium-206 ($^{206}_{81}\text{Tl}$) decays into lead-206 ($^{206}_{82}\text{Pb}$).

Identify the quark changes for this decay.

[1]

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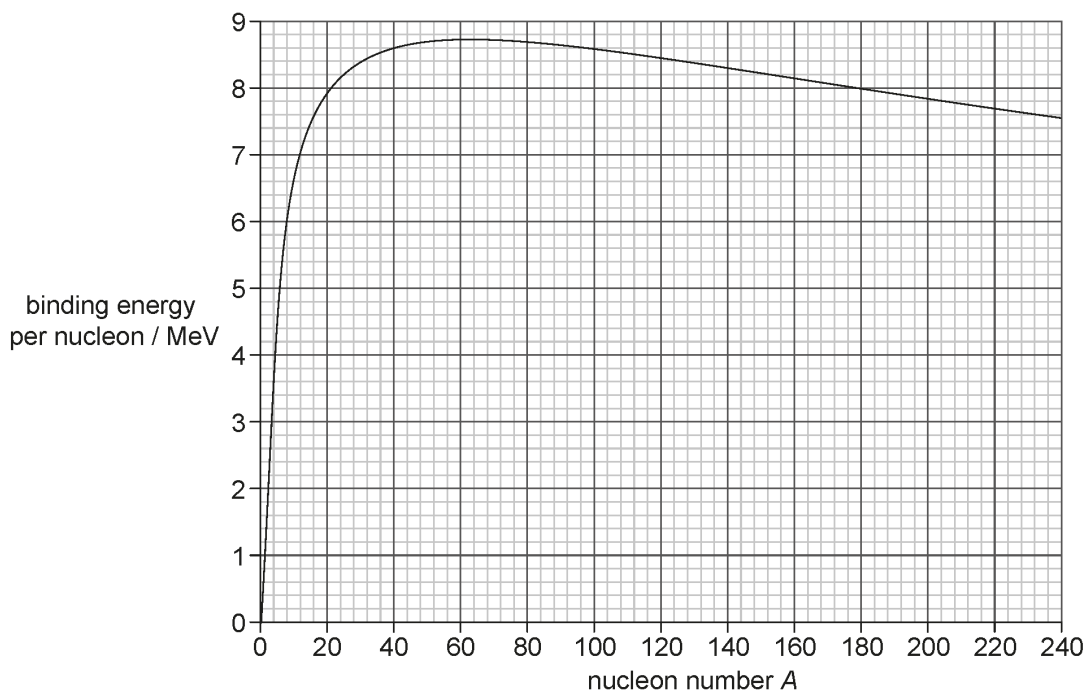
- (c) The half-life of uranium-238 is about 4.5×10^9 years. The half-life of thallium-206 is about 4.2 minutes.

Compare and contrast the methods to measure these half-lives.

[4]

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(d) The graph shows the variation with the nucleon number A of the binding energy per nucleon.



(i) Outline why high temperatures are required for fusion to occur.

[2]

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(ii) Outline, with reference to the graph, why energy is released both in fusion and in fission.

[1]

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- (iii) Uranium-235 ($^{235}_{92}\text{U}$) is used as a nuclear fuel. The fission of uranium-235 can produce krypton-89 and barium-144.



Determine, in MeV and using the graph, the energy released by this fission.

[2]

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13 - (PHYSI/21_HL_Summer_2021_Q9) - Atomic, nuclear & Particle Physics



Conservation of energy and conservation of momentum are two examples of conservation laws.

(a) Outline the significance of conservation laws for physics.

[1]

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(b) When a pi meson π^- ($d\bar{u}$) and a proton (uud) collide, a possible outcome is a sigma baryon Σ^0 (uds) and a kaon meson K^0 ($d\bar{s}$).

Apply **three** conservation laws to show that this interaction is possible.

[3]

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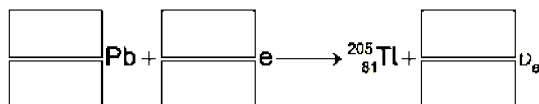
14 - (PHYSI/22_HL_Summer_2021_Q4) - Atomic, nuclear & Particle Physics



- (a) During electron capture, an atomic electron is captured by a proton in the nucleus. The stable nuclide thallium-205 ($^{205}_{81}\text{Tl}$) can be formed when an unstable lead (Pb) nuclide captures an electron.

(i) Write down the equation to represent this decay.

[2]



- (ii) The unstable lead nuclide has a half-life of 15×10^6 years. A sample initially contains $2.0 \mu\text{mol}$ of the lead nuclide. Calculate the number of thallium nuclei being formed each second 30×10^6 years later.

[3]

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- (b) The neutron number N and the proton number Z are not equal for the nuclide $^{205}_{81}\text{Tl}$. Explain, with reference to the forces acting within the nucleus, the reason for this.

[2]

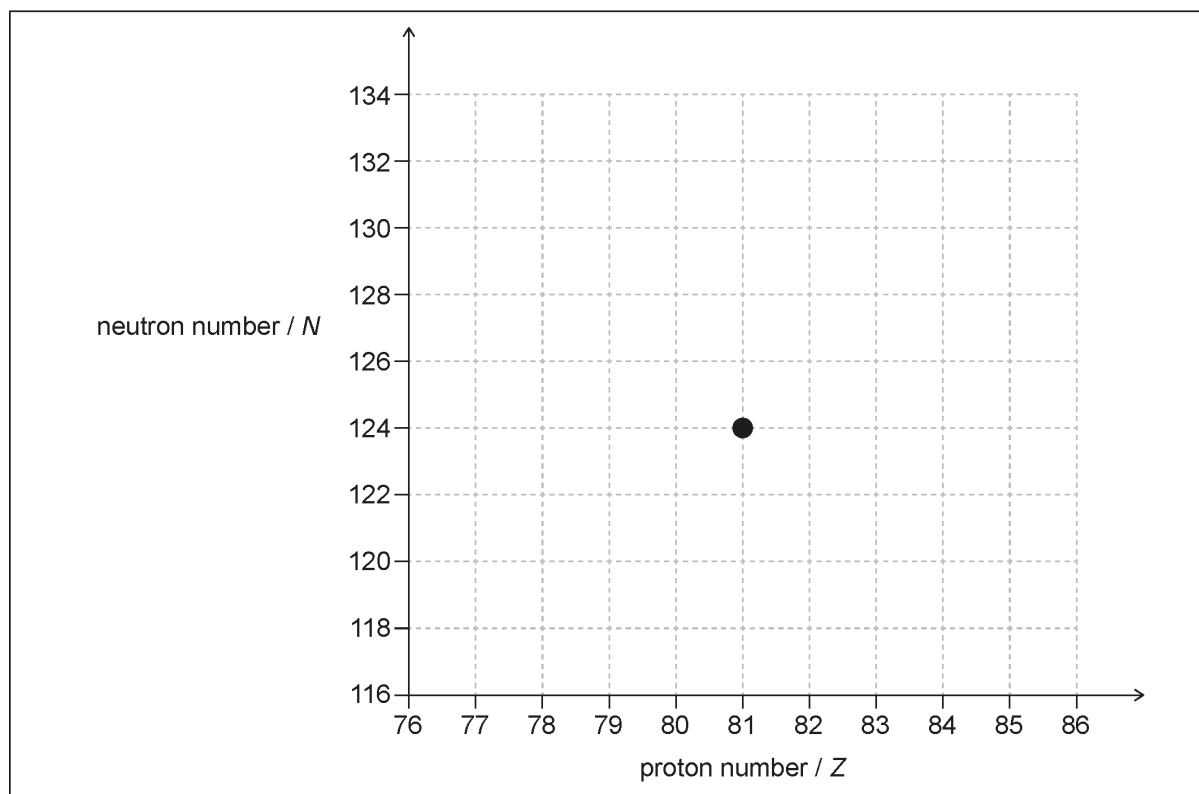
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- (c) Thallium-205 ($^{205}_{81}\text{Tl}$) can also form from successive alpha (α) and beta-minus (β^-) decays of an unstable nuclide. The decays follow the sequence $\alpha \beta^- \beta^- \alpha$. The diagram shows the position of $^{205}_{81}\text{Tl}$ on a chart of neutron number against proton number.



Draw **four** arrows to show the sequence of changes to N and Z that occur as the $^{205}_{81}\text{Tl}$ forms from the unstable nuclide.

[3]

15 – (PHYSI/20_HL_Winter_2021_Q4) – Atomic, nuclear & Particle Physics



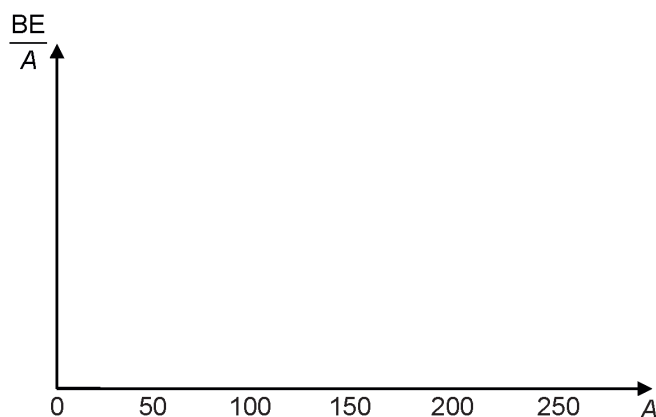
- (a) (i) State what is meant by the binding energy of a nucleus.

[1]

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- (ii) Draw, on the axes, a graph to show the variation with nucleon number A of the binding energy per nucleon, $\frac{BE}{A}$. Numbers are not required on the vertical axis.

[2]



- (iii) Identify, with a cross, on the graph in (a)(ii), the region of greatest stability.

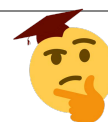
[1]

- (iv) Some unstable nuclei have many more neutrons than protons. Suggest the likely decay for these nuclei.

[1]

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- (b) Plutonium-238 (Pu) decays by alpha (α) decay into uranium (U).



The following data are available for binding energies per nucleon:

plutonium 7.568 MeV

uranium 7.600 MeV

alpha particle 7.074 MeV

- (i) Show that the energy released in this decay is about 6 MeV.

[3]

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- (ii) The plutonium nucleus is at rest when it decays.

Calculate the ratio $\frac{\text{kinetic energy of alpha particle}}{\text{kinetic energy of uranium}}$

[2]

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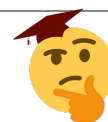
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- (c) The energy in b(i) can be transferred into electrical energy to run the instruments of a spacecraft. A spacecraft carries 33 kg of pure plutonium-238 at launch. The decay constant of plutonium is $2.50 \times 10^{-10} \text{ s}^{-1}$

(i) Estimate the power, in kW, that is available from the plutonium at launch.

[3]

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(ii) The spacecraft will take 7.2 years ($2.3 \times 10^8 \text{ s}$) to reach a planet in the solar system. Estimate the power available to the spacecraft when it gets to the planet.

[2]

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- (d) Solar radiation falls onto a metallic surface carried by the spacecraft causing the emission of photoelectrons. The radiation has passed through a filter so it is monochromatic. The spacecraft is moving away from the Sun. State and explain what happens to

(i) the kinetic energy of an emitted photoelectron.

[2]

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(ii) the rate at which charge leaves the metallic surface.

[2]

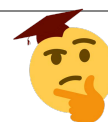
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16 – (PHYSI/21_HL_Summer_2022_Q5) – Atomic,nuclear & Particle Physics



(a) Describe the quark structure of a baryon.

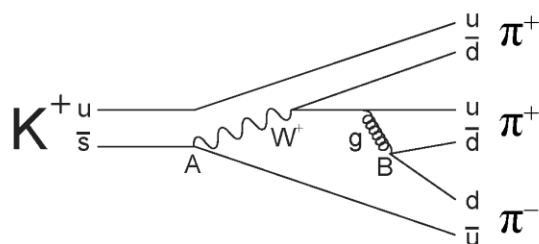
[2]

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(b) The Feynman diagram shows a possible decay of the K^+ meson.

Identify the interactions that are involved at points A and B in this decay.

[2]

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(c) The K^+ meson can decay as

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

State and explain the interaction that is responsible for this decay.

[2]

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17 - (PHYSI/21_HL_Summer_2022_Q9) - Atomic,nuclear & Particle Physics



Potassium-40 (${}^{40}_{19}\text{K}$) decays by two processes.

The first process is that of beta-minus (β^-) decay to form a calcium (Ca) nuclide.

- (a) Write down the equation for this decay. [2]

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- (b) Potassium-40 decays by a second process to argon-40. This decay accounts for 11 % of the total decay of the potassium-40.

Rocks can be dated by measuring the quantity of argon-40 gas trapped in them. One rock sample contains $340\text{ }\mu\text{mol}$ of potassium-40 and $12\text{ }\mu\text{mol}$ of argon-40.

- (i) Show that the initial quantity of potassium-40 in the rock sample was about $450\text{ }\mu\text{mol}$. [2]

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- (ii) The half-life of potassium-40 is 1.3×10^9 years. Estimate the age of the rock sample. [3]

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- (c) Outline how the decay constant of potassium-40 was determined in the laboratory for a pure sample of the nuclide.

[3]



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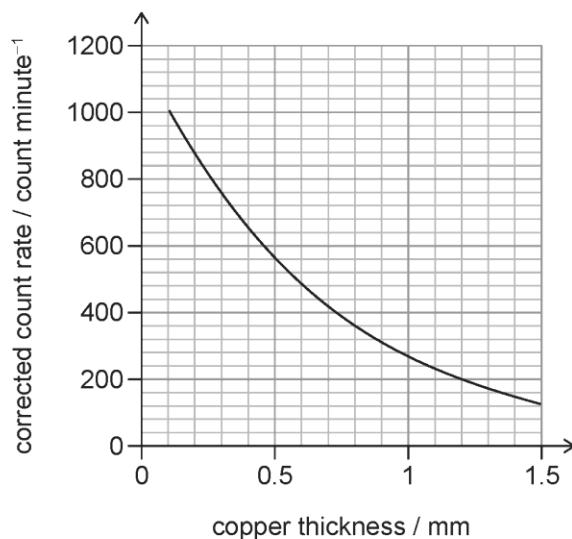
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18 - (PHYSI/22_HL_Summer_2022_Q5) - Atomic,nuclear & Particle Physics



An experiment is carried out to determine the count rate, corrected for background radiation, when different thicknesses of copper are placed between a radioactive source and a detector. The graph shows the variation of corrected count rate with copper thickness.



(a) Outline how the count rate was corrected for background radiation.

[1]

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(b) When a single piece of thin copper foil is placed between the source and detector, the count rate is $810 \text{ count minute}^{-1}$. The foil is replaced with one that has three times the thickness. Estimate the new count rate.

[2]

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- (c) Further results were obtained in this experiment with copper and lead absorbers.



Absorber	Thickness / mm	Corrected count rate / count minute ⁻¹
copper	3.5	32
lead	3.5	10

Comment on the radiation detected from this radioactive source.

[4]

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- (d) Another radioactive source consists of a nuclide of caesium ($^{137}_{55}\text{Cs}$) that decays to barium ($^{137}_{56}\text{Ba}$).

Write down the reaction for this decay.

[2]

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19 – (PHYSI/20_HL_Winter_2022_Q6) – Atomic, nuclear & Particle Physics



- (a) Outline, by reference to nuclear binding energy, why the mass of a nucleus is less than the sum of the masses of its constituent nucleons. [2]

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Polonium-210 (Po-210) decays by alpha emission into lead-206 (Pb-206).

The following data are available.

Nuclear mass of Po-210 = 209.93676 u

Nuclear mass of Pb-206 = 205.92945 u

Mass of the alpha particle = 4.00151 u

- (b) (i) Calculate, in MeV, the energy released in this decay. [2]

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- (ii) The polonium nucleus was stationary before the decay.

Show, by reference to the momentum of the particles, that the kinetic energy of the alpha particle is much greater than the kinetic energy of the lead nucleus. [3]

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- (iii) In the decay of polonium-210, alpha emissions can be accompanied by the emissions of gamma photons, all of the same wavelength of $1.54 \times 10^{-12} \text{ m}$.



Discuss how this observation provides evidence for discrete nuclear energy levels. [3]

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- (c) A sample contains 5.0 g of pure polonium-210. The decay constant of polonium-210 is $5.8 \times 10^{-8} \text{ s}^{-1}$. Lead-206 is stable.

Calculate the mass of lead-206 present in the sample after one year. [3]

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1 - (PHYSI/21_HL_Summer_2017_Q3) - *Energy Production, Electricity & Magnetism*



Two renewable energy sources are solar and wind.

- (a) Describe the difference between photovoltaic cells and solar heating panels. [1]

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- (b) A solar farm is made up of photovoltaic cells of area $25\,000\text{ m}^2$. The average solar intensity falling on the farm is 240 W m^{-2} and the average power output of the farm is 1.6 MW . Calculate the efficiency of the photovoltaic cells. [2]

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- (c) An alternative generation method is the use of wind turbines.

The following data are available:

Length of turbine blade = 17 m
Density of air = 1.3 kg m^{-3}
Average wind speed = 7.5 m s^{-1}

- (i) Determine the minimum number of turbines needed to generate the same power as the solar farm. [3]

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- (ii) Explain two reasons why the number of turbines required is likely to be greater than your answer to (c)(i).

[2]



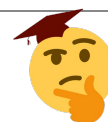
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2 - (PHYSI/22_HL_Summer_2017_Q2) - Oscillations & Waves, Energy Production



- (a) Outline the conditions necessary for simple harmonic motion (SHM) to occur.

[2]

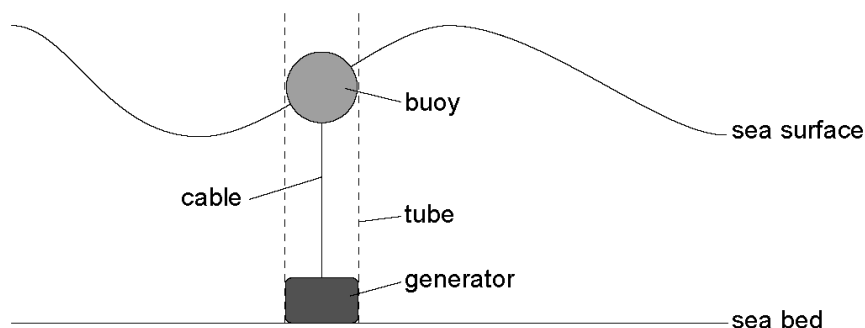
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- (b) A buoy, floating in a vertical tube, generates energy from the movement of water waves on the surface of the sea. When the buoy moves up, a cable turns a generator on the sea bed producing power. When the buoy moves down, the cable is wound in by a mechanism in the generator and no power is produced.



The motion of the buoy can be assumed to be simple harmonic.

- (i) A wave of amplitude 4.3 m and wavelength 35 m, moves with a speed of 3.4 m s^{-1} . Calculate the maximum vertical speed of the buoy.

[3]

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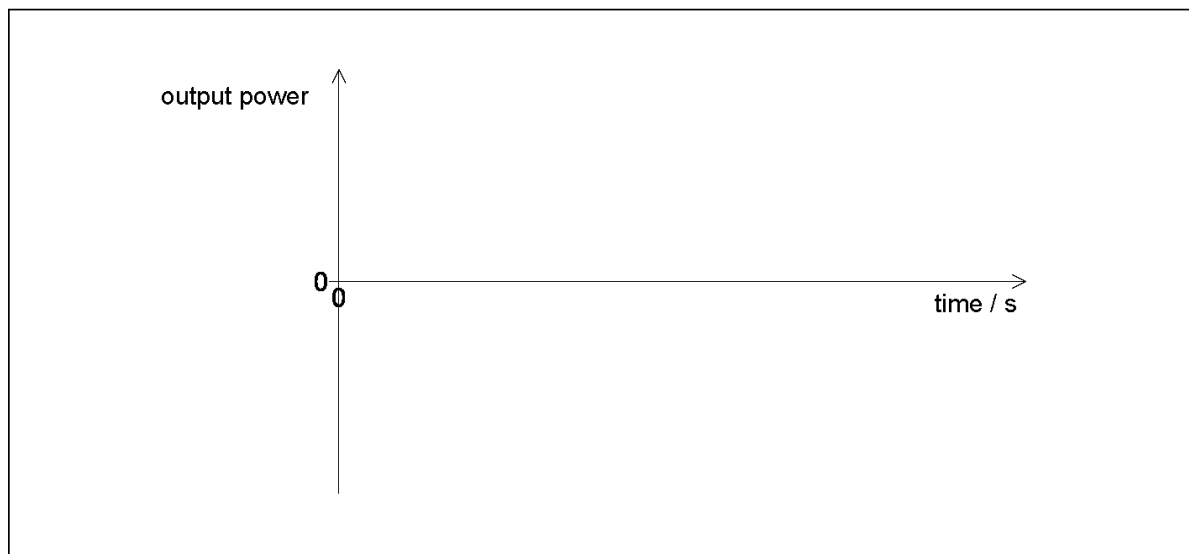
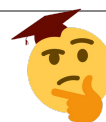
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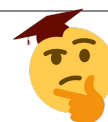
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- (ii) Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale.

[2]



(c) Water can be used in other ways to generate energy.



- (i) Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system.

[2]

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- (ii) The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which water arrives at the turbines. Assume that there is no energy loss in the system.

[2]

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- (iii) The hydroelectric system has four 250 MW generators. Determine the maximum time for which the hydroelectric system can maintain full output from the stored energy when a mass of 1.5×10^{10} kg of water passes through the turbines.

[2]

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- (iv) Not all the stored energy can be retrieved because of energy losses in the system.
Explain two such losses.

[2]

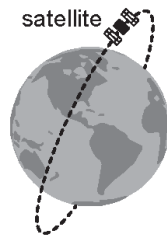


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3 – (PHYSI/20_HL_Winter_2017_Q7) – Energy Production



A satellite is orbiting the Earth in a polar orbit.



- (a) The satellite carries an experiment that measures the peak wavelength emitted by different objects. The Sun emits radiation that has a peak wavelength λ_s of 509 nm. The peak wavelength λ_E of the radiation emitted by the Earth is 10.1 μm .

- (i) Determine the mean temperature of the Earth.

[2]

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- (ii) Suggest how the difference between λ_s and λ_E helps to account for the greenhouse effect.

[3]

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- (b) Not all scientists agree that global warming is caused by the activities of man. Outline how scientists try to ensure agreement on a scientific issue.

[1]

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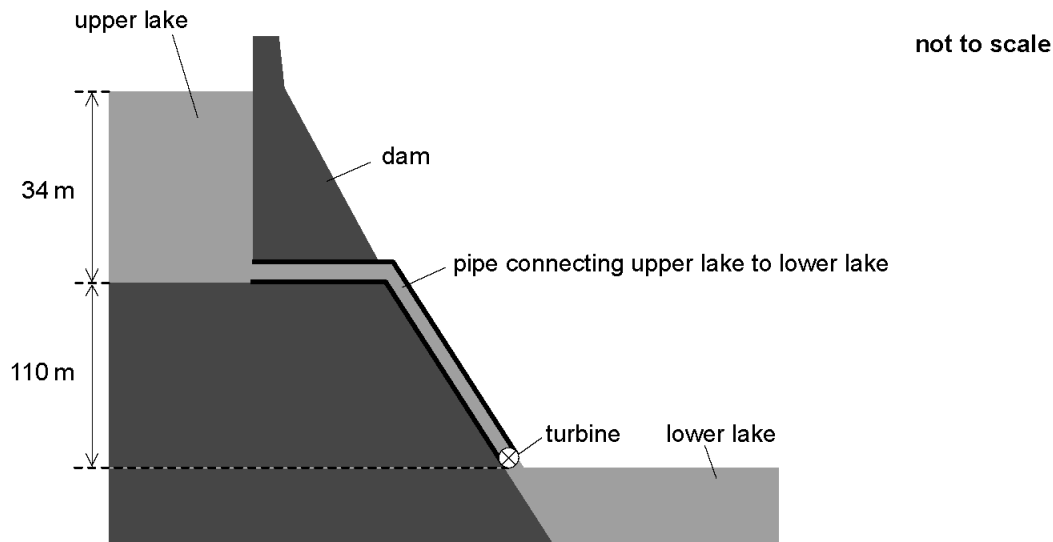
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4 - (PHYSI/22_HL_Summer_2018_Q7) - Energy Production



In a pumped storage hydroelectric system, water is stored in a dam of depth 34 m.



The water leaving the upper lake descends a vertical distance of 110 m and turns the turbine of a generator before exiting into the lower lake.

- (a) Water flows out of the upper lake at a rate of $1.2 \times 10^5 \text{ m}^3$ per minute. The density of water is $1.0 \times 10^3 \text{ kg m}^{-3}$.

- (i) Estimate the specific energy of water in this storage system, giving an appropriate unit for your answer.

[2]

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- (ii) Show that the average rate at which the gravitational potential energy of the water decreases is 2.5 GW.

[3]



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- (iii) The storage system produces 1.8 GW of electrical power. Determine the overall efficiency of the storage system.

[1]

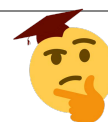
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- (b) After the upper lake is emptied it must be refilled with water from the lower lake and this requires energy. Suggest how the operators of this storage system can still make a profit.

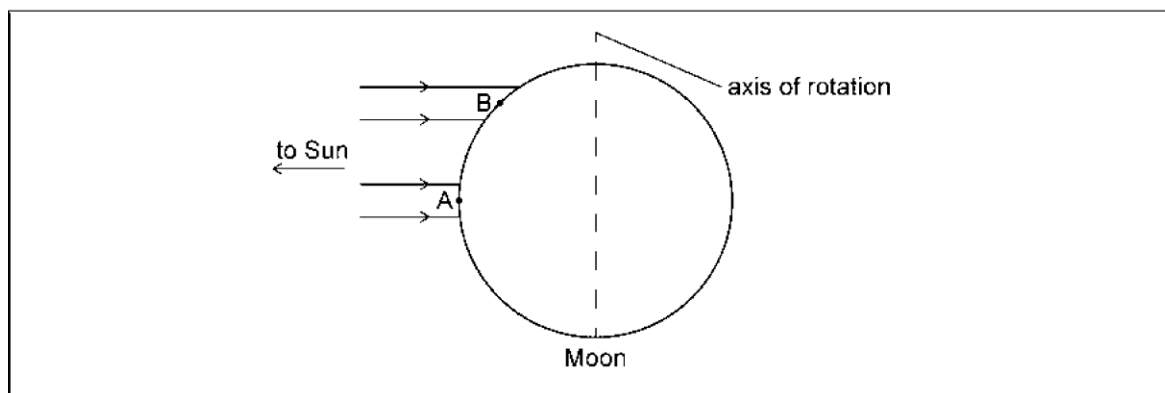
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5 - (PHYSI/21_HL_Summer_2019_Q7) - Energy Production



The Moon has no atmosphere and orbits the Earth. The diagram shows the Moon with rays of light from the Sun that are incident at 90° to the axis of rotation of the Moon.



- (a) (i) A black body is on the Moon's surface at point A. Show that the maximum temperature that this body can reach is 400 K. Assume that the Earth and the Moon are the same distance from the Sun.

[2]

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- (ii) Another black body is on the Moon's surface at point B.

Outline, without calculation, why the maximum temperature of the black body at point B is less than at point A.

[2]

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- (b) The albedo of the Earth's atmosphere is 0.28. Outline why the maximum temperature of a black body on the Earth when the Sun is overhead is less than that at point A on the Moon.

[1]

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6 - (PHYSI/22_HL_Summer_2019_Q7) - *Energy Production*

The average temperature of ocean surface water is 289 K. Oceans behave as black bodies.

- (a) Show that the intensity radiated by the oceans is about 400 W m^{-2} . [1]

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- (b) Explain why some of this radiation is returned to the oceans from the atmosphere. [3]

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- (c) The intensity in (b) returned to the oceans is 330 W m^{-2} . The intensity of the solar radiation incident on the oceans is 170 W m^{-2} .

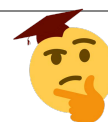
- (i) Calculate the additional intensity that must be lost by the oceans so that the water temperature remains constant. [2]

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- (ii) Suggest a mechanism by which the additional intensity can be lost. [1]

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7 – (PHYSI/20_HL_Winter_2019_Q6) – Energy Production



Wind is incident on the blades of a wind turbine. The radius of the blades is 12 m. The following data are available for the air immediately before and after impact with the blades.

	Before	After
Density of air	1.20 kg m^{-3}	1.32 kg m^{-3}
Wind speed	8.0 m s^{-1}	4.0 m s^{-1}

- (a) Determine the maximum power that can be extracted from the wind by this turbine. [3]

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- (b) Suggest why the answer in (a) is a maximum. [1]

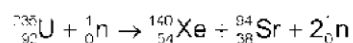
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8 - (PHYSI/20_HL_Winter_2020_Q6) - Atomic, nuclear & Particle Physics, Energy Production



- (a) One possible fission reaction of uranium-235 (U-235) is



The following data are available.

Mass of one atom of U-235 = 235 u

Binding energy per nucleon for U-235 = 7.59 MeV

Binding energy per nucleon for Xe-140 = 8.29 MeV

Binding energy per nucleon for Sr-94 = 8.59 MeV

- (i) State what is meant by binding energy of a nucleus. [1]

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- (ii) Outline why quantities such as atomic mass and nuclear binding energy are often expressed in non-SI units. [1]

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- (iii) Show that the energy released in the reaction is about 180 MeV. [1]

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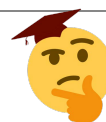
- (b) A nuclear power station uses U-235 as fuel. Assume that every fission reaction of U-235 gives rise to 180 MeV of energy.

- (i) Estimate, in J kg^{-1} , the specific energy of U-235. [2]

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- (ii) The power station has a useful power output of 1.2 GW and an efficiency of 36 %. Determine the mass of U-235 that undergoes fission in one day.

[2]



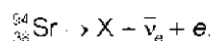
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- (iii) The specific energy of fossil fuel is typically 30 MJ kg^{-1} . Suggest, with reference to your answer to (b)(i), one advantage of U-235 compared with fossil fuels in a power station.

[1]

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- (c) A sample of waste produced by the reactor contains 1.0 kg of strontium-94 (Sr-94). Sr-94 is radioactive and undergoes beta-minus (β^-) decay into a daughter nuclide X. The reaction for this decay is



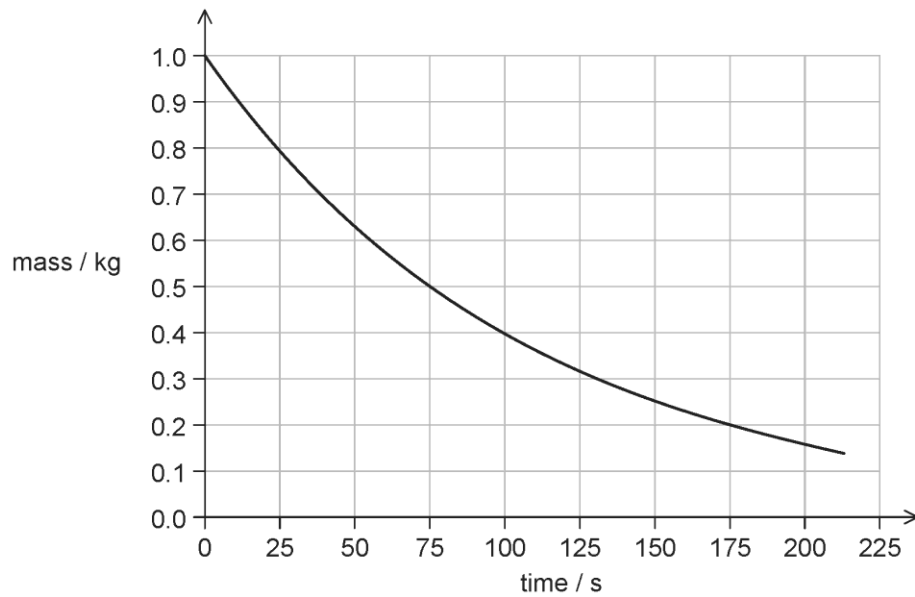
- (i) Write down the proton number of nuclide X.

[1]

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The graph shows the variation with time of the mass of Sr-94 remaining in the sample.



(ii) State the half-life of Sr-94.

[1]

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(iii) Calculate the mass of Sr-94 remaining in the sample after 10 minutes.

[2]

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9 - (PHYSI/21_HL_Summer_2021_Q4) - Energy Production



A planet orbits at a distance d from a star. The power emitted by the star is P . The total surface area of the planet is A .

- (a) (i) Explain why the power incident on the planet is

$$\frac{P}{4\pi d^2} \times \frac{A}{4} \quad [2]$$

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- (ii) The albedo of the planet is α_p . The equilibrium surface temperature of the planet is T . Derive the expression

$$T = \sqrt[4]{\frac{P(1-\alpha_p)}{16\pi d^2 e \sigma}}$$

where e is the emissivity of the planet. [2]

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- (b) On average, the Moon is the same distance from the Sun as the Earth. The Moon can be assumed to have an emissivity $e = 1$ and an albedo $\alpha_M = 0.13$. The solar constant is $1.36 \times 10^3 \text{ W m}^{-2}$. Calculate the surface temperature of the Moon. [2]

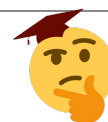
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10 - (PHYSI/22_HL_Summer_2021_Q6) - Electricity & Magnetism, Energy Production



A photovoltaic cell is supplying energy to an external circuit. The photovoltaic cell can be modelled as a practical electrical cell with internal resistance.

The intensity of solar radiation incident on the photovoltaic cell at a particular time is at a maximum for the place where the cell is positioned.

The following data are available for this particular time:

Operating current = 0.90 A
Output potential difference to external circuit = 14.5 V
Output emf of photovoltaic cell = 21.0 V
Area of panel = 350 mm × 450 mm

- (a) Explain why the output potential difference to the external circuit and the output emf of the photovoltaic cell are different. [2]

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- (b) Calculate the internal resistance of the photovoltaic cell for the maximum intensity condition using the model for the cell. [3]

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- (c) The maximum intensity of sunlight incident on the photovoltaic cell at the place on the Earth's surface is 680 W m^{-2} .



A measure of the efficiency of a photovoltaic cell is the ratio

$$\frac{\text{energy available every second to the external circuit}}{\text{energy arriving every second at the photovoltaic cell surface}}$$

Determine the efficiency of this photovoltaic cell when the intensity incident upon it is at a maximum.

[3]

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- (d) State **two** reasons why future energy demands will be increasingly reliant on sources such as photovoltaic cells.

[2]

Reason 1:

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Reason 2:

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11 - (PHYSI/20_HL_Winter_2021_Q6) - *Energy Production*



- (a) Titan is a moon of Saturn. The Titan-Sun distance is 9.3 times greater than the Earth-Sun distance.

(i) Show that the intensity of the solar radiation at the location of Titan is 16 Wm^{-2} [1]

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(ii) Titan has an atmosphere of nitrogen. The albedo of the atmosphere is 0.22. The surface of Titan may be assumed to be a black body. Explain why the **average** intensity of solar radiation **absorbed** by the whole surface of Titan is 3.1 Wm^{-2} [3]

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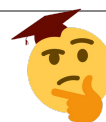
(iii) Show that the equilibrium surface temperature of Titan is about 90 K. [1]

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- (b) The mass of Titan is 0.025 times the mass of the Earth and its radius is 0.404 times the radius of the Earth. The escape speed from Earth is 11.2 km s^{-1} . Show that the escape speed from Titan is 2.8 km s^{-1}

[1]



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- (c) (i) The orbital radius of Titan around Saturn is R and the period of revolution is T .
Show that $T^2 = \frac{4\pi^2 R^3}{GM}$ where M is the mass of Saturn.

[2]

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- (ii) The orbital radius of Titan around Saturn is $1.2 \times 10^9 \text{ m}$ and the orbital period is 15.9 days. Estimate the mass of Saturn.

[2]

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(d) The molar mass of nitrogen is 28 g mol^{-1} .

(i) Show that the mass of a nitrogen molecule is $4.7 \times 10^{-26} \text{ kg}$.

[1]



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(ii) Estimate the root mean square speed of nitrogen molecules in the Titan atmosphere. Assume an atmosphere temperature of 90 K .

[2]

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(e) Discuss, by reference to the answer in (b), whether it is likely that Titan will lose its atmosphere of nitrogen.

[1]

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1 - (PHYSI/21_HL_Summer_2017_Q2) - *Oscillations & Waves, Wave Phenomena (ahl)*



- (a) Outline what is meant by the principle of superposition of waves.

[2]

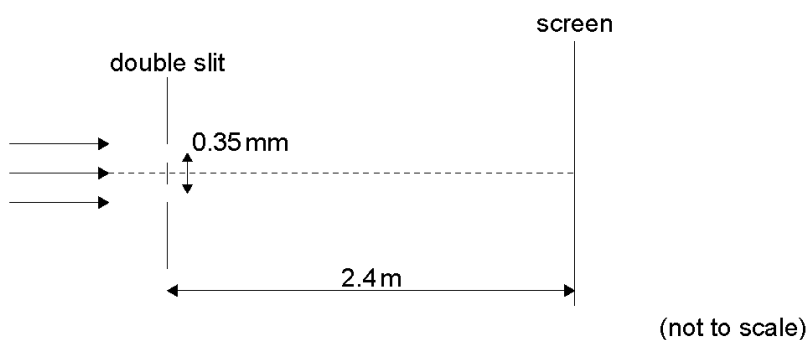
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- (b) Red laser light is incident on a double slit with a slit separation of 0.35 mm. A double-slit interference pattern is observed on a screen 2.4 m from the slits. The distance between successive maxima on the screen is 4.7 mm.



Calculate the wavelength of the light. Give your answer to an appropriate number of significant figures.

[3]

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- (c) Explain the change to the appearance of the interference pattern when the red-light laser is replaced by one that emits green light.

[2]



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- (d) One of the slits is now covered.

Describe the appearance of the pattern on the screen.

[2]

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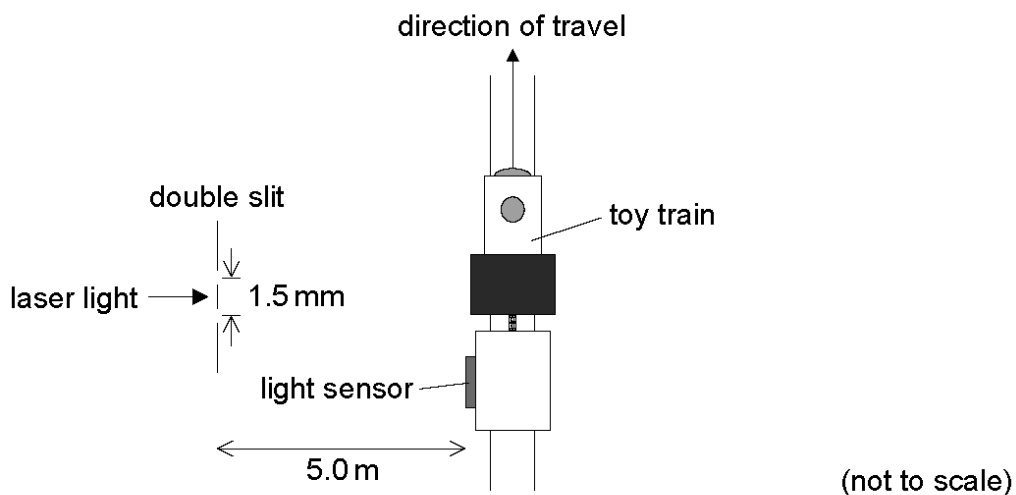
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2 - (PHYSI/22_HL_Summer_2017_Q4) - Wave Phenomena (ahl)

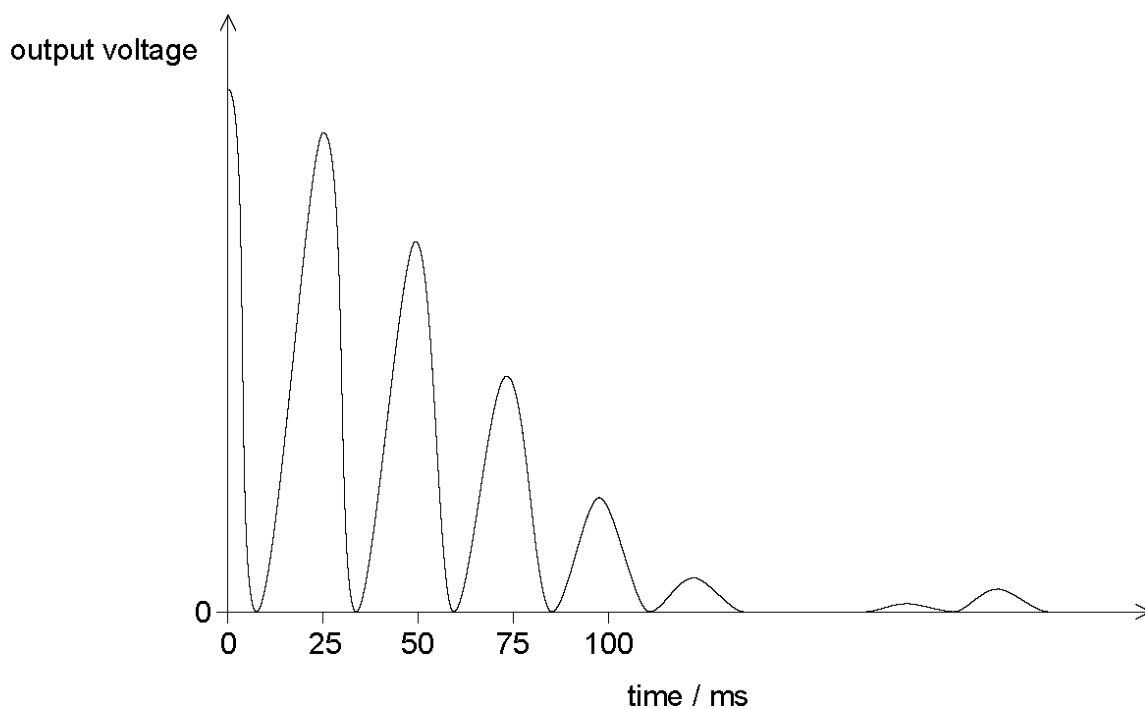


A student investigates how light can be used to measure the speed of a toy train.



Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.



- (a) Explain, with reference to the light passing through the slits, why a series of voltage peaks occurs.

[3]



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- (b) (i) The slits are separated by 1.5 mm and the laser light has a wavelength of 6.3×10^{-7} m. The slits are 5.0 m from the train track. Calculate the separation between two adjacent positions of the train when the output voltage is at a maximum.

[1]

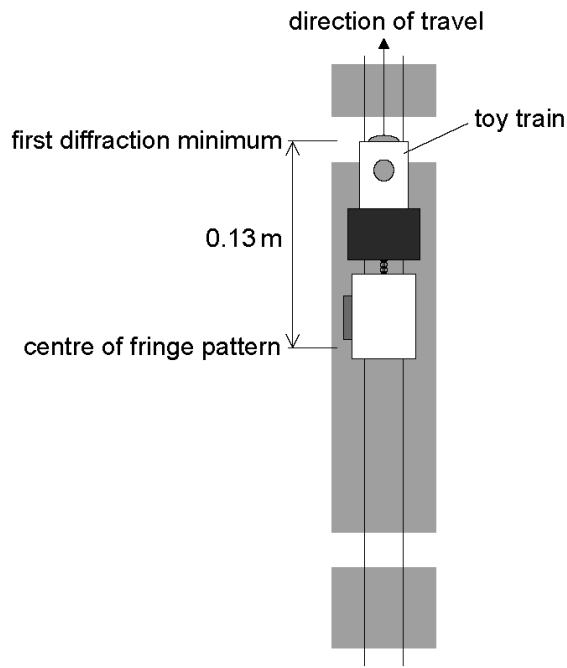
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- (ii) Estimate the speed of the train.

[2]

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- (c) As the train continues to move, the first diffraction minimum is observed when the light sensor is at a distance of 0.13 m from the centre of the fringe pattern.



- (i) Determine the width of one of the slits.

[2]

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- (ii) Suggest the variation in the output voltage from the light sensor that will be observed as the train moves beyond the first diffraction minimum.

[2]

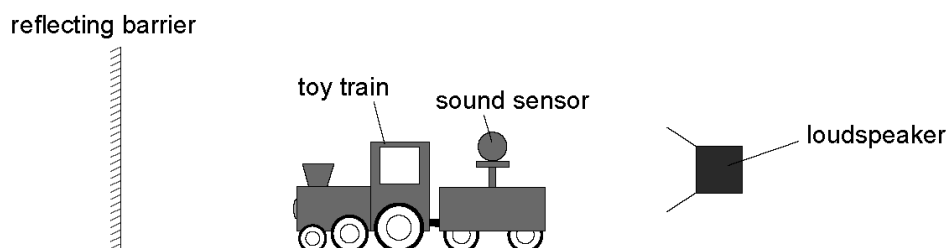
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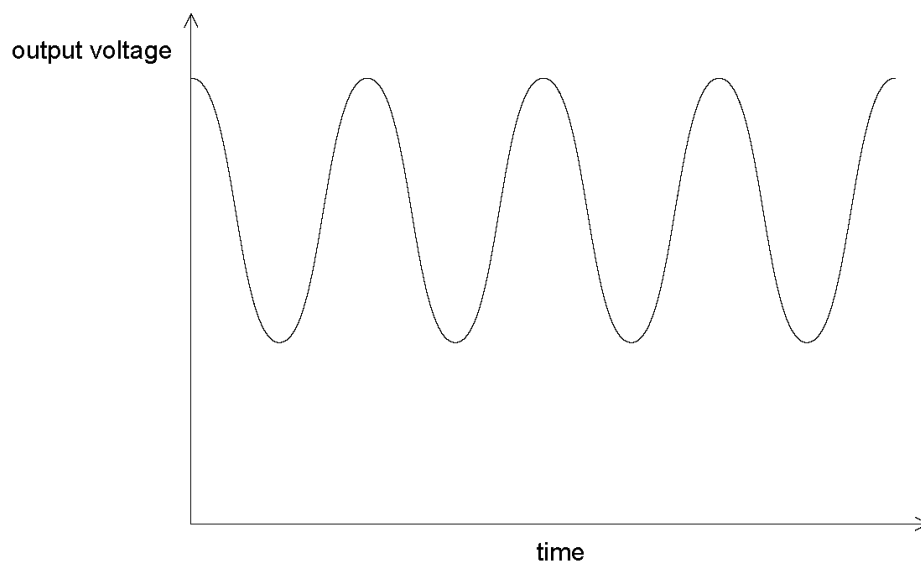
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- (d) In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier.



The graph shows the variation with time of the output voltage from the sounds sensor.



Explain how this effect arises.

[2]

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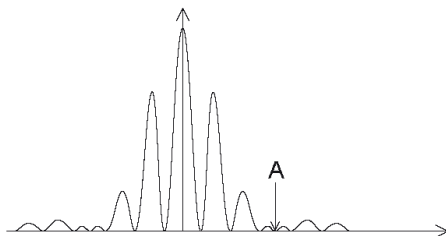
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3 - (PHYSI/20_HL_Winter_2017_Q6) - Wave Phenomena (ahl)



- (a) Yellow light from a sodium lamp of wavelength 590 nm is incident at normal incidence on a double slit. The resulting interference pattern is observed on a screen. The intensity of the pattern on the screen is shown.

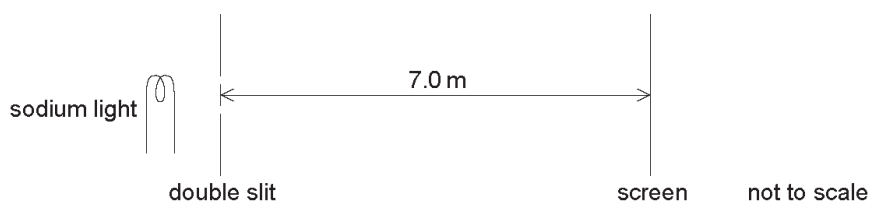


- (i) Explain why zero intensity is observed at position A.

[2]

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- (ii) The distance from the centre of the pattern to A is 4.1×10^{-2} m. The distance from the screen to the slits is 7.0 m.



Calculate the width of each slit.

[2]

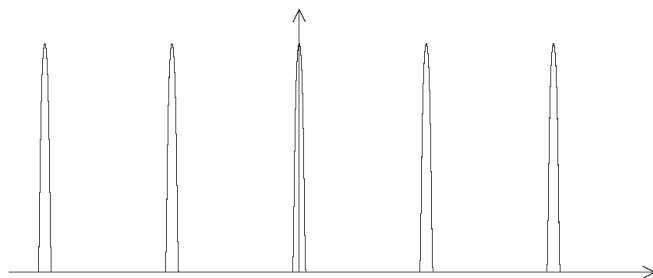
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- (iii) Calculate the separation of the two slits.

[2]

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- (b) The double slit is replaced by a diffraction grating that has 600 lines per millimetre. The resulting pattern on the screen is shown.



- (i) State and explain the differences between the pattern on the screen due to the grating and the pattern due to the double slit.

[3]

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- (ii) The yellow light is made from two very similar wavelengths that produce two lines in the spectrum of sodium. The wavelengths are 588.995 nm and 589.592 nm. These two lines can just be resolved in the second-order spectrum of this diffraction grating. Determine the beam width of the light incident on the diffraction grating.

[3]

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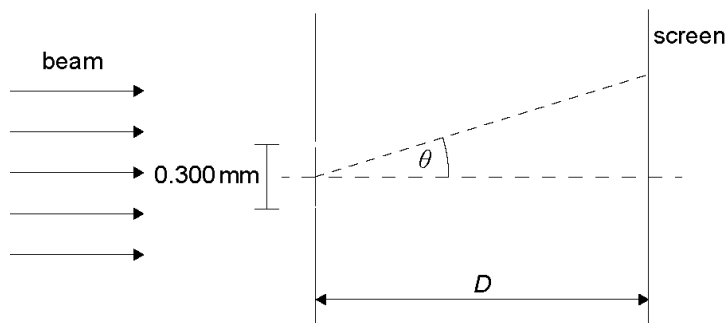
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4 – (PHYSI/21_HL_Summer_2018_Q3) – *Oscillations & Waves, Wave Phenomena (ahl)*



A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

- (a) The beam is incident normally on a double slit. The distance between the slits is 0.300 mm . A screen is at a distance D from the slits. The diffraction angle θ is labelled.



- (i) A series of dark and bright fringes appears on the screen. Explain how a dark fringe is formed.

[3]

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- (ii) Outline why the beam has to be coherent in order for the fringes to be visible.

[1]

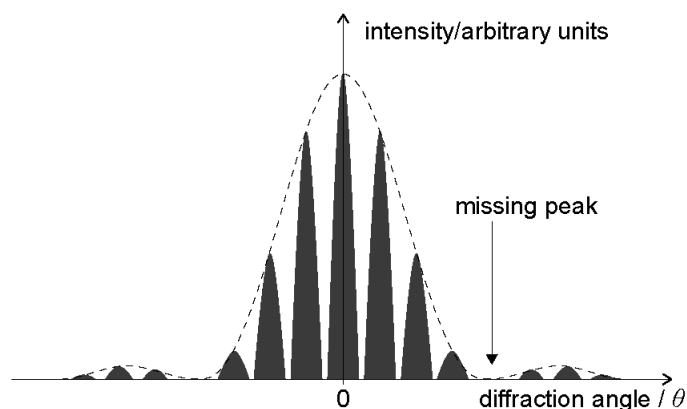
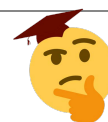
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- (iii) The wavelength of the beam as observed on Earth is 633.0 nm . The separation between a dark and a bright fringe on the screen is 4.50 mm . Calculate D .

[2]

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- (b) The graph of variation of intensity with diffraction angle for this experiment is shown.



- (i) Calculate the angular separation between the central peak and the missing peak in the double-slit interference intensity pattern. State your answer to an appropriate number of significant figures.

[3]

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- (ii) Deduce, in mm, the width of one slit.

[2]

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- (c) The wavelength of the light in the beam when emitted by the galaxy was 621.4 nm.



Explain, without further calculation, what can be deduced about the relative motion of the galaxy and the Earth.

[2]

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- (d) The air between the slits and the screen is replaced with water. The refractive index of water is 1.33.

- (i) Calculate the wavelength of the light in water.

[1]

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- (ii) State **two** ways in which the intensity pattern on the screen changes.

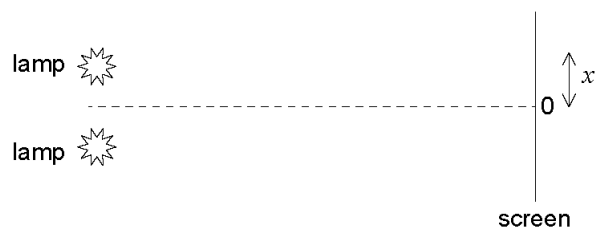
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5 - (PHYSI/22_HL_Summer_2018_Q5) - Oscillations & Waves, Wave Phenomena (ahl)



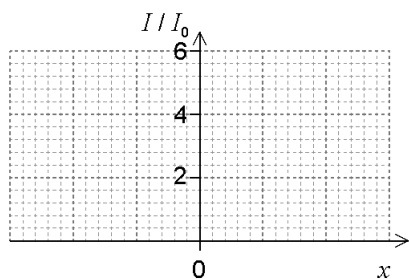
- (a) Monochromatic light from two identical lamps arrives on a screen.



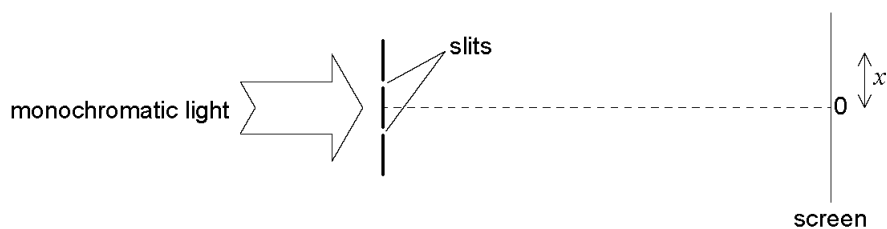
The intensity of light on the screen from each lamp separately is I_0 .

On the axes, sketch a graph to show the variation with distance x on the screen of the intensity I of light on the screen.

[1]



- (b) Monochromatic light from a single source is incident on two thin, parallel slits.

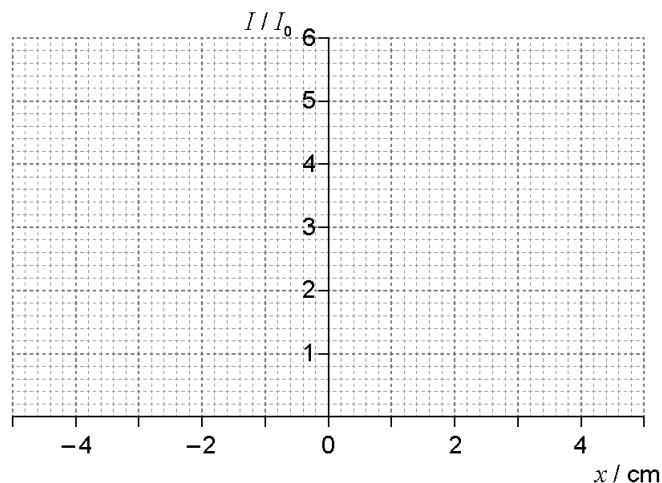


The following data are available.

Slit separation	= 0.12 mm
Wavelength	= 680 nm
Distance to screen	= 3.5 m

The intensity I of light at the screen from each slit separately is I_0 . Sketch, on the axes, a graph to show the variation with distance x on the screen of the intensity of light on the screen for this arrangement.

[3]

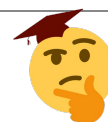


- (c) The slit separation is increased. Outline one change observed on the screen.

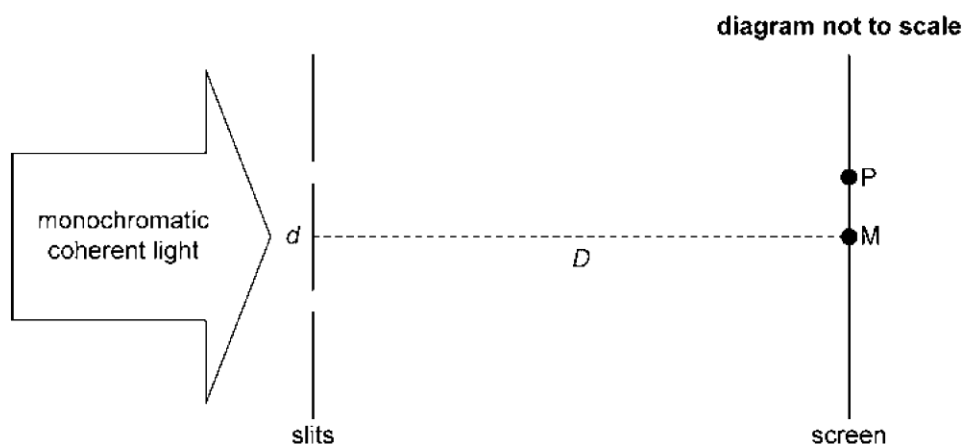
[1]

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6 – (PHYSI/22_HL_Summer_2019_Q8) – Wave Phenomena (ahl)



Monochromatic coherent light is incident on two parallel slits of negligible width a distance d apart. A screen is placed a distance D from the slits. Point M is directly opposite the midpoint of the slits.



Initially the lower slit is covered and the intensity of light at M due to the upper slit alone is 22 W m^{-2} . The lower slit is now uncovered.

- (a) Deduce, in W m^{-2} , the intensity at M. [3]

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- (b) P is the first maximum of intensity on **one** side of M. The following data are available.

$$d = 0.12 \text{ mm}$$

$$D = 1.5 \text{ m}$$

$$\text{Distance MP} = 7.0 \text{ mm}$$

- Calculate, in nm, the wavelength λ of the light. [2]

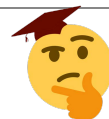
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(c) The width of each slit is increased to 0.030 mm. D , d and λ remain the same.



(i) Suggest why, after this change, the intensity at P will be less than that at M. [1]

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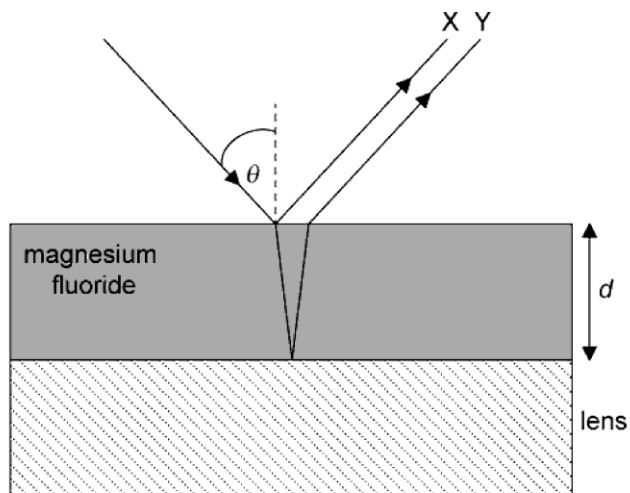
(ii) Show that, due to single slit diffraction, the intensity at a point on the screen a distance of 28 mm from M is zero. [2]

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7 - (PHYSI/20_HL_Winter_2019_Q10) - Oscillations & Waves, Wave Phenomena (ahl)



The lens of an optical system is coated with a thin film of magnesium fluoride of thickness d . Monochromatic light of wavelength 656 nm in air is incident on the lens. The angle of incidence is θ . Two reflected rays, X and Y, are shown.



The following refractive indices are available.

Air	= 1.00
Magnesium fluoride	= 1.38
Lens	= 1.58

(a) Predict whether reflected ray X undergoes a phase change.

[2]

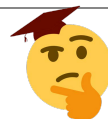
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(b) The thickness of the magnesium fluoride film is d . For the case of normal incidence ($\theta = 0$),



(i) state, in terms of d , the path difference between the reflected rays X and Y. [1]

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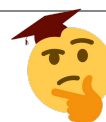
(ii) calculate the smallest value of d that will result in destructive interference between ray X and ray Y. [2]

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(iii) discuss a practical advantage of this arrangement. [2]

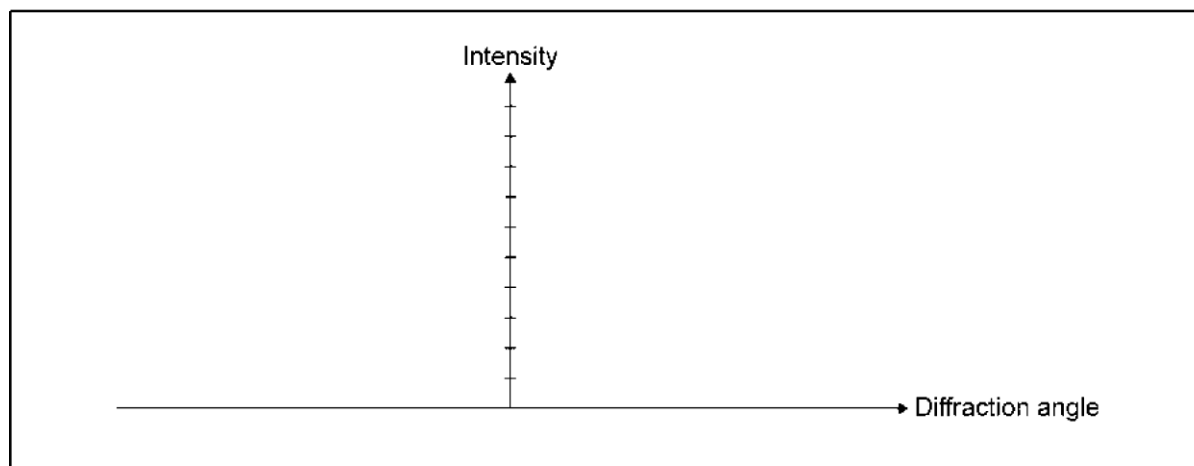
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- (c) Light from a point source is incident on the pupil of the eye of an observer.
The diameter of the pupil is 2.8 mm.



- (i) Draw, on the axes, the variation with diffraction angle of the intensity of light incident on the retina of the observer.

[2]



- (ii) Estimate, in rad, the smallest angular separation of two distinct point sources of light of wavelength 656 nm that can be resolved by the eye of this observer.

[2]

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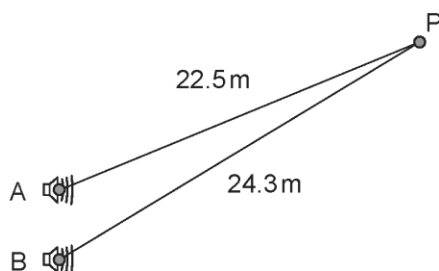
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8 - (PHYSI/20_HL_Winter_2020_Q4) - Oscillations & Waves, Wave Phenomena (ahl)



Two loudspeakers, A and B, are driven in phase and with the same amplitude at a frequency of 850 Hz. Point P is located 22.5 m from A and 24.3 m from B. The speed of sound is 340 m s^{-1} .



(a) Deduce that a minimum intensity of sound is heard at P.

[4]

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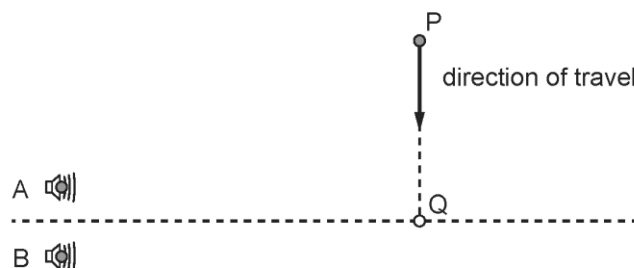
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- (b) A microphone moves along the line from P to Q. PQ is normal to the line midway between the loudspeakers.



The intensity of sound is detected by the microphone. Predict the variation of detected intensity as the microphone moves from P to Q.

[2]

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- (c) When both loudspeakers are operating, the intensity of sound recorded at Q is I_0 . Loudspeaker B is now disconnected. Loudspeaker A continues to emit sound with unchanged amplitude and frequency. The intensity of sound recorded at Q changes to I_A .

Estimate $\frac{I_A}{I_0}$.

[2]

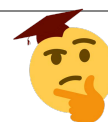
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- (d) In another experiment, loudspeaker A is stationary and emits sound with a frequency of 850 Hz. The microphone is moving directly away from the loudspeaker with a constant speed v . The frequency of sound recorded by the microphone is 845 Hz.



- (i) Explain why the frequency recorded by the microphone is lower than the frequency emitted by the loudspeaker.

[2]

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- (ii) Calculate v .

[2]

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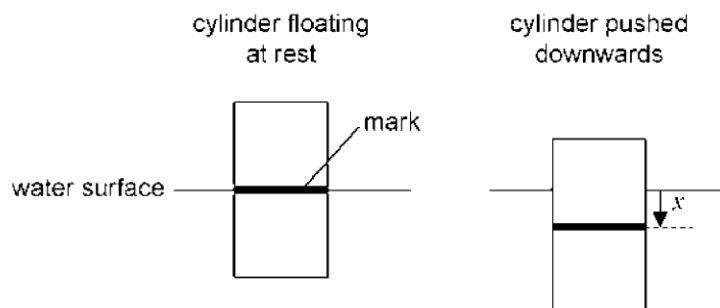
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9 - (PHYSI/20_HL_Winter_2020_Q7) - Wave Phenomena (ahl)



A vertical solid cylinder of uniform cross-sectional area A floats in water. The cylinder is partially submerged. When the cylinder floats at rest, a mark is aligned with the water surface. The cylinder is pushed vertically downwards so that the mark is a distance x below the water surface.



At time $t = 0$ the cylinder is released. The resultant vertical force F on the cylinder is related to the displacement x of the mark by

$$F = -\rho Agx$$

where ρ is the density of water.

- (a) Outline why the cylinder performs simple harmonic motion when released.

[1]

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- (b) The mass of the cylinder is 118 kg and the cross-sectional area of the cylinder is $2.29 \times 10^{-1} \text{ m}^2$. The density of water is $1.03 \times 10^3 \text{ kg m}^{-3}$. Show that the angular frequency of oscillation of the cylinder is about 4.4 rad s^{-1} .

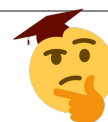
[2]

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(c) The cylinder was initially pushed down a distance $x = 0.250$ m.

(i) Determine the maximum kinetic energy E_{kmax} of the cylinder.

[2]



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(ii) Draw, on the axes, the graph to show how the kinetic energy of the cylinder varies with time during **one** period of oscillation T .

[2]

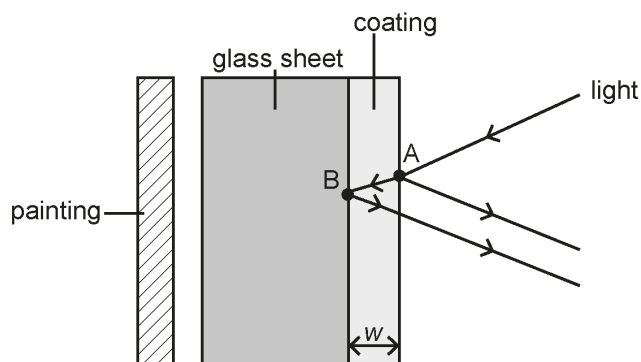


10 - (PHYSI/21_HL_Summer_2021_Q6) - Wave Phenomena (ahl)



A painting is protected behind a transparent glass sheet of refractive index n_{glass} . A coating of thickness w is added to the glass sheet to reduce reflection. The refractive index of the coating n_{coating} is such that $n_{\text{glass}} > n_{\text{coating}} > 1$.

The diagram illustrates rays **normally** incident on the coating. Incident angles on the diagram are drawn away from the normal for clarity.



- (a) State the phase change when a ray is reflected at B.

[1]

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- (b) Explain the condition for w that eliminates reflection for a particular light wavelength in air λ_{air} .

[3]

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- (c) (i) State the Rayleigh criterion for resolution.

[1]



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- (ii) The painting contains a pattern of red dots with a spacing of 3 mm. Assume the wavelength of red light is 700 nm. The average diameter of the pupil of a human eye is 4 mm. Calculate the maximum possible distance at which these red dots are distinguished.

[2]

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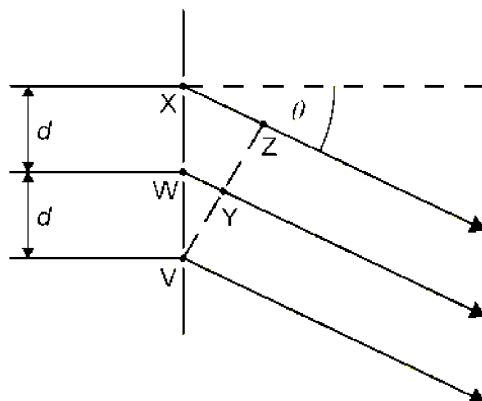
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11 - (PHYSI/22_HL_Summer_2021_Q8) - Wave Phenomena (ahl)



- (a) Monochromatic light of wavelength λ is normally incident on a diffraction grating. The diagram shows adjacent slits of the diffraction grating labelled V, W and X. Light waves are diffracted through an angle θ to form a **second-order** diffraction maximum. Points Z and Y are labelled.



- (i) State the phase difference between the waves at V and Y. [1]

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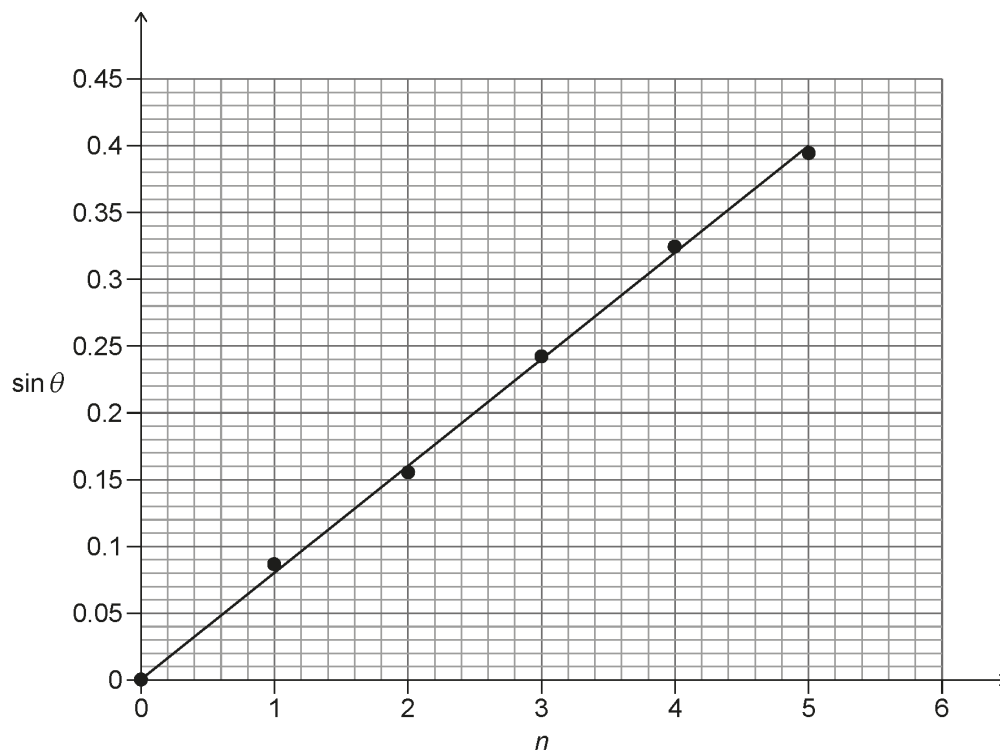
- (ii) State, in terms of λ , the path length between points X and Z. [1]

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- (iii) The separation of adjacent slits is d . Show that for the second-order diffraction maximum $2\lambda = d \sin \theta$. [1]

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- (b) Monochromatic light of wavelength 633 nm is normally incident on a diffraction grating. The diffraction maxima incident on a screen are detected and their angle θ to the central beam is determined. The graph shows the variation of $\sin \theta$ with the order n of the maximum. The central order corresponds to $n = 0$.



Determine a mean value for the number of slits per millimetre of the grating.

[4]

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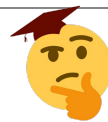
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(c) State the effect on the graph of the variation of $\sin \theta$ with n of:

(i) using a light source with a smaller wavelength.

[1]



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(ii) increasing the distance between the diffraction grating and the screen.

[1]

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12 – (PHYSI/20_HL_Winter_2021_Q8) – Wave Phenomena (ahl)



- (a) State what is meant by the Doppler effect.

[2]

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- (b) A plate performs simple harmonic oscillations with a frequency of 39 Hz and an amplitude of 8.0 cm.

Show that the maximum speed of the oscillating plate is about 20 m s^{-1}

[2]

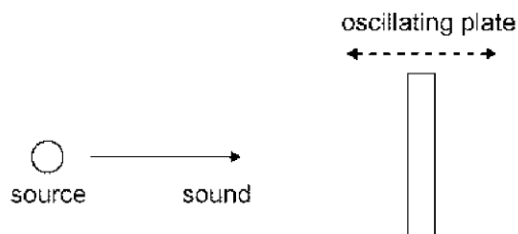
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- (c) Sound of frequency 2400 Hz is emitted from a stationary source towards the oscillating plate in (b). The speed of sound is 340 m s^{-1}



Determine the maximum frequency of the sound that is received back at the source after reflection at the plate.

[2]

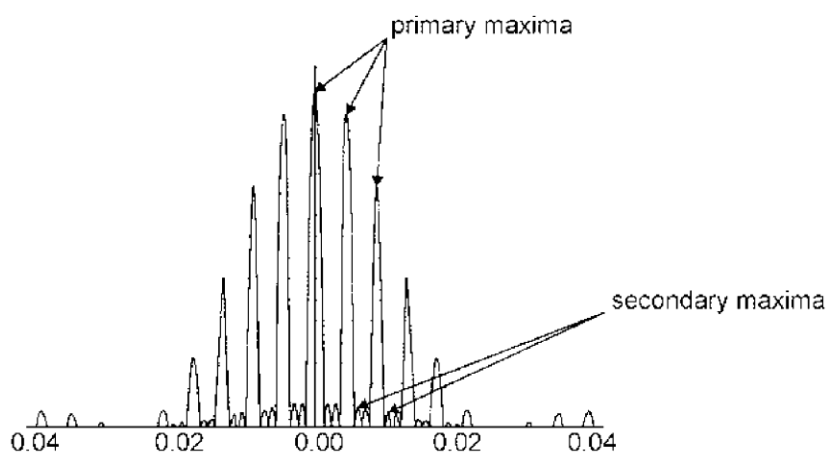
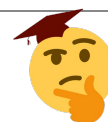
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- (d) The graph shows the variation with diffraction angle of the intensity of light after it has passed through four parallel slits.



The number of slits is increased but their separation and width stay the same. All slits are illuminated. State what will happen to

- (i) the angular position of the primary maxima [1]

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- (ii) the width of the primary maxima [1]

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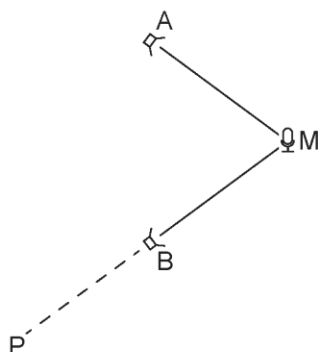
- (iii) the intensity of the secondary maxima. [1]

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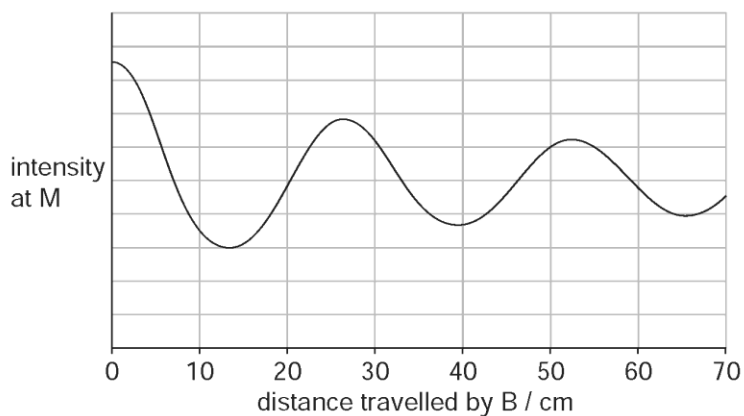
13 - (PHYSI/21_HL_Summer_2022_Q3) - Wave Phenomena (ahl)



Two loudspeakers A and B are initially equidistant from a microphone M. The frequency and intensity emitted by A and B are the same. A and B emit sound in phase. A is fixed in position.



B is moved slowly away from M along the line MP. The graph shows the variation with distance travelled by B of the received intensity at M.



- (a) Explain why the received intensity varies between maximum and minimum values. [3]

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- (b) State and explain the wavelength of the sound measured at M.

[2]



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- (c) B is placed at the first minimum. The frequency is then changed until the received intensity is again at a maximum.

Show that the lowest frequency at which the intensity maximum can occur is about 3 kHz.

Speed of sound = 340 m s^{-1}

[2]

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- (d) Loudspeaker A is switched off. Loudspeaker B moves away from M at a speed of 1.5 m s^{-1} while emitting a frequency of 3.0 kHz.

Determine the difference between the frequency detected at M and that emitted by B.

[2]

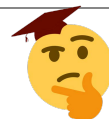
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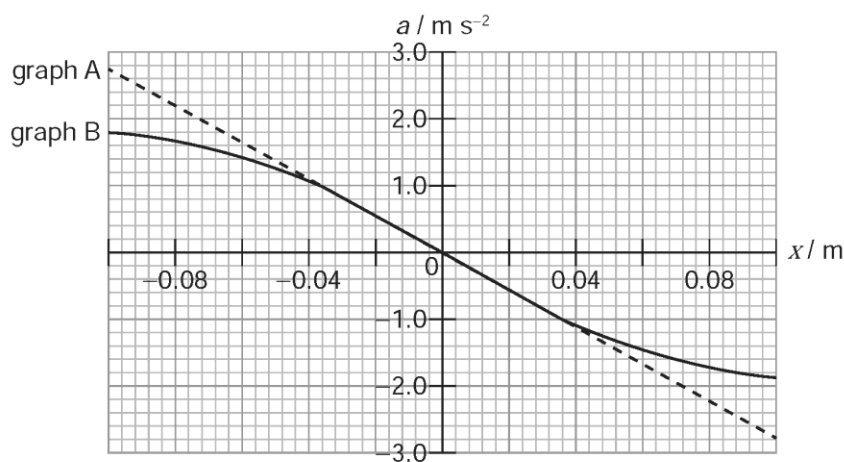
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14 – (PHYSI/21_HL_Summer_2022_Q6) – Wave Phenomena (ahl)



A mass–spring system oscillates horizontally on a frictionless surface. The mass has an acceleration a when its displacement from its equilibrium position is x .

The variation of a with x is modelled in two different ways, A and B, by the graphs shown.



- (a) Outline **two** reasons why both models predict that the motion is simple harmonic when a is small.

[2]

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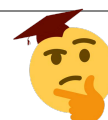
- (b) Determine the time period of the system when a is small.

[4]

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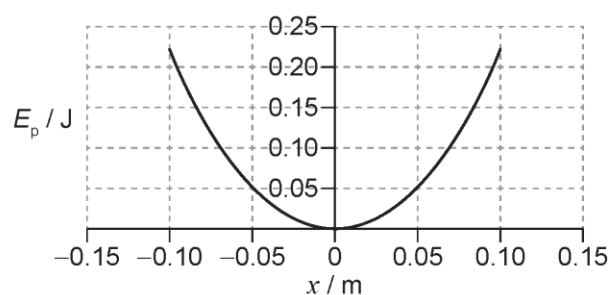
- (c) Outline, without calculation, the change to the time period of the system for the model represented by graph B when a is large.

[2]



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- (d) The graph shows for model A the variation with x of elastic potential energy E_p stored in the spring.



Describe the graph for model B.

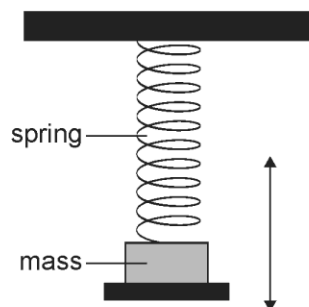
[2]

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15 - (PHYSI/22_HL_Summer_2022_Q6) - Wave Phenomena (ahl)

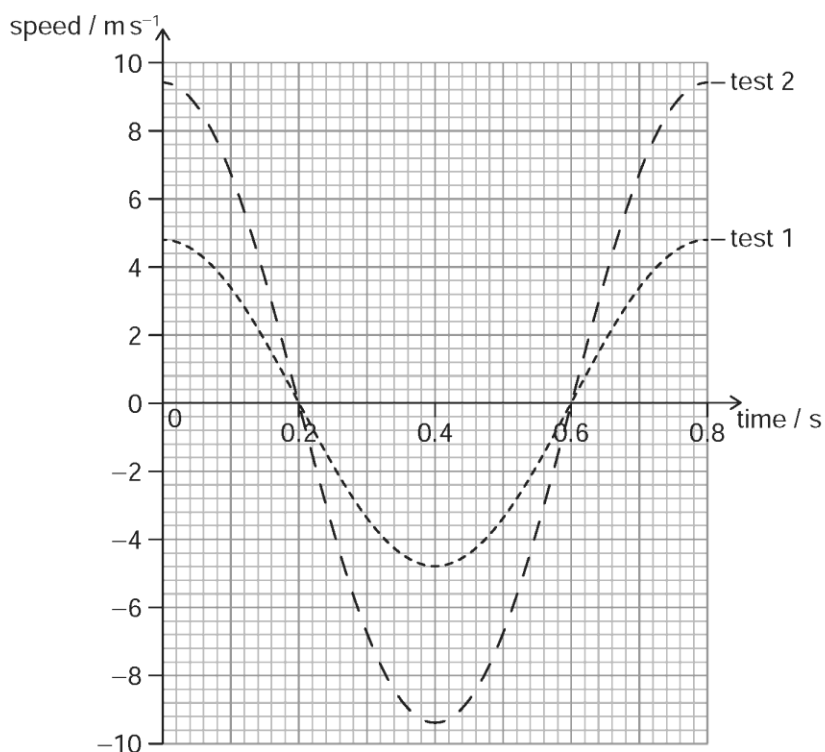


An experiment to investigate simple harmonic motion consists of a mass oscillating at the end of a vertical spring.



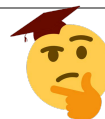
The mass oscillates vertically above a motion sensor that measures the speed of the mass. Test 1 is carried out with a 1.0 kg mass and spring of spring constant k_1 . Test 2 is a repeat of the experiment with a 4.0 kg mass and spring of spring constant k_2 .

The variation with time of the vertical speed of the masses, for one cycle of the oscillation, is shown for each test.



- (a) (i) Calculate the frequency of the oscillation for both tests.

[1]



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- (ii) Deduce $\frac{k_1}{k_2}$.

[2]

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- (iii) Determine the amplitude of oscillation for test 1.

[2]

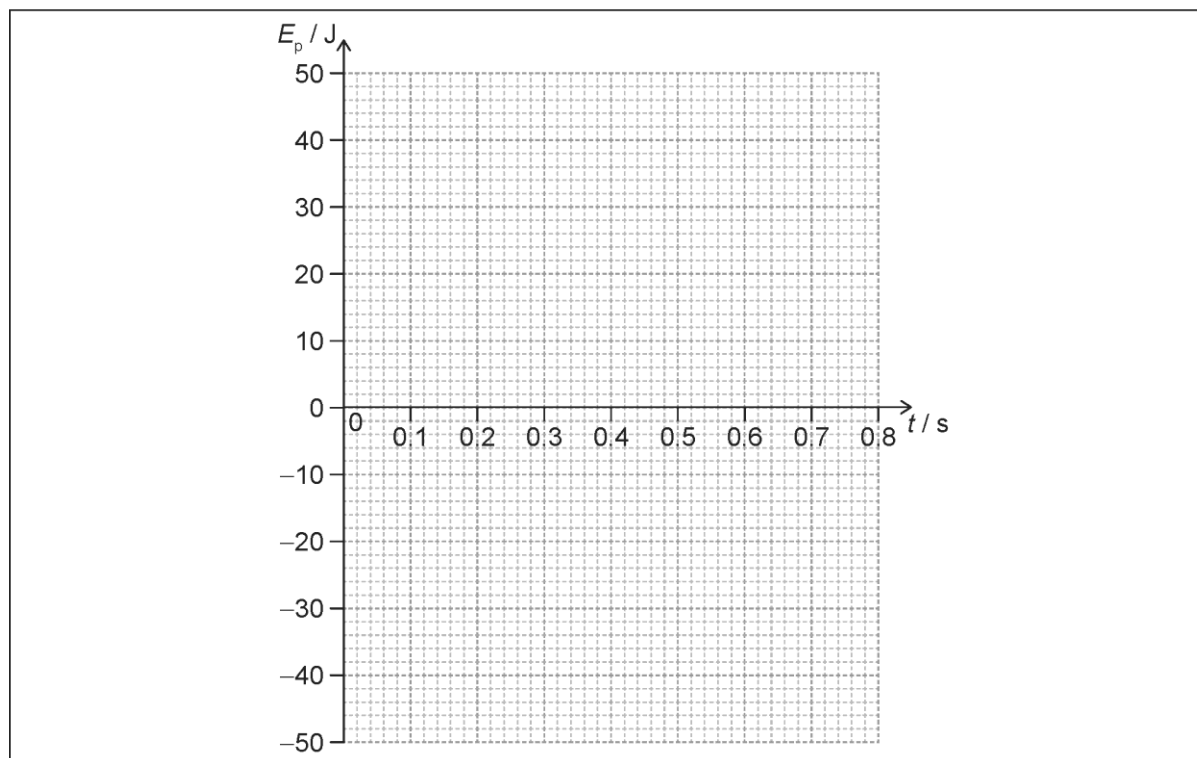
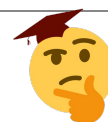
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(iv) In test 2, the maximum elastic potential energy E_p stored in the spring is 44 J.

When $t = 0$ the value of E_p for test 2 is zero.

Sketch, on the axes, the variation with time of E_p for test 2.

[2]



- (b) The motion sensor operates by detecting the sound waves reflected from the base of the mass. The sensor compares the frequency detected with the frequency emitted when the signal returns.

The sound frequency emitted by the sensor is 35 kHz. The speed of sound is 340 m s^{-1} .

Determine the maximum frequency change detected by the sensor for test 2.

[4]

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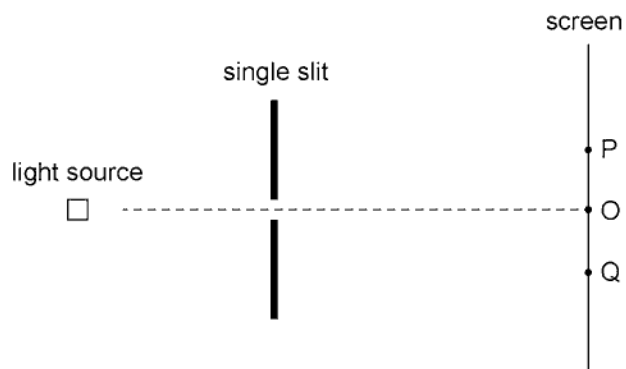
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16 – (PHYSI/20_HL_Winter_2022_Q7) – Wave Phenomena (ahl)



A beam of coherent monochromatic light is incident normally on a single rectangular slit. The diffraction pattern is observed on a screen.

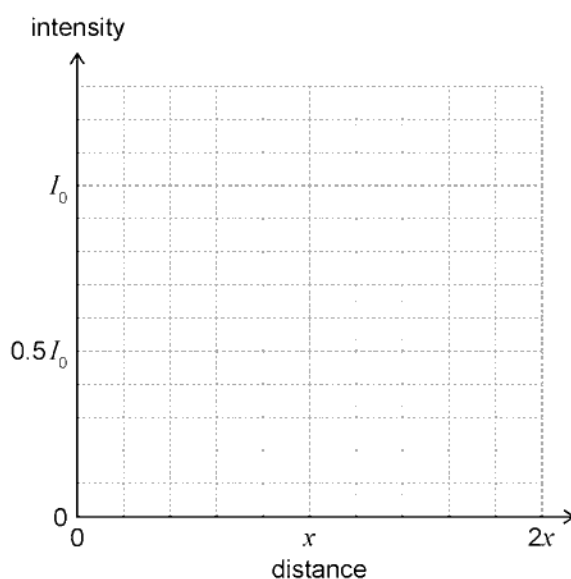


O is the point on the screen directly opposite the slit. P and Q are the first minima on either side of the central fringe of the diffraction pattern.

- (a) (i) The intensity of light at point O is I_0 . The distance OP is x .

Sketch, on the axes, a graph to show the variation of the intensity of light with distance from point O on the screen. Your graph should cover the distance range from 0 to $2x$.

[2]



- (ii) Early theories of light suggest that a geometrical shadow of the slit will be observed on the screen. Explain how the diffraction pattern formed on the screen provides evidence for the wave theory of light.

[2]



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- (iii) The following data are available.

Wavelength of light = 590 nm

Distance between the slit and the screen = 2.4 m

Width of the slit = 0.10 mm

Calculate distance PQ.

[2]

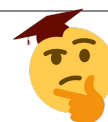
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- (b) The single slit is replaced by a double slit. The width of each slit in this arrangement is the same as the width of the single slit in (a).



Outline how the intensity variation observed between points P and Q will change.

[2]

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- (c) The light source actually emits two wavelengths of light. The average wavelength is 590 nm and the difference between the two wavelengths is 0.60 nm.

A student attempts to resolve the wavelengths using a diffraction grating with 750 lines per mm. The incident beam is 2.0 mm wide.

Comment on whether this diffraction grating can resolve the wavelengths in the first-order spectrum.

[3]

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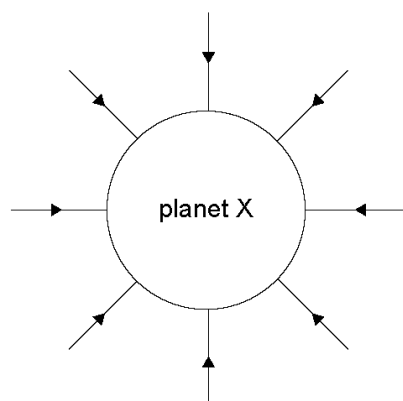
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1 - (PHYSI/21_HL_Summer_2017_Q6) - Fields (ahl), Thermal Physics



The diagram shows the gravitational field lines of planet X.

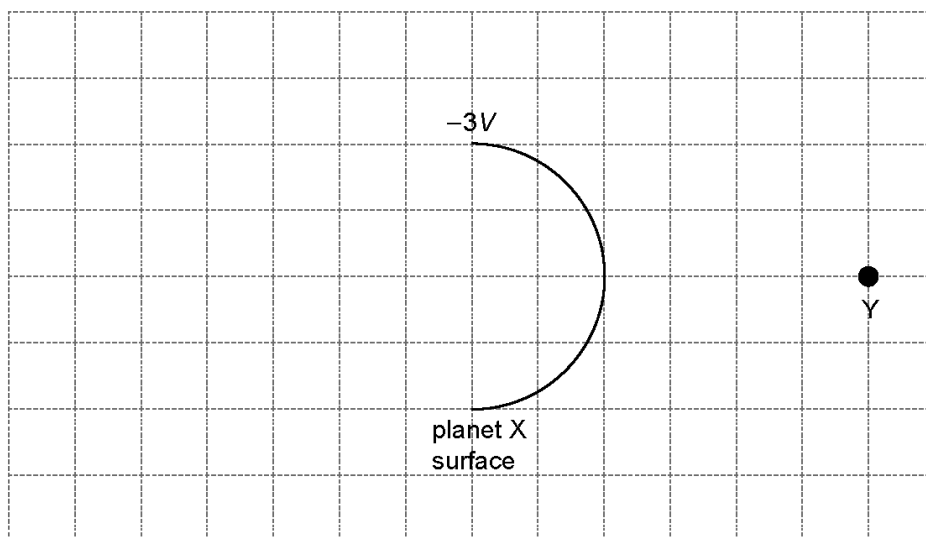


- (a) Outline how this diagram shows that the gravitational field strength of planet X decreases with distance from the surface.

[1]

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- (b) The diagram shows part of the surface of planet X. The gravitational potential at the surface of planet X is $-3V$ and the gravitational potential at point Y is $-V$.

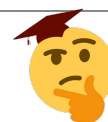


Sketch on the grid the equipotential surface corresponding to a gravitational potential of $-2V$.

[2]

- (c) A meteorite, very far from planet X begins to fall to the surface with a negligibly small initial speed. The mass of planet X is $3.1 \times 10^{21} \text{ kg}$ and its radius is $1.2 \times 10^6 \text{ m}$. The planet has no atmosphere. Calculate the speed at which the meteorite will hit the surface.

[3]



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- (d) At the instant of impact the meteorite which is made of ice has a temperature of 0°C . Assume that all the kinetic energy at impact gets transferred into internal energy in the meteorite. Calculate the percentage of the meteorite's mass that melts. The specific latent heat of fusion of ice is $3.3 \times 10^5 \text{ J kg}^{-1}$.

[2]

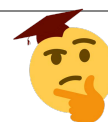
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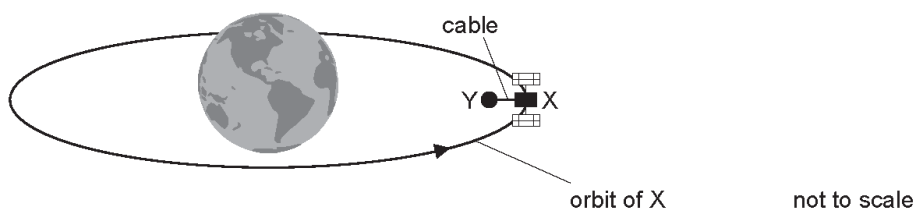
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2 - (PHYSI/20_HL_Winter_2017_Q2) - Circular Motion & Gravitation, Oscillations & Waves, Fields (ahl)



There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



- (a) Satellite X orbits 6600 km from the centre of the Earth.

$$\text{Mass of the Earth} = 6.0 \times 10^{24} \text{ kg}$$

Show that the orbital speed of satellite X is about 8 km s^{-1} . [2]

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- (b) Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

- (i) the orbital times for X and Y are different. [1]

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- (ii) satellite Y requires a propulsion system. [2]

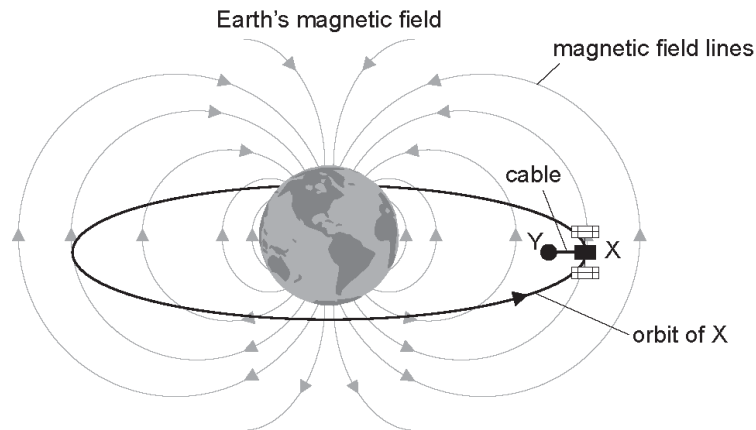
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- (c) The cable between the satellites cuts the magnetic field lines of the Earth at right angles.



Explain why satellite X becomes positively charged.

[3]

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- (d) Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y.

[3]

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- (e) The magnetic field strength of the Earth is $31 \mu\text{T}$ at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]



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- (f) The cable acts as a spring. Satellite Y has a mass m of $3.5 \times 10^2 \text{ kg}$. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period T of 5.2 s.

- (i) Estimate the value of k in the following expression.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X. [3]

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- (ii) Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. [2]

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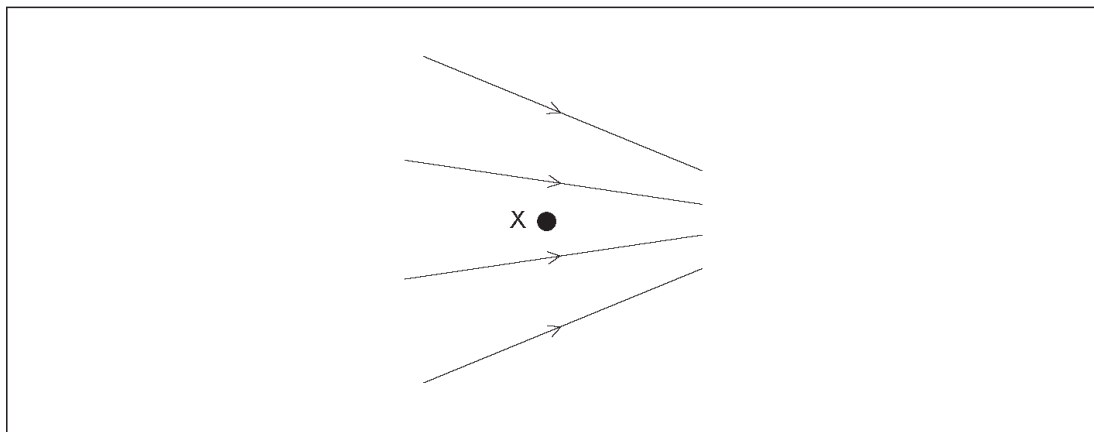
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3 - (PHYSI/20_HL_Winter_2017_Q8) - Fields (ahl)



A non-uniform electric field, with field lines as shown, exists in a region where there is no gravitational field. X is a point in the electric field. The field lines and X lie in the plane of the paper.



- (a) Outline what is meant by electric field strength.

[2]

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- (b) An electron is placed at X and released from rest. Draw, on the diagram, the direction of the force acting on the electron due to the field.

[1]

- (c) The electron is replaced by a proton which is also released from rest at X. Compare, without calculation, the motion of the electron with the motion of the proton after release. You may assume that no frictional forces act on the electron or the proton.

[4]

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4 - (PHYSI/21_HL_Summer_2018_Q7) - *Electromagnetic Induction (ahl), Fields (ahl)*

A capacitor consists of two parallel square plates separated by a vacuum. The plates are $2.5\text{ cm} \times 2.5\text{ cm}$ squares. The capacitance of the capacitor is 4.3 pF .

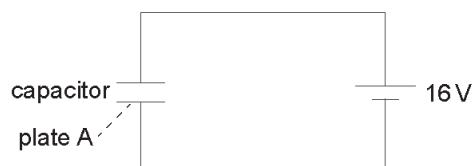
- (a) Calculate the distance between the plates.

[1]

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- (b) The capacitor is connected to a 16 V cell as shown.

diagram not to scale



Calculate the magnitude and the sign of the charge on plate A when the capacitor is fully charged.

[2]

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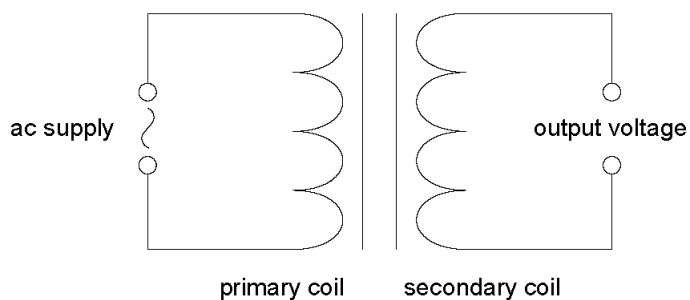
- (c) The capacitor is fully charged and the space between the plates is then filled with a dielectric of permittivity $\epsilon = 3.0\epsilon_0$.

Explain whether the magnitude of the charge on plate A increases, decreases or stays constant.

[2]

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- (d) In a different circuit, a transformer is connected to an alternating current (ac) supply.



The transformer has 100 turns in the primary coil and 1200 turns in the secondary coil. The peak value of the voltage of the ac supply is 220 V. Determine the root mean square (rms) value of the output voltage.

[3]

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- (e) Describe the use of transformers in electrical power distribution.

[3]

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5 - (PHYSI/22_HL_Summer_2018_Q6) - Circular Motion & Gravitation, Fields (ahl)



- (a) A planet has radius R . At a distance h above the surface of the planet the gravitational field strength is g and the gravitational potential is V .

- (i) State what is meant by gravitational field strength. [1]

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- (ii) Show that $V = -g(R + h)$. [2]

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- (iii) Draw a graph, on the axes, to show the variation of the gravitational potential V of the planet with height h above the surface of the planet. [2]



- (b) A planet has a radius of 3.1×10^6 m. At a point P a distance 2.4×10^7 m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1} . Calculate the gravitational potential at point P, include an appropriate unit for your answer.

[1]



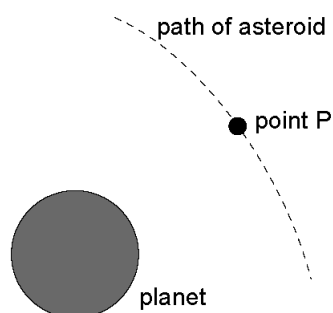
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- (c) The diagram shows the path of an asteroid as it moves past the planet.



When the asteroid was far away from the planet it had negligible speed.
Estimate the speed of the asteroid at point P as defined in (b).

[3]

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- (d) The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the planet when the asteroid is at point P.

[2]

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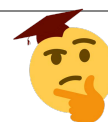
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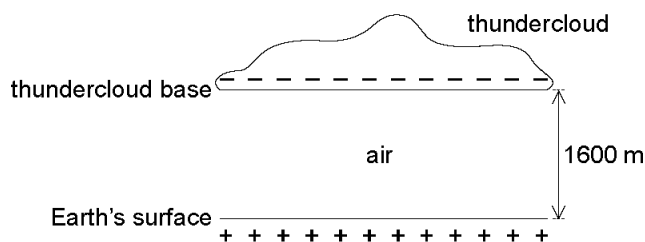
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6 - (PHYSI/22_HL_Summer_2018_Q8) - *Fields (ahl), Electromagnetic Induction (ahl)*



A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

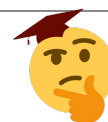
The following data are available.

Area of thundercloud base = $1.2 \times 10^8 \text{ m}^2$
Charge on thundercloud base = -25 C
Distance of thundercloud base from Earth's surface = 1600 m
Permittivity of air = $8.8 \times 10^{-12} \text{ F m}^{-1}$

(a) Show that the capacitance of this arrangement is $C = 6.6 \times 10^{-7} \text{ F}$. [1]

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(b) Calculate



(i) in V, the potential difference between the thundercloud and the Earth's surface. [2]

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(ii) in J, the energy stored in the system. [2]

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(c) Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 32 ms. A lightning strike lasts for 18 ms.

(i) Show that about -11 C of charge is delivered to the Earth's surface. [3]

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(ii) Calculate, in A, the average current during the discharge. [1]

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- (d) State **one** assumption that needs to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor.

[1]



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7 – (PHYSI/22_HL_Summer_2019_Q9) – Fields (ahl)



- (a) A planet of mass m is in a circular orbit around a star. The gravitational potential due to the star at the position of the planet is V .

- (i) Show that the total energy of the planet is given by the equation shown. [2]

$$E = \frac{1}{2}mV$$

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- (ii) Suppose the star could contract to half its original radius without any loss of mass. Discuss the effect, if any, this has on the total energy of the planet. [2]

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- (b) The diagram shows some of the electric field lines for two fixed, charged particles X and Y.

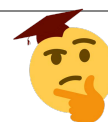
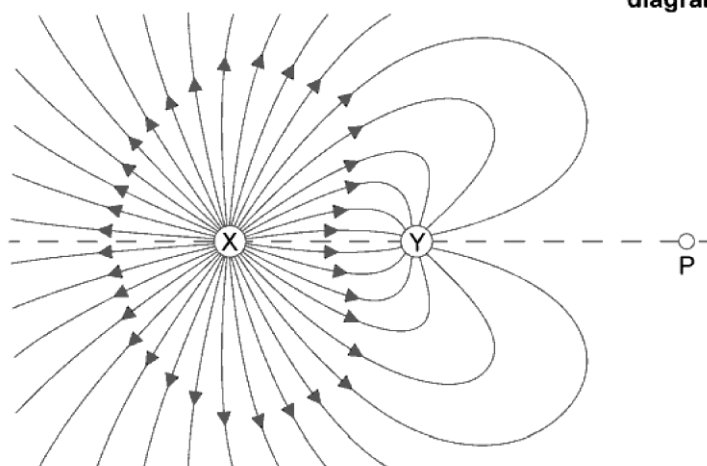


diagram not to scale



The magnitude of the charge on X is Q and that on Y is q . The distance between X and Y is 0.600 m. The distance between P and Y is 0.820 m.

At P the electric field is zero. Determine, to **one** significant figure, the ratio $\frac{Q}{q}$. [2]

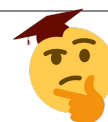
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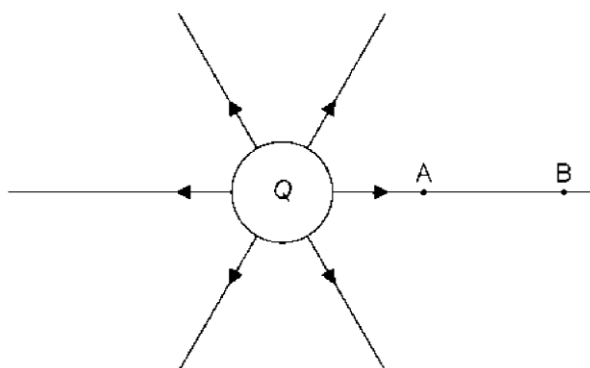
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8 – (PHYSI/20_HL_Winter_2020_Q8) – Fields (ahl)



The diagram shows the electric field lines of a positively charged conducting sphere of radius R and charge Q .



Points A and B are located on the same field line.

(a) Explain why the electric potential decreases from A to B.

[2]

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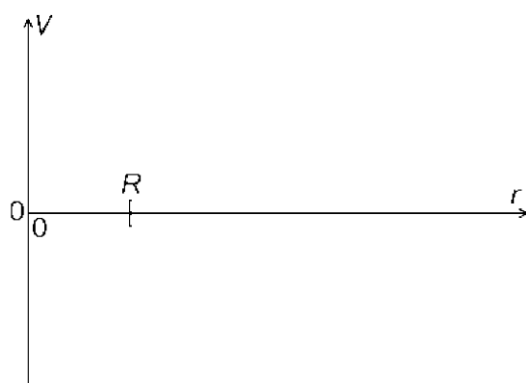
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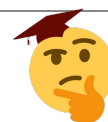
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(b) Draw, on the axes, the variation of electric potential V with distance r from the centre of the sphere.

[2]



- (c) A proton is placed at A and released from rest. The magnitude of the work done by the electric field in moving the proton from A to B is $1.7 \times 10^{-16} \text{ J}$. Point A is at a distance of $5.0 \times 10^{-2} \text{ m}$ from the centre of the sphere. Point B is at a distance of $1.0 \times 10^{-2} \text{ m}$ from the centre of the sphere.



- (i) Calculate the electric potential difference between points A and B.

[1]

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- (ii) Determine the charge Q of the sphere.

[2]

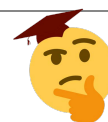
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- (d) The concept of potential is also used in the context of gravitational fields. Suggest why scientists developed a common terminology to describe different types of fields.

[1]

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9 - (PHYSI/21_HL_Summer_2021_Q2) - Circular Motion & Gravitation, Fields (ahl)



A planet is in a circular orbit around a star. The speed of the planet is constant. The following data are given:

$$\text{Mass of planet} = 8.0 \times 10^{24} \text{ kg}$$

$$\text{Mass of star} = 3.2 \times 10^{30} \text{ kg}$$

$$\text{Distance from the star to the planet } R = 4.4 \times 10^{10} \text{ m.}$$

- (a) Explain why a centripetal force is needed for the planet to be in a circular orbit. [2]

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- (b) Calculate the value of the centripetal force. [1]

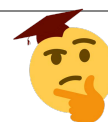
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- (c) A spacecraft is to be launched from the surface of the planet to escape from the star system. The radius of the planet is $9.1 \times 10^3 \text{ km}$.



- (i) Show that the gravitational potential due to the planet and the star at the surface of the planet is about $-5 \times 10^9 \text{ J kg}^{-1}$.

[3]

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- (ii) Estimate the escape speed of the spacecraft from the planet–star system.

[2]

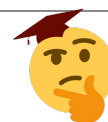
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10 – (PHYSI/22_HL_Summer_2021_Q10) – Fields (ahl)



The table gives data for Jupiter and three of its moons, including the radius r of each object.

Object	Mass/kg	r / m	Orbital radius around Jupiter/m
Jupiter	1.9×10^{27}	7.1×10^7	
Io	8.9×10^{22}	1.8×10^6	4.9×10^8
Ganymede	1.5×10^{23}	2.6×10^6	1.06×10^9
Callisto	1.1×10^{23}	2.4×10^6	1.88×10^9

- (a) Calculate, for the surface of Io, the gravitational field strength g_{Io} due to the mass of Io. State an appropriate unit for your answer.

[2]

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- (b) A spacecraft is to be sent from Io to infinity.

- (i) Show that the $\frac{\text{gravitational potential due to Jupiter at the orbit of Io}}{\text{gravitational potential due to Io at the surface of Io}}$ is about 80.

[2]

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- (ii) Outline, using (b)(i), why it is not correct to use the equation $\sqrt{\frac{2G \times \text{mass of Io}}{\text{radius of Io}}}$ to calculate the speed required for the spacecraft to reach infinity from the surface of Io.

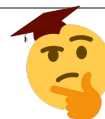
[1]

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- (c) An engineer needs to move a space probe of mass 3600 kg from Ganymede to Callisto. Calculate the energy required to move the probe from the orbital radius of Ganymede to the orbital radius of Callisto. Ignore the mass of the moons in your calculation.

[2]



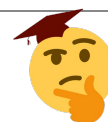
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11 – (PHYSI/21_HL_Summer_2022_Q7) – Fields (ahl)



Two identical positive point charges X and Y are placed 0.30 m apart on a horizontal line. O is the point midway between X and Y. The charge on X and the charge on Y is $+4.0\text{ }\mu\text{C}$.

- (a) Calculate the electric potential at O. [3]

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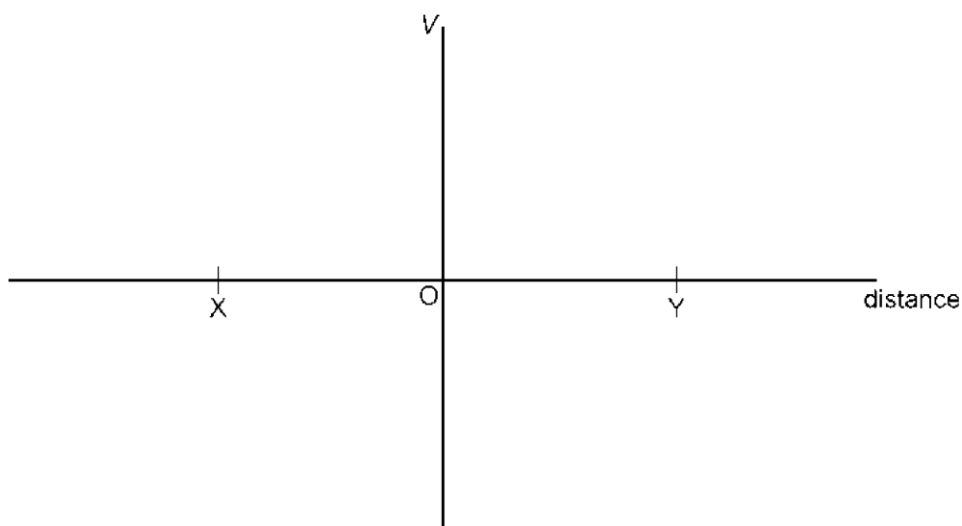
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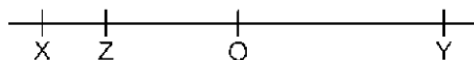
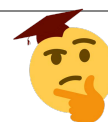
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- (b) Sketch, on the axes, the variation of the electric potential V with distance between X and Y. [2]



- (c) A positive charge Z is released from rest 0.010 m from O on the line between X and Y. Z then begins to oscillate about point O.



- (i) Identify the direction of the resultant force acting on Z as it oscillates.

[2]

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- (ii) Deduce whether the motion of Z is simple harmonic.

[2]

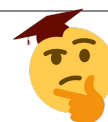
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12 - (PHYSI/22_HL_Summer_2022_Q7) - Fields (ahl)



A metal sphere is charged positively and placed far away from other charged objects.
The electric potential at a point on the surface of the sphere is 53.9 kV.

- (a) Outline what is meant by electric potential at a point. [2]

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- (b) The electric potential at a point a distance 2.8 m from the centre of the sphere is 7.71 kV.
Determine the radius of the sphere. [2]

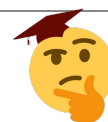
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- (c) A small positively charged object moves towards the centre of the metal sphere. When the object is 2.8 m from the centre of the sphere, its speed is 3.1 m s^{-1} . The mass of the object is 0.14 g and its charge is $2.4 \times 10^{-8} \text{ C}$.



- (i) Comment on the angle at which the object meets equipotential surfaces around the sphere.

[1]

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- (ii) Show that the kinetic energy of the object is about 0.7 mJ.

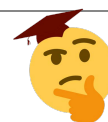
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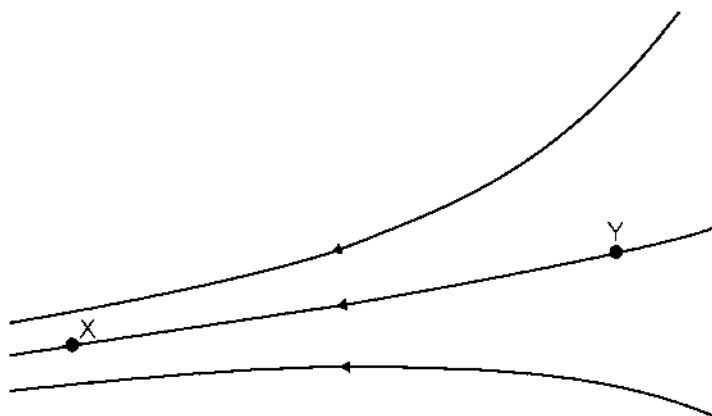
- (iii) Determine whether the object will reach the surface of the sphere.

[3]

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13 – (PHYSI/20_HL_Winter_2022_Q8) – *Fields (ahl)*

- (a) The diagram shows field lines for an electrostatic field. X and Y are two points on the same field line.



Outline which of the two points has the larger electric potential.

[2]

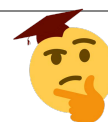
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- (b) A satellite is launched from the surface of Earth into a circular orbit.



The following data are given.

$$\text{Mass of the satellite} = 8.0 \times 10^2 \text{ kg}$$

$$\text{Height of the orbit above the surface of Earth} = 5.0 \times 10^6 \text{ m}$$

$$\text{Mass of Earth} = 6.0 \times 10^{24} \text{ kg}$$

$$\text{Radius of Earth} = 6.4 \times 10^6 \text{ m}$$

- (i) Show that the kinetic energy of the satellite in orbit is about $2 \times 10^9 \text{ J}$. [2]

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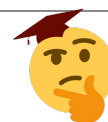
- (ii) Determine the minimum energy required to launch the satellite. Ignore the original kinetic energy of the satellite due to Earth's rotation. [2]

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1 - (PHYSI/21_HL_Summer_2017_Q8) - *Electromagnetic Induction (ahl)*

(a) State Faraday's law of induction.

[2]

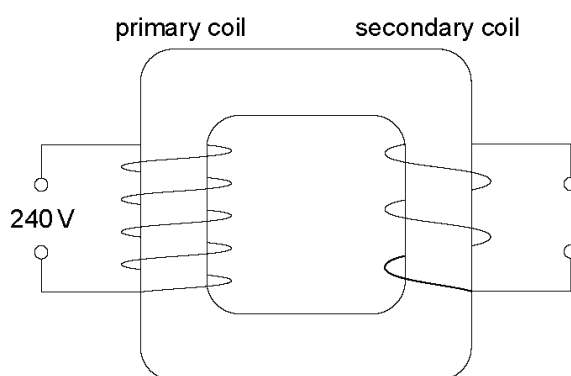
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(b) The diagram shows a sketch of an ideal step-down transformer.



The number of turns in the primary coil is 1800 and that in the secondary coil is 90.

(i) Explain, using Faraday's law of induction, how the transformer steps down the voltage.

[4]

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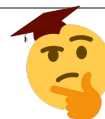
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- (ii) The input voltage is 240 V. Calculate the output voltage.

[2]



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- (c) Outline how energy losses are reduced in the core of a practical transformer.

[2]

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- (d) Step-up transformers are used in power stations to increase the voltage at which the electricity is transmitted. Explain why this is done.

[2]

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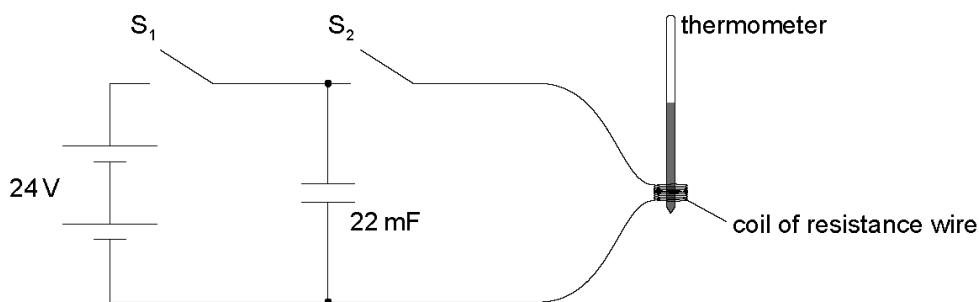
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2 - (PHYSI/22_HL_Summer_2017_Q3) - *Electromagnetic Induction (ahl), Electricity & Magnetism*

The electrical circuit shown is used to investigate the temperature change in a wire that is wrapped around a mercury-in-glass thermometer.



A power supply of emf (electromotive force) 24 V and of negligible internal resistance is connected to a capacitor and to a coil of resistance wire using an arrangement of two switches. Switch S_1 is closed and, a few seconds later, opened. Then switch S_2 is closed.

- (a) The capacitance of the capacitor is 22 mF. Calculate the energy stored in the capacitor when it is fully charged.

[1]

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- (b) The resistance of the wire is $8.0\ \Omega$. Determine the time taken for the capacitor to discharge through the resistance wire. Assume that the capacitor is completely discharged when the potential difference across it has fallen to 0.24 V.

[3]

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- (c) (i) The mass of the resistance wire is 0.61 g and its observed temperature rise is 28 K. Estimate the specific heat capacity of the wire. Include an appropriate unit for your answer.

[2]



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- (ii) Suggest one other energy loss in the experiment and the effect it will have on the value for the specific heat capacity of the wire.

[2]

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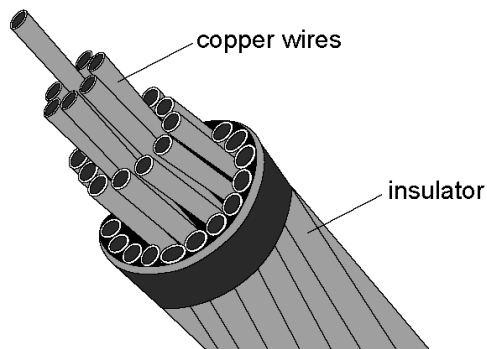
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3 - (PHYSI/22_HL_Summer_2017_Q6) - *Electromagnetic Induction (ahl)*

A cable consisting of many copper wires is used to transfer electrical energy from an alternating current (ac) generator to an electrical load. The copper wires are protected by an insulator.



- (a) The copper wires and insulator are both exposed to an electric field. Discuss, with reference to charge carriers, why there is a significant electric current only in the copper wires.

[3]

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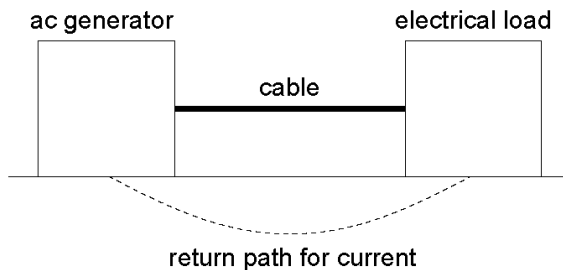
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- (b) The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of $64\ \Omega$. The cable is connected to the ac generator which has an output power of 110 MW when the peak potential difference is 150 kV. The resistivity of copper is $1.7 \times 10^{-8}\ \Omega\text{ m}$.

output power = 110 MW



- (i) Calculate the radius of each wire.

[2]

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- (ii) Calculate the peak current in the cable.

[1]

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- (iii) Determine the power dissipated in the cable per unit length.

[3]

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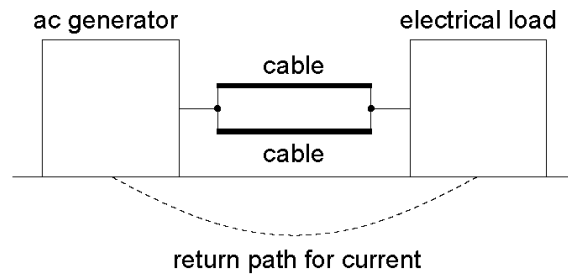
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- (c) To ensure that the power supply cannot be interrupted, two identical cables are connected in parallel.



Calculate the root mean square (rms) current in each cable.

[1]

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- (d) The two cables in part (c) are suspended a constant distance apart. Explain how the magnetic forces acting between the cables vary during the course of one cycle of the alternating current (ac).

[2]

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- (e) The energy output of the ac generator is at a much lower voltage than the 150 kV used for transmission. A step-up transformer is used between the generator and the cables.



- (i) Suggest the advantage of using a step-up transformer in this way.

[2]

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- (ii) The use of alternating current (ac) in a transformer gives rise to energy losses. State how eddy current loss is minimized in the transformer.

[1]

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4 - (PHYSI/21_HL_Summer_2018_Q7) - *Electromagnetic Induction (ahl), Fields (ahl)*

A capacitor consists of two parallel square plates separated by a vacuum. The plates are $2.5\text{ cm} \times 2.5\text{ cm}$ squares. The capacitance of the capacitor is 4.3 pF .

(a) Calculate the distance between the plates.

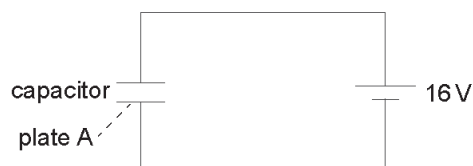
[1]

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(b) The capacitor is connected to a 16 V cell as shown.

diagram not to scale



Calculate the magnitude and the sign of the charge on plate A when the capacitor is fully charged.

[2]

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(c) The capacitor is fully charged and the space between the plates is then filled with a dielectric of permittivity $\epsilon = 3.0\epsilon_0$.

Explain whether the magnitude of the charge on plate A increases, decreases or stays constant.

[2]

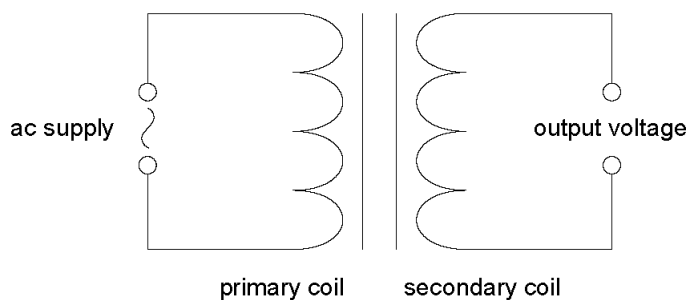
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- (d) In a different circuit, a transformer is connected to an alternating current (ac) supply.



The transformer has 100 turns in the primary coil and 1200 turns in the secondary coil. The peak value of the voltage of the ac supply is 220 V. Determine the root mean square (rms) value of the output voltage.

[3]

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- (e) Describe the use of transformers in electrical power distribution.

[3]

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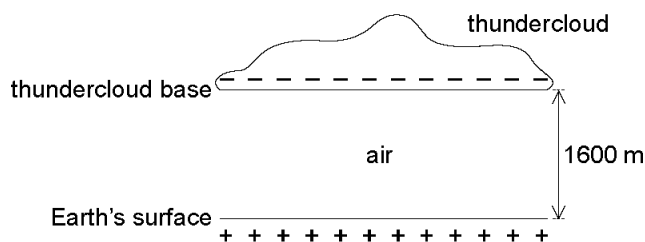
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5 - (PHYSI/22_HL_Summer_2018_Q8) - *Fields (ahl), Electromagnetic Induction (ahl)*

A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

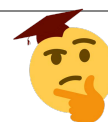
The following data are available.

Area of thundercloud base = $1.2 \times 10^8 \text{ m}^2$
Charge on thundercloud base = -25 C
Distance of thundercloud base from Earth's surface = 1600 m
Permittivity of air = $8.8 \times 10^{-12} \text{ F m}^{-1}$

(a) Show that the capacitance of this arrangement is $C = 6.6 \times 10^{-7} \text{ F}$. [1]

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(b) Calculate



(i) in V, the potential difference between the thundercloud and the Earth's surface. [2]

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(ii) in J, the energy stored in the system. [2]

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(c) Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 32 ms. A lightning strike lasts for 18 ms.

(i) Show that about -11 C of charge is delivered to the Earth's surface. [3]

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(ii) Calculate, in A, the average current during the discharge. [1]

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- (d) State **one** assumption that needs to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor.

[1]

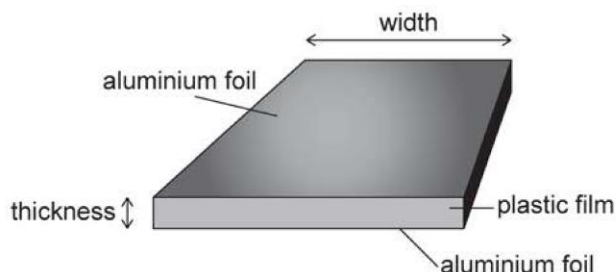


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6 - (PHYSI/21_HL_Summer_2019_Q8) - *Electromagnetic Induction (ahl), Electricity & Magnetism*

A student makes a parallel-plate capacitor of capacitance 68 nF from aluminium foil and plastic film by inserting one sheet of plastic film between two sheets of aluminium foil.

diagram not to scale



The aluminium foil and the plastic film are 450 mm wide.

The plastic film has a thickness of 55 μm and a permittivity of $2.5 \times 10^{-11} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$.

- (a) (i) Calculate the total length of aluminium foil that the student will require. [3]

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- (ii) The plastic film begins to conduct when the electric field strength in it exceeds 1.5 MN C^{-1} . Calculate the maximum charge that can be stored on the capacitor. [2]

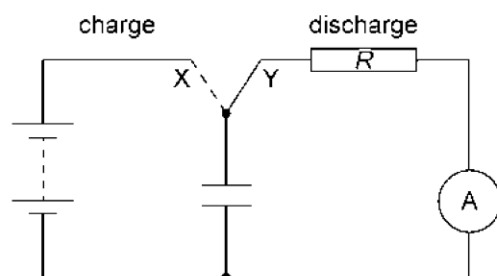
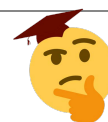
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- (b) The student uses a switch to charge and discharge the capacitor using the circuit shown. The ammeter is ideal.



The emf of the battery is 12 V.

- (i) The resistor R in the circuit has a resistance of $1.2 \text{ k}\Omega$. Calculate the time taken for the charge on the capacitor to fall to 50 % of its fully charged value.

[3]

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- (ii) The ammeter is replaced by a coil. Explain why there will be an induced emf in the coil while the capacitor is discharging.

[2]

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- (iii) Suggest **one** change to the discharge circuit, apart from changes to the coil, that will increase the maximum induced emf in the coil.

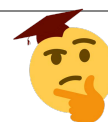
[2]

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7 - (PHYSI/22_HL_Summer_2019_Q10) - *Electromagnetic Induction (ahl)*

A small magnet is dropped from rest above a stationary horizontal conducting ring. The south (S) pole of the magnet is upwards.

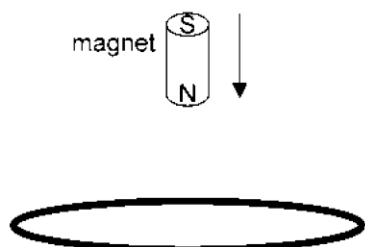


Diagram 1: side view

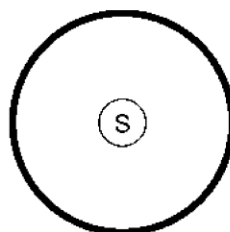


Diagram 2: view from above

While the magnet is moving towards the ring,

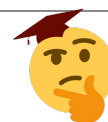
- (a) state why the magnetic flux in the ring is increasing. [1]

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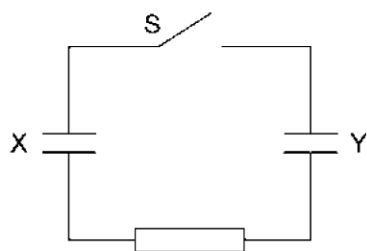
- (b) sketch, using an arrow on **Diagram 2**, the direction of the induced current in the ring. [1]

- (c) deduce the direction of the magnetic force on the magnet. [2]

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8 - (PHYSI/20_HL_Winter_2019_Q9) - *Electromagnetic Induction (ahl)*

X has a capacitance of $18\ \mu\text{F}$. X is charged so that the one plate has a charge of $48\ \mu\text{C}$. X is then connected to an uncharged capacitor Y and a resistor via an open switch S.



(a) Calculate, in J, the energy stored in X with the switch S open.

[2]

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(b) The capacitance of Y is $12\ \mu\text{F}$. S is now closed.

(i) Calculate the final charge on X and the final charge on Y.

[3]

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(ii) Calculate the final total energy, in J, stored in X and Y.

[2]

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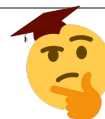
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(c) Suggest why the answers to (a) and (b)(ii) are different.

[2]



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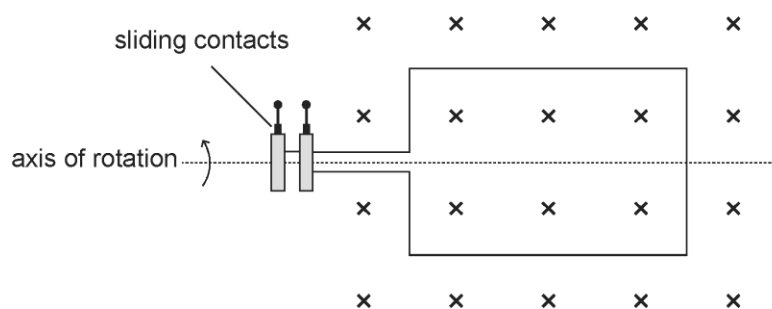
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9 - (PHYSI/20_HL_Winter_2020_Q9) - *Electromagnetic Induction (ahl)*

The diagram shows an alternating current generator with a rectangular coil rotating at a constant frequency in a uniform magnetic field.



- (a) Explain, by reference to Faraday's law of induction, how an electromotive force (emf) is induced in the coil.

[3]

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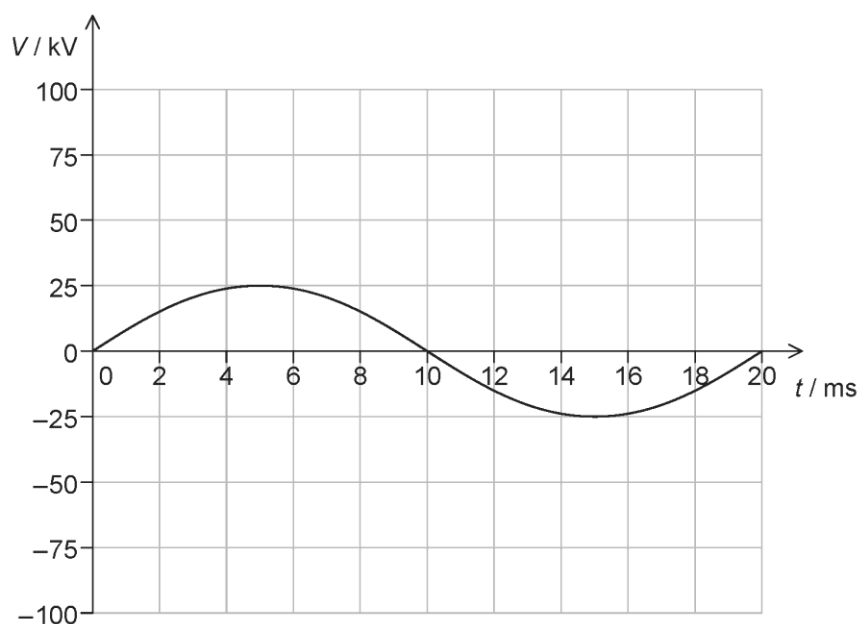
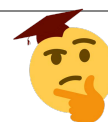
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- (b) The graph shows how the generator output voltage V varies with time t .



Electrical power produced by the generator is delivered to a consumer some distance away.

- (i) The average power output of the generator is $8.5 \times 10^5 \text{ W}$. Calculate the root mean square (rms) value of the generator output current. [2]

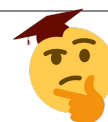
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- (ii) The voltage output from the generator is stepped up before transmission to the consumer. Estimate the factor by which voltage has to be stepped up in order to reduce power loss in the transmission line by a factor of 2.5×10^2 . [1]

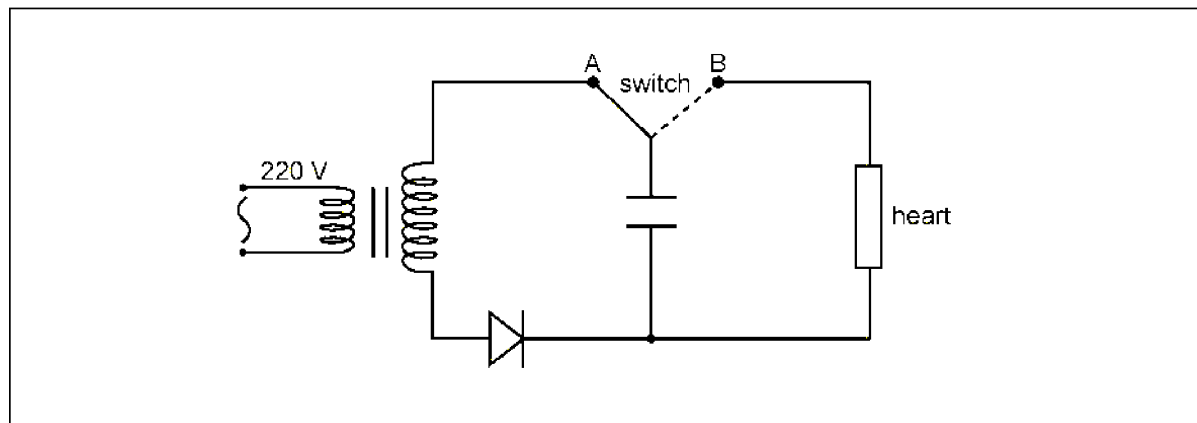
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- (iii) The frequency of the generator is doubled with no other changes being made. Draw, on the axes, the variation with time of the voltage output of the generator. [2]

10 - (PHYSI/21_HL_Summer_2021_Q5) - Electromagnetic Induction (ahl)



A device sends an impulse of electrical energy to maintain a regular heartbeat in a person. The device is powered by an alternating current (ac) supply connected to a step-up transformer that charges a capacitor of capacitance $30\mu\text{F}$.



- (a) Explain the role of the diode in the circuit when the switch is at position A. [2]

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- (b) The voltage across the primary coil of the transformer is 220 V. The number of turns on the secondary coil is 15 times greater than the number of turns on the primary coil.

- (i) Show that the maximum energy stored by the capacitor is about 160 J. [2]

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- (ii) Calculate the maximum charge Q_0 stored in the capacitor. [1]

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- (iii) Identify, using the label + on the diagram, the polarity of the capacitor. [1]

(c) The switch is moved to position B.



- (i) Describe what happens to the energy stored in the capacitor when the switch is moved to position B.

[1]

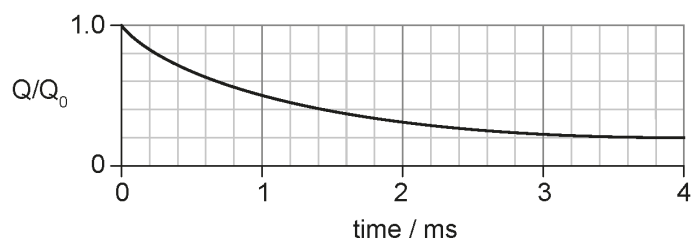
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- (ii) Show that the charge remaining in the capacitor after a time equal to one time constant τ of the circuit will be $0.37 Q_0$.

[1]

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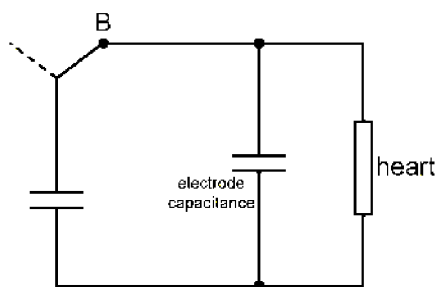
- (iii) The graph shows the variation with time of the charge in the capacitor as it is being discharged through the heart.



Determine the electrical resistance of the closed circuit with the switch in position B. [2]

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- (d) In practice, two electrodes connect the heart to the circuit. These electrodes introduce an additional capacitance.



Explain the effect of the electrode capacitance on the discharge time.

[2]

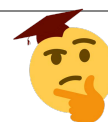
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11 - (PHYSI/22_HL_Summer_2021_Q7) - Oscillations & Waves, Electromagnetic Induction (ahl)



- (a) The primary coil of a transformer is connected to a 110V alternating current (ac) supply. The secondary coil of the transformer is connected to a 15V garden lighting system that consists of 8 lamps connected in parallel. Each lamp is rated at 35W when working at its normal brightness. Root mean square (rms) values are used throughout this question.

- (i) The primary coil has 3300 turns. Calculate the number of turns on the secondary coil. [1]

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- (ii) Determine the total resistance of the lamps when they are working normally. [2]

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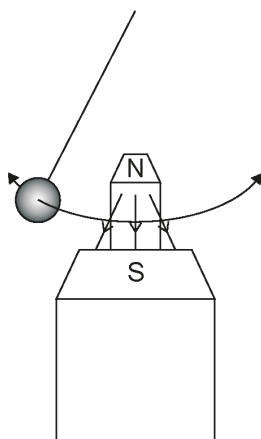
- (iii) Calculate the current in the primary of the transformer assuming that it is ideal. [2]

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- (iv) Flux leakage is one reason why a transformer may not be ideal. Explain the effect of flux leakage on the transformer. [2]

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- (b) A pendulum with a metal bob comes to rest after 200 swings. The same pendulum, released from the same position, now swings at 90° to the direction of a strong magnetic field and comes to rest after 20 swings.



Explain why the pendulum comes to rest after a smaller number of swings.

[4]

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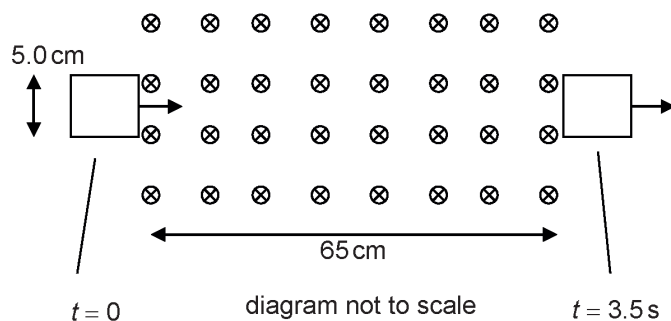
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12 - (PHYSI/20_HL_Winter_2021_Q5) - *Electromagnetic Induction (ahl)*

A square loop of side 5.0 cm enters a region of uniform magnetic field at $t = 0$. The loop exits the region of magnetic field at $t = 3.5$ s. The magnetic field strength is 0.94 T and is directed into the plane of the paper. The magnetic field extends over a length 65 cm. The speed of the loop is constant.



- (a) Show that the speed of the loop is 20 cm s^{-1}

[1]

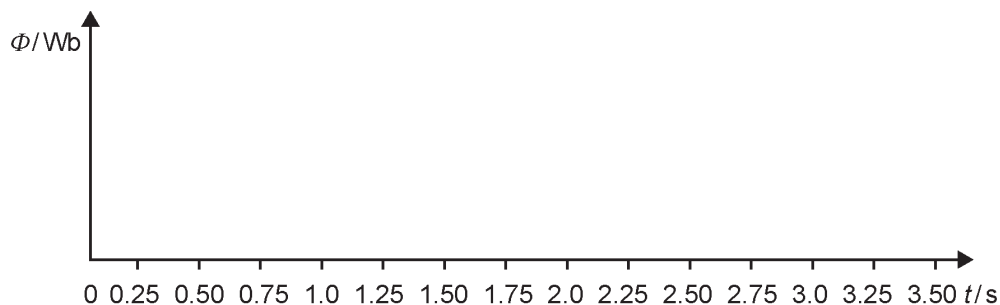
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- (b) Sketch graphs, on the axes, to show the variation with time of

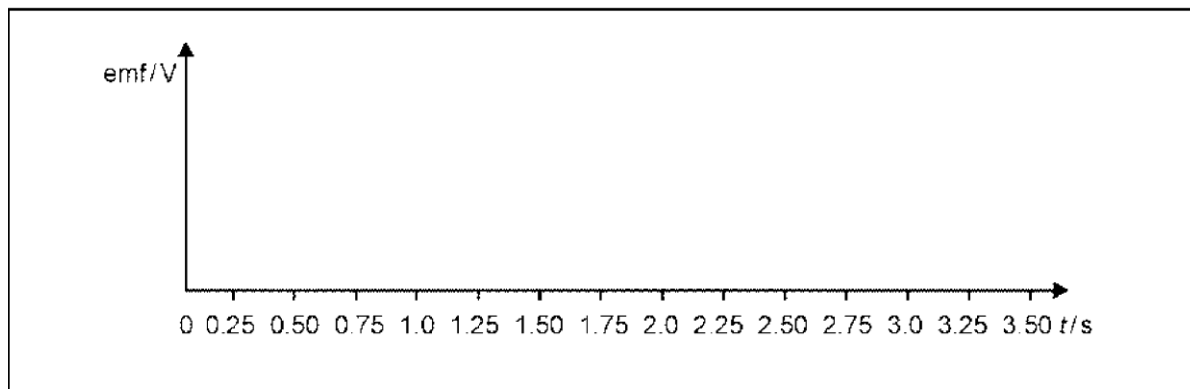
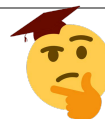
- (i) the magnetic flux linkage Φ in the loop.

[1]



- (ii) the magnitude of the emf induced in the loop.

[1]



- (c) (i) There are 85 turns of wire in the loop. Calculate the maximum induced emf in the loop.

[2]

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- (ii) The resistance of the loop is $2.4\ \Omega$. Calculate the magnitude of the magnetic force on the loop as it enters the region of magnetic field.

[2]

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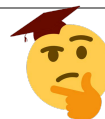
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- (d) (i) Show that the energy dissipated in the loop from $t = 0$ to $t = 3.5\text{ s}$ is 0.13 J .

[2]



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- (ii) The mass of the wire is 18 g . The specific heat capacity of copper is $385\text{ J kg}^{-1}\text{ K}^{-1}$.
Estimate the increase in temperature of the wire.

[2]

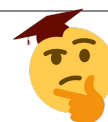
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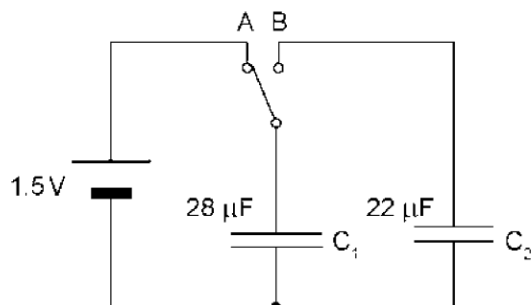
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13 – (PHYSI/21_HL_Summer_2022_Q8) – Electromagnetic Induction (ahl)



Two capacitors C_1 and C_2 of capacitance $28\ \mu\text{F}$ and $22\ \mu\text{F}$ respectively are connected in a circuit with a two-way switch and a cell of emf $1.5\ \text{V}$ with a negligible internal resistance. The capacitors are initially uncharged. The switch is then connected to position A.



- (a) Show that the charge stored on C_1 is about $0.04\ \text{mC}$.

[1]

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- (b) The switch is moved to position B.

- (i) Calculate the energy transferred from capacitor C_1 .

[4]

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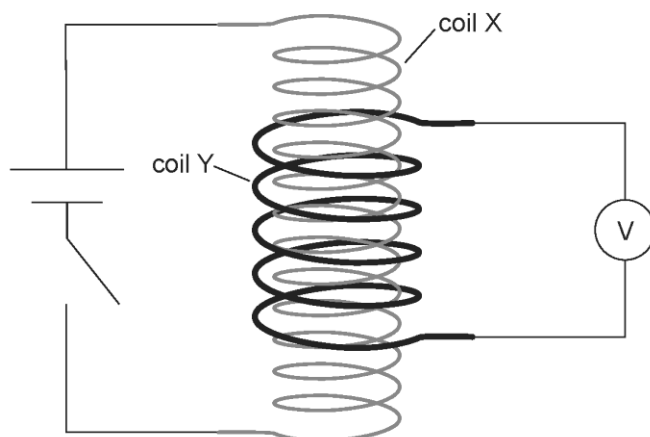
- (ii) Explain why the energy gained by capacitor C_2 differs from your answer in (b)(i).

[1]

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- (c) A cell is now connected by a switch to a coil X. A second coil Y of cross-sectional area 6.4 cm^2 with 5 turns is looped around coil X and connected to an ideal voltmeter.



- (i) The switch is closed at time $t = 0$. Explain how the voltmeter reading varies after the switch is closed.

[2]

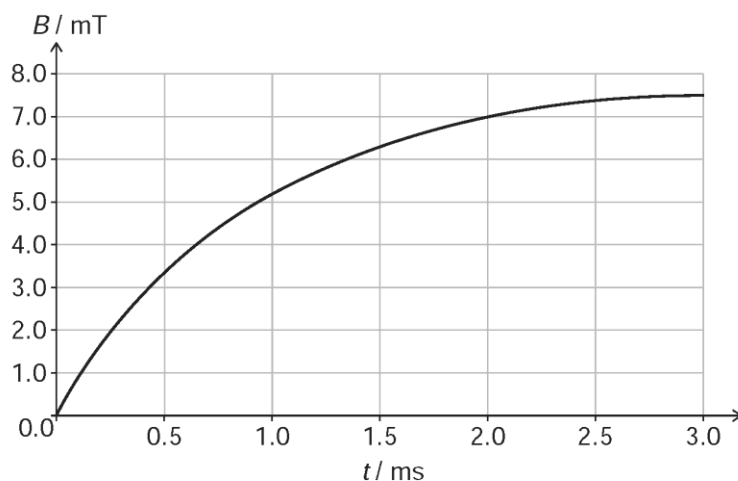
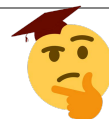
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The graph shows the variation with t of the magnetic flux density B in coil Y.



(ii) Determine the average emf induced across coil Y in the first 3.0 ms.

[3]

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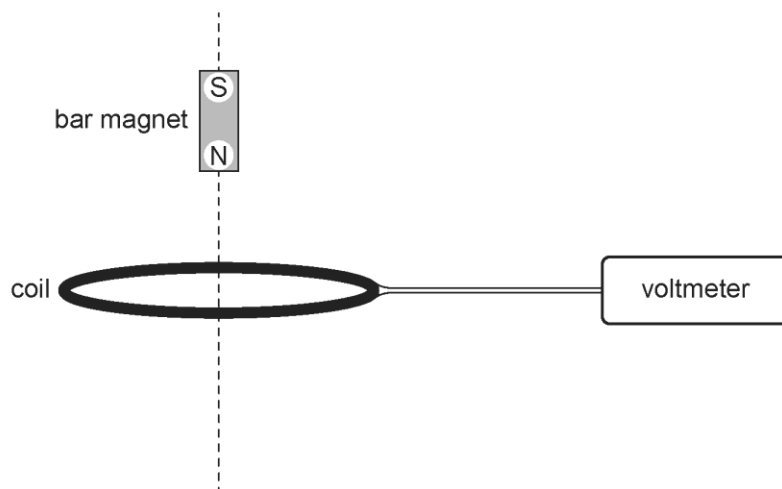
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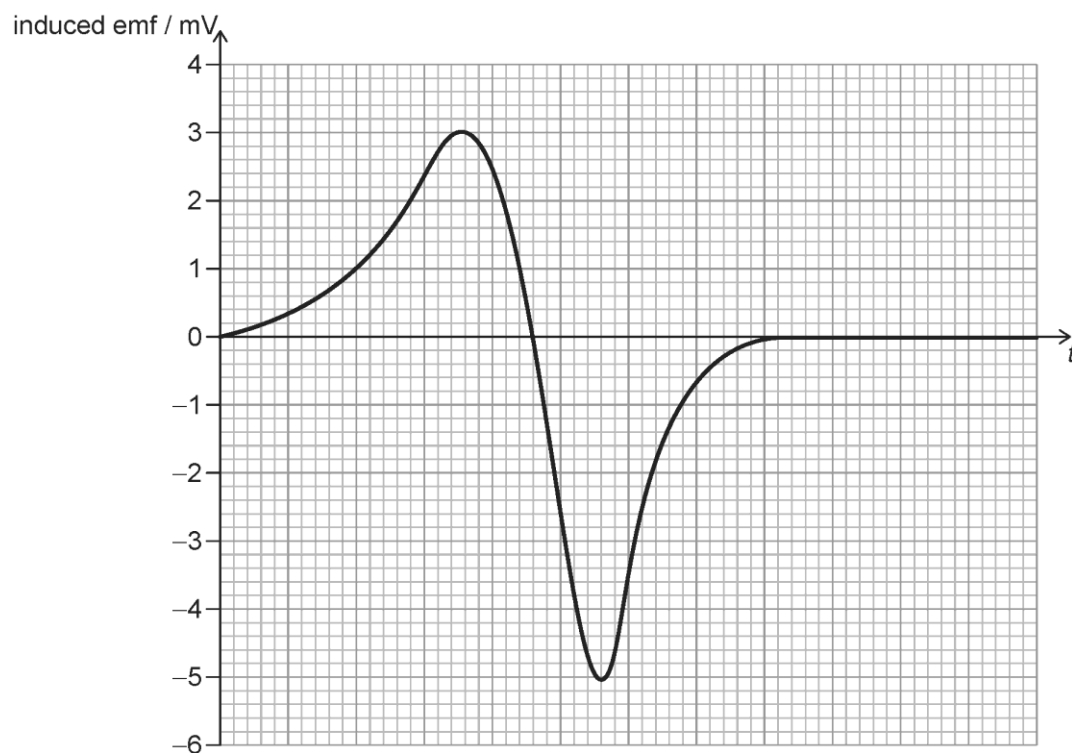
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14 - (PHYSI/22_HL_Summer_2022_Q8) - *Electromagnetic Induction (ahl)*

A fixed horizontal coil is connected to an ideal voltmeter. A bar magnet is released from rest so that it falls vertically through the coil along the central axis of the coil.



The variation with time t of the emf induced in the coil is shown.



- (a) (i) Write down the maximum magnitude of the rate of change of flux linked with the coil.

[1]



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- (ii) State the fundamental SI unit for your answer to (a)(i).

[1]

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- (b) (i) Explain why the graph becomes negative.

[3]

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- (ii) Part of the graph is above the t -axis and part is below. Outline why the areas between the t -axis and the curve for these two parts are likely to be the same.

[2]

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- (c) Predict the changes to the graph when the magnet is dropped from a lower height above the coil.

[3]



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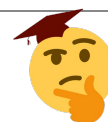
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15 – (PHYSI/20_HL_Winter_2022_Q9) – *Electromagnetic Induction (ahl)*

A parallel-plate capacitor of capacitance $1.5 \times 10^{-10} \text{ F}$ is made from two metal plates separated by an air gap of 1.0 mm. The capacitor is initially charged to a potential difference of 24 V.

(a) Calculate the energy stored in the capacitor.

[1]

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The charged capacitor is disconnected from the voltage supply and the separation between the plates is increased to 4.0 mm.

(b) (i) Explain the change, if any, to the potential difference between the plates.

[2]

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(ii) Determine the work required to increase the separation of the plates.

[2]

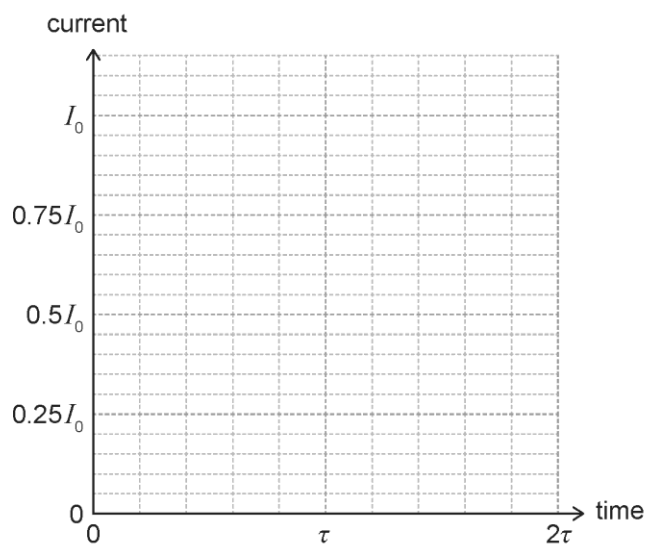
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The capacitor is then discharged through a fixed resistor. The initial current in the resistor is I_0 and the time constant of the circuit is τ .



- (c) (i) Draw, on the axes, a graph to show the variation with time of the current in the resistor.

[2]



- (ii) A similar mathematical relationship can be used to model phenomena in other areas of physics.

State an example of such a phenomenon.

[1]

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- (d) A diode bridge rectification circuit is often modified by adding a capacitor in parallel with the output (load) resistance.

Describe the reason for this modification.

[2]

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1 - (PHYSI/21_HL_Summer_2017_Q5) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



(a) State the quark structures of a meson and a baryon.

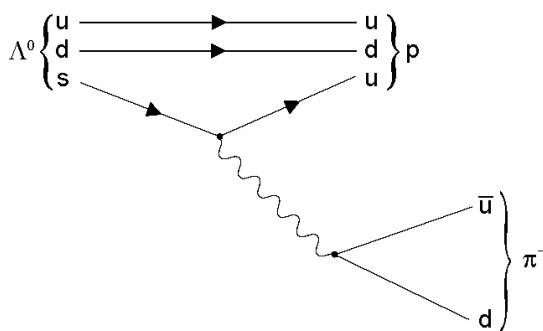
[2]

Meson:

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Baryon:

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(b) A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.

(i) Explain which interaction is responsible for this decay.

[2]

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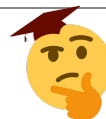
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(ii) Draw arrow heads on the lines representing $\bar{u}$ and d in the π^- .

[1]

(iii) Identify the exchange particle in this decay.

[1]



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(c) Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators.

[1]

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2 - (PHYSI/21_HL_Summer_2017_Q9) - *Quantum & Nuclear Physics (ahl)*

Two observations about the photoelectric effect are

Observation 1: For light below the threshold frequency no electrons are emitted from the metal surface.

Observation 2: For light above the threshold frequency, the emission of electrons is almost instantaneous.

(a) Explain how each observation provides support for the particle theory but not the wave theory of light.

[4]

Observation 1:

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Observation 2:

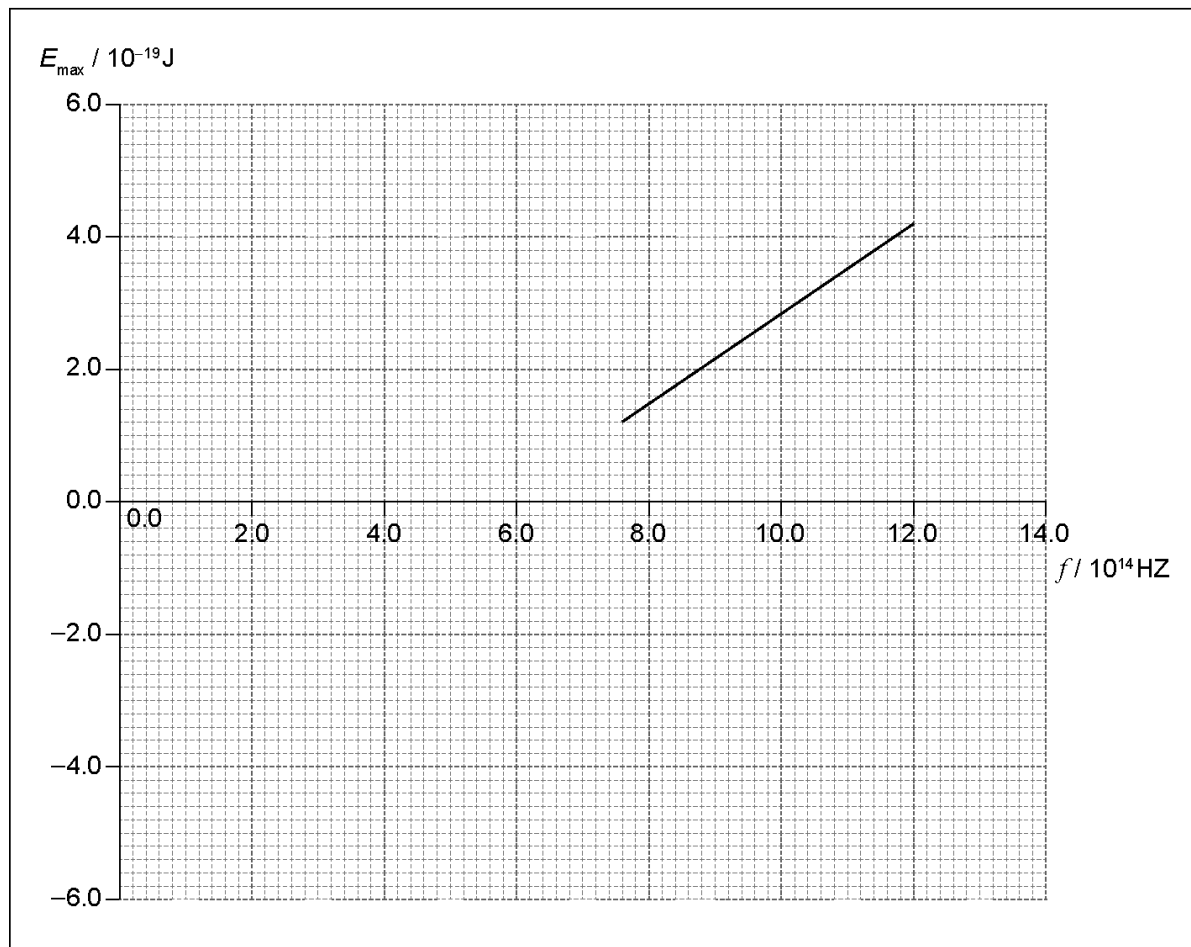
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- (b) The graph shows how the maximum kinetic energy $E_{\max}$ of electrons emitted from a surface of barium metal varies with the frequency f of the incident radiation.



- (i) Determine a value for Planck's constant.

[2]

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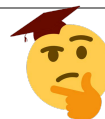
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(ii) State what is meant by the work function of a metal.

[1]



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(iii) Calculate the work function of barium in eV.

[2]

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(c) The experiment is repeated with a metal surface of cadmium, which has a greater work function. Draw a second line on the graph to represent the results of this experiment.

[2]

3 - (PHYSI/22_HL_Summer_2017_Q5) - *Quantum & Nuclear Physics (ahl)*

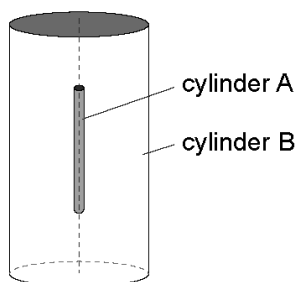


The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{88}\text{Ra}$) decays by alpha emission to form a nuclide known as radon (Rn).

(a) Write down the nuclear equation for this decay.

[2]

- (b) At the start of the experiment, Rutherford and Royds put 6.2×10^{-4} mol of pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B.



The experiment lasted for 6 days. The decay constant of radium-226 is $1.4 \times 10^{-11} \text{ s}^{-1}$.

- (i) Deduce that the activity of the radium-226 is almost constant during the experiment.

[2]

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- (ii) Show that about 3×10^{15} alpha particles are emitted by the radium-226 in 6 days.

[3]

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- (c) At the start of the experiment, all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of cylinder A to form helium gas in cylinder B.



- (i) The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin.

[1]

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- (ii) The experiment was carried out at a temperature of 18°C . The volume of cylinder B was $1.3 \times 10^{-5} \text{ m}^3$ and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B over the 6 day period. Helium is a monatomic gas.

[3]

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- (d) Rutherford and Royds identified the helium gas in cylinder B by observing its emission spectrum. Outline, with reference to atomic energy levels, how an emission spectrum is formed.

[3]



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- (e) The work was first reported in a peer-reviewed scientific journal. Outline why Rutherford and Royds chose to publish their work in this way.

[1]

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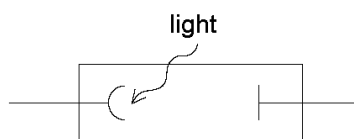
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4 - (PHYSI/22_HL_Summer_2017_Q7) - Quantum & Nuclear Physics (ahl)



- (a) Yellow light of photon energy $3.5 \times 10^{-19} \text{ J}$ is incident on the surface of a particular photocell.



- (i) Calculate the wavelength of the light.

[1]

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- (ii) Electrons emitted from the surface of the photocell have almost no kinetic energy. Explain why this does **not** contradict the law of conservation of energy.

[2]

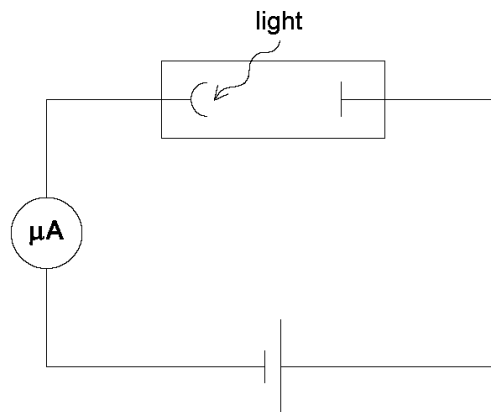
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- (b) Radiation of photon energy $5.2 \times 10^{-19} \text{ J}$ is now incident on the photocell. Calculate the maximum velocity of the emitted electrons.

[2]

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- (c) The photocell is connected to a cell as shown. The photoelectric current is at its maximum value (the saturation current).



Radiation with a greater photon energy than that in (b) is now incident on the photocell. The intensity of this radiation is the same as that in (b).

- (i) Describe the change in the number of photons per second incident on the surface of the photocell.

[1]

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- (ii) State and explain the effect on the maximum photoelectric current as a result of increasing the photon energy in this way.

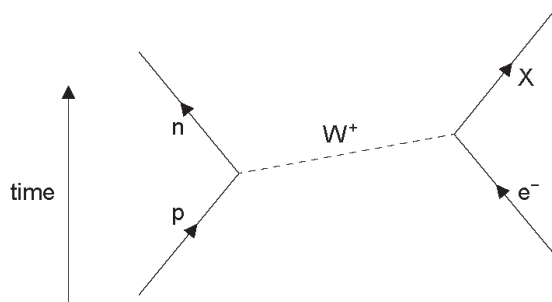
[3]

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5 - (PHYSI/20_HL_Winter_2017_Q3) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl), Measurements & Uncertainties



(a) The Feynman diagram shows electron capture.



(i) State and explain the nature of the particle labelled X.

[3]

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(ii) Distinguish between hadrons and leptons.

[2]

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(b) Particles can be used in scattering experiments to estimate nuclear sizes.



(i) Outline how these experiments are carried out.

[2]

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(ii) Outline why the particles must be accelerated to high energies in scattering experiments.

[3]

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(c) State and explain **one** example of a scientific analogy.

[2]

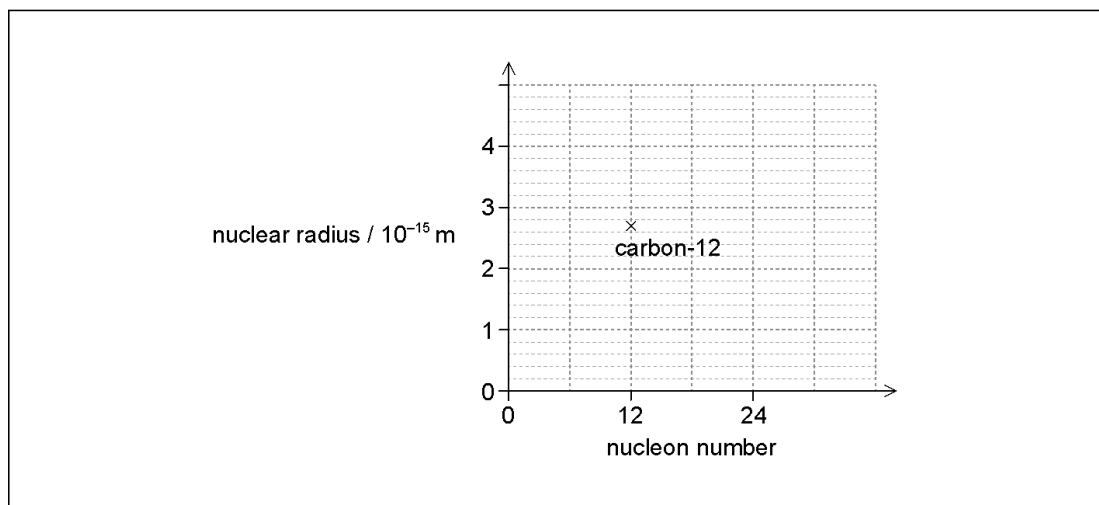
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- (d) Electron diffraction experiments indicate that the nuclear radius of carbon-12 ($^{12}_6\text{C}$) is $2.7 \times 10^{-15} \text{ m}$. The graph shows the variation of nuclear radius with nucleon number. The nuclear radius of the carbon-12 is shown on the graph.



- (i) Determine the radius of the magnesium-24 ($^{24}_{12}\text{Mg}$) nucleus. [2]

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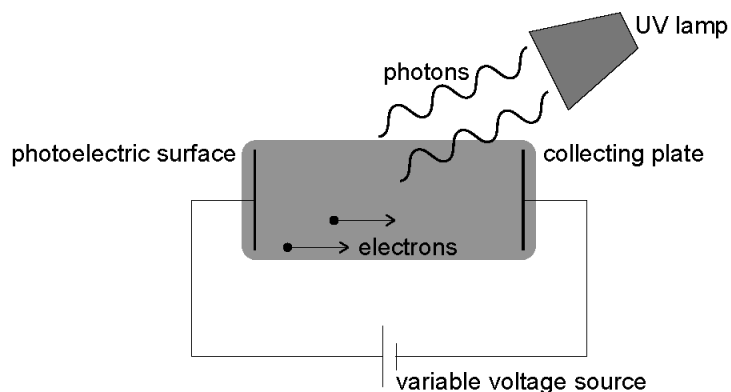
- (ii) Plot the position of magnesium-24 on the graph. [1]

- (iii) Draw a line on the graph, to show the variation of nuclear radius with nucleon number. [2]

6 - (PHYSI/21_HL_Summer_2018_Q8) - Quantum & Nuclear Physics (ahl)



Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



- (a) Show that the energy of photons from the UV lamp is about 10 eV. [2]

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- (b) The photons cause the emission of electrons from the photoelectric surface.
The work function of the photoelectric surface is 5.1 eV.

- (i) Calculate, in J, the maximum kinetic energy of the emitted electrons. [2]

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- (ii) Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. [2]

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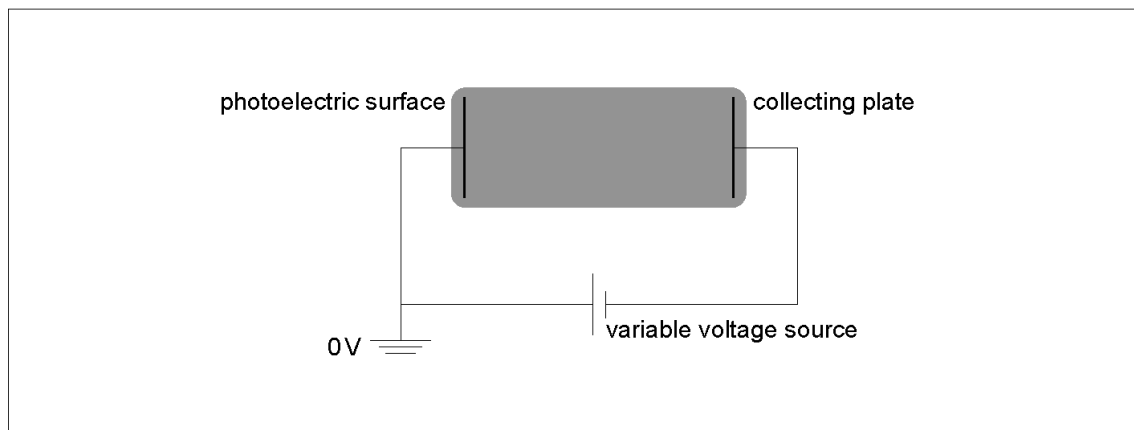
- (iii) The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate.

[1]



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- (c) The electric potential of the photoelectric surface is 0V. The variable voltage is adjusted so that the collecting plate is at -1.2V .



- (i) On the diagram, draw and label the equipotential lines at -0.4V and -0.8V . [2]
- (ii) An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV . Calculate the speed of the electron at the collecting plate. [2]

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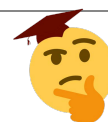
7 - (PHYSI/22_HL_Summer_2018_Q9) - *Quantum & Nuclear Physics (ahl), Atomic, nuclear & Particle Physics*

- (a) Rutherford constructed a model of the atom based on the results of the alpha particle scattering experiment. Describe this model. [2]

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- (b) Bohr modified the Rutherford model by introducing the condition $mvr = n \frac{h}{2\pi}$. Outline the reason for this modification. [3]

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- (c) (i) Show that the speed v of an electron in the hydrogen atom is related to the radius r of the orbit by the expression

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

where k is the Coulomb constant.

[1]

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- (ii) Using the answer in (b) and (c)(i), deduce that the radius r of the electron's orbit in the ground state of hydrogen is given by the following expression.

[2]

$$r = \frac{h^2}{4\pi^2 k m_e e^2}$$

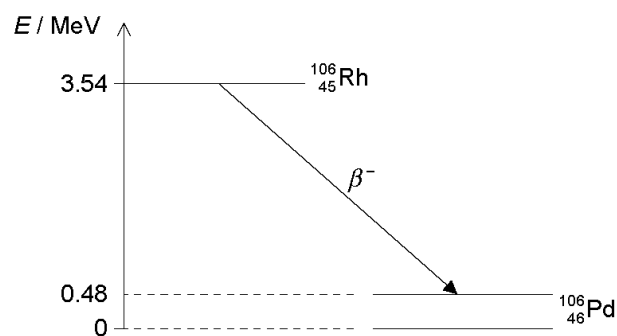
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- (iii) Calculate the electron's orbital radius in (c)(ii).

[1]

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- (d) Rhodium-106 ($^{106}_{45}\text{Rh}$) decays into palladium-106 ($^{106}_{46}\text{Pd}$) by beta minus (β^-) decay. The diagram shows some of the nuclear energy levels of rhodium-106 and palladium-106. The arrow represents the β^- decay.



- (i) Explain what may be deduced about the energy of the electron in the β^- decay. [3]

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- (ii) Suggest why the β^- decay is followed by the emission of a gamma ray photon. [1]

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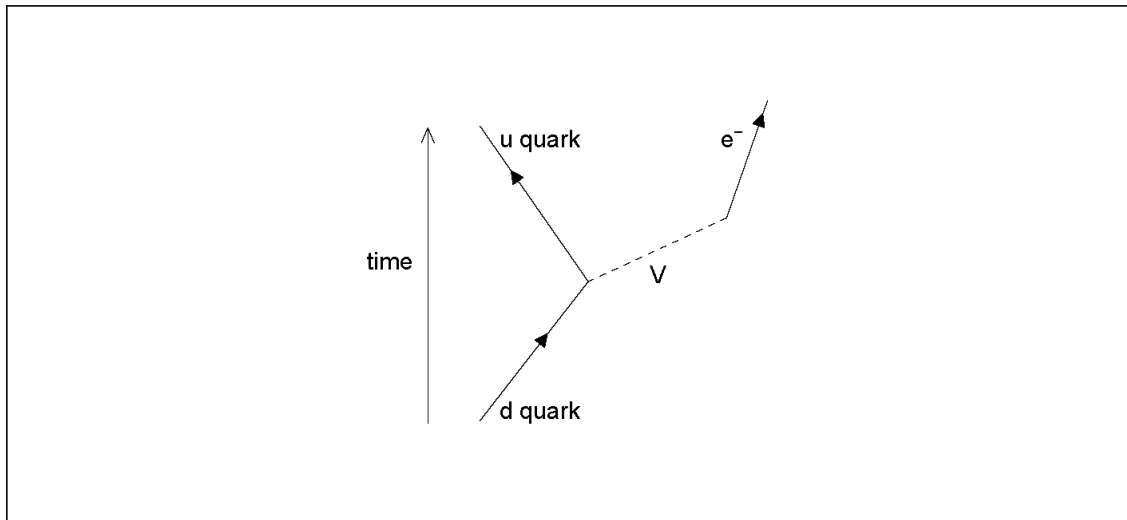
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- (iii) Calculate the wavelength of the gamma ray photon in (d)(ii). [2]

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(e) β^- decay is described by the following incomplete Feynman diagram.

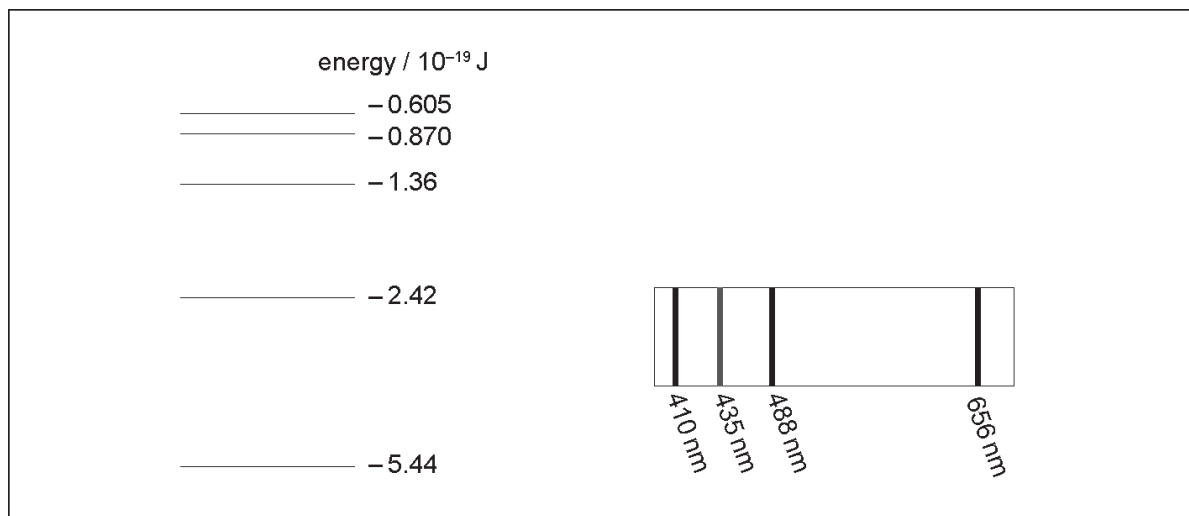


- (i) Draw a labelled arrow to complete the Feynman diagram. [1]
- (ii) Identify particle V. [1]

8 - (PHYSI/20_HL_Winter_2018_Q5) - Atomic, nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



- (a) The diagram shows the position of the principal lines in the visible spectrum of atomic hydrogen and some of the corresponding energy levels of the hydrogen atom.



- (i) Determine the energy of a photon of blue light (435nm) emitted in the hydrogen spectrum.

[3]

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- (ii) Identify, with an arrow labelled B on the diagram, the transition in the hydrogen spectrum that gives rise to the photon with the energy in (a)(i).

[1]

- (iii) Explain your answer to (a)(ii).

[2]

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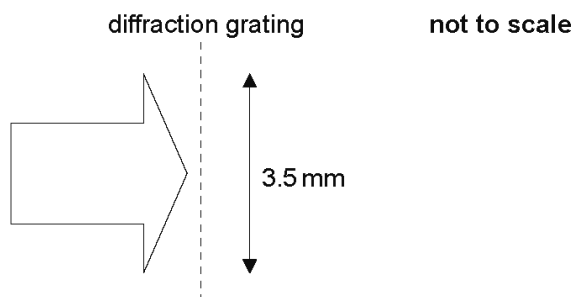
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- (b) A low-pressure hydrogen discharge lamp contains a small amount of deuterium gas in addition to the hydrogen gas. The deuterium spectrum contains a red line with a wavelength very close to that of the hydrogen red line. The wavelengths for the principal lines in the visible spectra of deuterium and hydrogen are given in the table.



	Hydrogen wavelength / nm	Deuterium wavelength / nm
Red line	656.288	656.107
Violet line	410.180	410.048

Light from the discharge lamp is normally incident on a diffraction grating.



- (i) The light illuminates a width of 3.5 mm of the grating. The deuterium and hydrogen red lines can just be resolved in the second-order spectrum of the diffraction grating. Show that the grating spacing of the diffraction grating is about 2×10^{-6} m.

[2]

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- (ii) Calculate the angle between the first-order line of the red light in the hydrogen spectrum and the second-order line of the violet light in the hydrogen spectrum.

[3]



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- (iii) The light source is changed so that white light is incident on the diffraction grating. Outline the appearance of the diffraction pattern formed with white light.

[3]

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9 - (PHYSI/22_HL_Summer_2019_Q11) - Quantum & Nuclear Physics (ahl)



- (a) Suggest why de Broglie's hypothesis is **not** consistent with Bohr's conclusion that the electron's orbit in the hydrogen atom has a well defined radius.

[2]

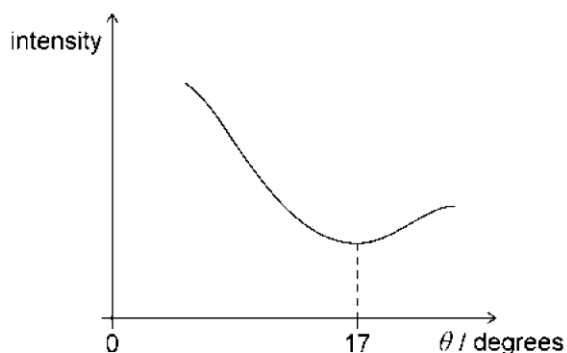
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- (b) In an experiment to determine the radius of a carbon-12 nucleus, a beam of neutrons is scattered by a thin film of carbon-12. The graph shows the variation of intensity of the scattered neutrons with scattering angle. The de Broglie wavelength of the neutrons is 1.6×10^{-16} m.



- (i) Estimate, using the graph, the radius of a carbon-12 nucleus.

[2]

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- (ii) The ratio $\frac{\text{volume of a nucleus of mass number } A}{\text{volume of a nucleon}}$ is approximately A .

Comment on this observation by reference to the strong nuclear force.

[2]

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- (c) A pure sample of copper-64 has a mass of 28 mg. The decay constant of copper-64 is $5.5 \times 10^{-2} \text{ hour}^{-1}$.



- (i) Estimate, in Bq, the initial activity of the sample.

[2]

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- (ii) Calculate, in hours, the time at which the activity of the sample has decreased to one-third of the initial activity.

[2]

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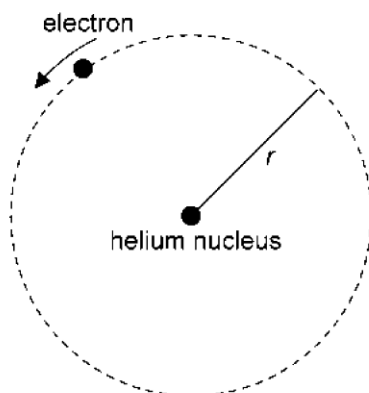
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10 – (PHYSI/20_HL_Winter_2019_Q8) – Quantum & Nuclear Physics (ahl)



- (a) In a classical model of the singly-ionized helium atom, a single electron orbits the nucleus in a circular orbit of radius r .



- (i) Show that the speed v of the electron with mass m , is given by $v = \sqrt{\frac{2ke^2}{mr}}$. [1]

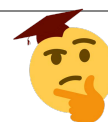
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- (ii) Hence, deduce that the total energy of the electron is given by $E_{\text{TOT}} = -\frac{ke^2}{r}$. [2]

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- (iii) In this model the electron loses energy by emitting electromagnetic waves. Describe the predicted effect of this emission on the orbital radius of the electron. [2]

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- (b) The Bohr model for hydrogen can be applied to the singly-ionized helium atom. In this model the radius r , in m, of the orbit of the electron is given by $r = 2.7 \times 10^{-11} \times n^2$ where n is a positive integer.

- (i) Show that the de Broglie wavelength λ of the electron in the $n = 3$ state is $\lambda = 5.1 \times 10^{-10}$ m.

The formula for the de Broglie wavelength of a particle is $\lambda = \frac{h}{mv}$. [2]

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- (ii) Estimate for $n = 3$, the ratio $\frac{\text{circumference of orbit}}{\text{de Broglie wavelength of electron}}$.

State your answer to one significant figure. [1]

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- (c) The description of the electron is different in the Schrodinger theory than in the Bohr model. Compare and contrast the description of the electron according to the Bohr model and to the Schrodinger theory. [3]

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11 – (PHYSI/20_HL_Winter_2019_Q11) – Quantum & Nuclear Physics (ahl)



(a) Monochromatic light of very low intensity is incident on a metal surface. The light causes the emission of electrons almost instantaneously. Explain how this observation

(i) does not support the wave nature of light.

[2]

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(ii) does support the photon nature of light.

[2]

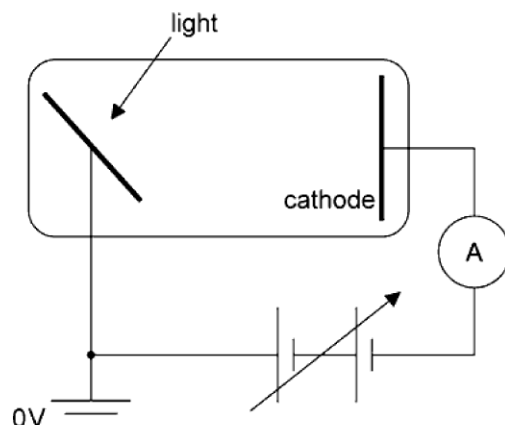
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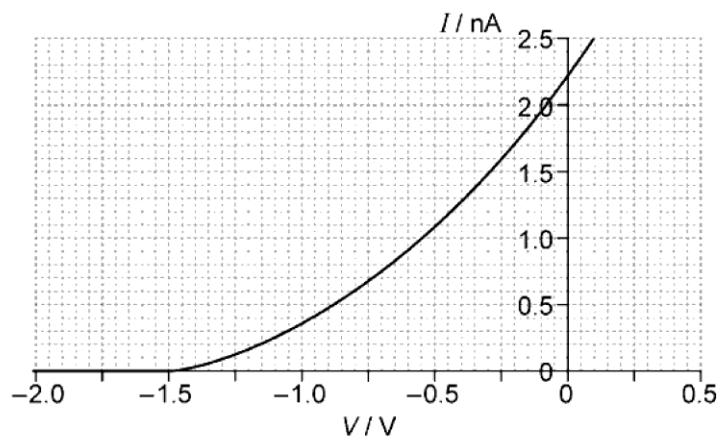
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- (b) In an experiment to demonstrate the photoelectric effect, light of wavelength 480 nm is incident on a metal surface.



The graph shows the variation of the current I in the ammeter with the potential V of the cathode.



- (i) Calculate, in eV, the work function of the metal surface.

[3]

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- (ii) The intensity of the light incident on the surface is reduced by half without changing the wavelength. Draw, on the graph, the variation of the current I with potential V after this change.

[2]

12 - (PHYSI/20_HL_Winter_2020_Q10) - Atomic, nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



The de Broglie wavelength λ of a particle accelerated close to the speed of light is approximately

$$\lambda \approx \frac{hc}{E}$$

where E is the energy of the particle.

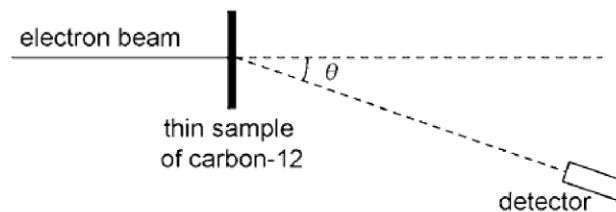
A beam of electrons of energy $4.2 \times 10^8 \text{ eV}$ is produced in an accelerator.

(a) Show that the wavelength of an electron in the beam is about $3 \times 10^{-15} \text{ m}$.

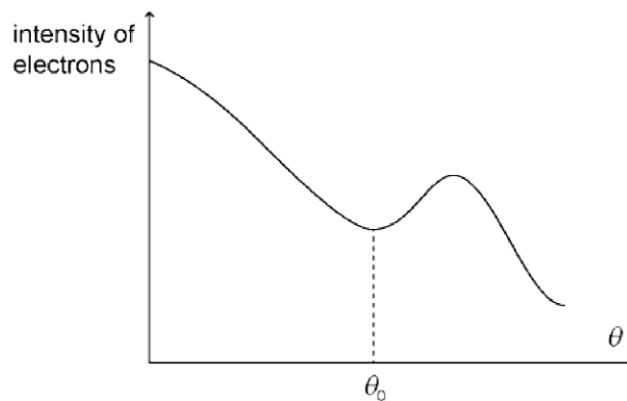
[1]

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(b) The electron beam is used to study the nuclear radius of carbon-12. The beam is directed from the left at a thin sample of carbon-12. A detector is placed at an angle θ relative to the direction of the incident beam.

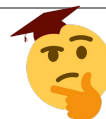


The graph shows the variation of the intensity of electrons with θ . There is a minimum of intensity for $\theta = \theta_0$.



- (i) Discuss how the results of the experiment provide evidence for matter waves.

[2]



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- (ii) The accepted value of the diameter of the carbon-12 nucleus is $4.94 \times 10^{-15} \text{ m}$. Estimate the angle θ_0 at which the minimum of the intensity is formed.

[2]

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- (iii) Outline why electrons with energy of approximately 10^7 eV would be unsuitable for the investigation of nuclear radii.

[2]

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- (c) Experiments with many nuclides suggest that the radius of a nucleus is proportional to $A^{\frac{1}{3}}$, where A is the number of nucleons in the nucleus. Show that the density of a nucleus remains approximately the same for all nuclei.

[2]

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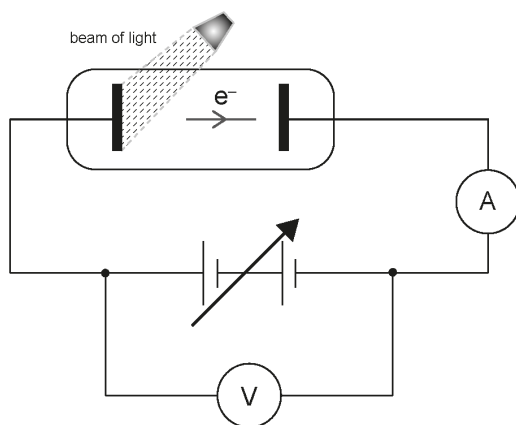
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13 - (PHYSI/21_HL_Summer_2021_Q10) - Quantum & Nuclear Physics (ahl)



In an electric circuit used to investigate the photoelectric effect, the voltage is varied until the reading in the ammeter is zero. The stopping voltage that produces this reading is 1.40 V.



(a) Describe the photoelectric effect.

[2]

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(b) Show that the maximum velocity of the photoelectrons is 700 km s^{-1} .

[2]

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- (c) The photoelectrons are emitted from a sodium surface. Sodium has a work function of 2.3 eV.



Calculate the wavelength of the radiation incident on the sodium. State an appropriate unit for your answer.

[3]

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14 - (PHYSI/22_HL_Summer_2021_Q9) - Quantum & Nuclear Physics (ahl)



- (a) In an experiment to demonstrate the photoelectric effect, monochromatic electromagnetic radiation from source A is incident on the surfaces of metal P and metal Q. Observations of the emission of electrons from P and Q are made.

The experiment is then repeated with two other sources of electromagnetic radiation: B and C. The table gives the results for the experiment and the wavelengths of the radiation sources.

Radiation source	Wavelength / 10^{-7} m	Metal P	Metal Q
A	3.0	electrons emitted	electrons emitted
B	6.0	electrons emitted	no electrons emitted
C	8.0	no electrons emitted	no electrons emitted

Outline

- (i) the cause of the electron emission for radiation A; [1]

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- (ii) why electrons are never emitted for radiation C; [1]

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- (iii) why radiation B gives different results. [1]

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- (b) Explain why there is no effect on the table of results when the intensity of source B is doubled. [1]

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- (c) Photons with energy $1.1 \times 10^{-18} \text{ J}$ are incident on a third metal surface. The maximum energy of electrons emitted from the surface of the metal is $5.1 \times 10^{-19} \text{ J}$.



Calculate, in eV, the work function of the metal.

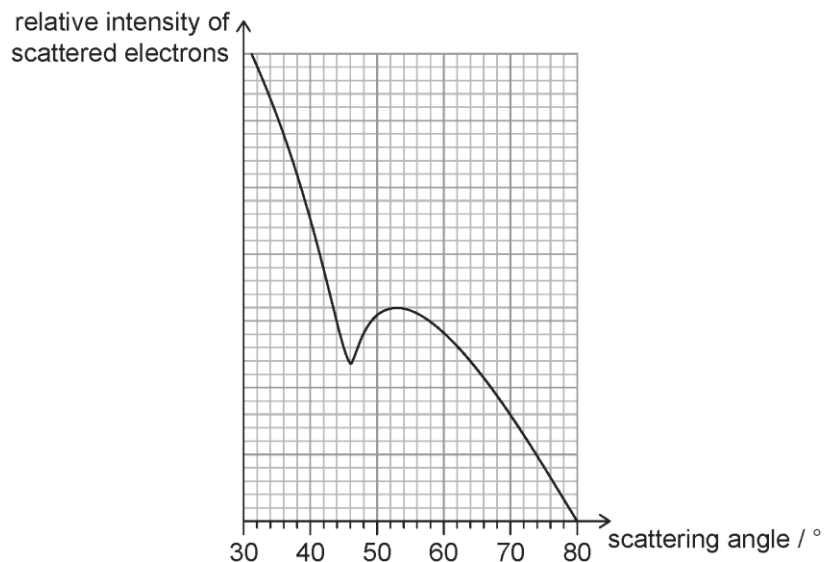
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15 - (PHYSI/22_HL_Summer_2022_Q9) - Quantum & Nuclear Physics (ahl)



In an experiment a beam of electrons with energy 440 MeV are incident on oxygen-16 ($^{16}_8\text{O}$) nuclei. The variation with scattering angle of the relative intensity of the scattered electrons is shown.



- (a) (i) Identify a property of electrons demonstrated by this experiment. [1]

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- (ii) Show that the energy E of each electron in the beam is about $7 \times 10^{-11} \text{ J}$. [1]

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- (iii) The de Broglie wavelength for an electron is given by $\frac{hc}{E}$. Show that the diameter of an oxygen-16 nucleus is about 4 fm.

[3]



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- (b) Estimate, using the result in (a)(iii), the volume of a tin-118 ($^{118}_{50}\text{Sn}$) nucleus. State your answer to an appropriate number of significant figures.

[4]

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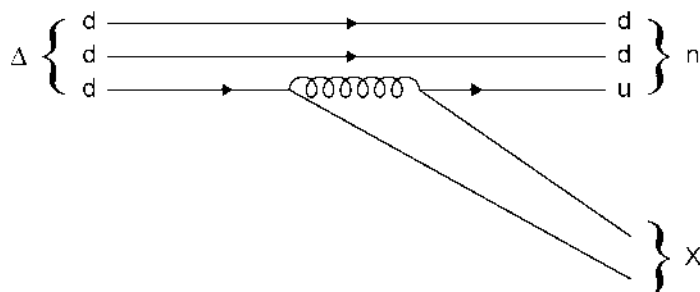
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16 - (PHYSI/20_HL_Winter_2022_Q10) - Quantum & Nuclear Physics (ahl)



The Feynman diagram shows a delta baryon (Δ) decaying into a neutron and particle X.
The exchange particle involved in the decay is a gluon. Particle X has two constituent quarks.



- (a) (i) Identify the fundamental force responsible for the decay. [1]

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- (ii) Deduce, referring to one conservation law, that X is a quark-antiquark pair. [3]

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- (b) The energy released in the decay is of the order of 10^5 eV.

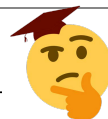
Estimate, using the uncertainty principle, the mean lifetime of the delta baryon. [2]

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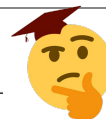
ANSWERS

1 - (PHYSI/21_HL_Summer_2017_Q7) - Oscillations & Waves, Measurements & Uncertainties

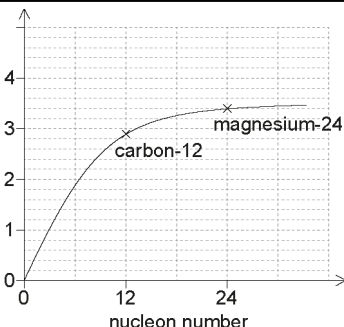


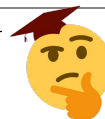
a		acceleration/restoring force is proportional to displacement ✓ and in the opposite direction/directed towards equilibrium ✓
b		ALTERNATIVE 1 $\frac{T_1^2}{T_2^2} = \frac{m_1}{m_2}$ ✓ mass = 0.38 / 0.39 «kg» ✓ ALTERNATIVE 2 «use of $T = 2\pi\sqrt{\frac{m}{k}}$ » $k = 28$ «Nm ⁻¹ » ✓ «use of $T = 2\pi\sqrt{\frac{m}{k}}$ » $m = 0.38 / 0.39$ «kg» ✓
c		$\omega = \left\langle \frac{2\pi}{0.74} \right\rangle = 8.5$ «rads ⁻¹ » ✓ total energy = $\frac{1}{2} \times 0.39 \times 8.5^2 \times (4.8 \times 10^{-2})^2$ ✓ = 0.032 «J» ✓
d		spring constant/k/stiffness would increase ✓ <i>T</i> would be smaller ✓ fractional uncertainty in <i>T</i> would be greater, so fractional uncertainty of mass of block would be greater ✓
e	i	left ✓
	ii	coils to the right of P move right and the coils to the left move left ✓ hence P at centre of rarefaction ✓

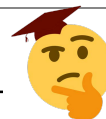
2 – (PHYSI/20_HL_Winter_2017_Q3) – Atomic, nuclear & Particle Physics, Quantum & Nuclear Physics (ahl), Measurements & Uncertainties



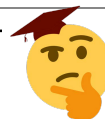
a	i	«electron» neutrino ✓ it has a lepton number of 1 «as lepton number is conserved» ✓ it has a charge of zero/is neutral «as charge is conserved» ✓ OR it has a baryon number of 0 «as baryon number is conserved» ✓	<i>Do not allow antineutrino</i> <i>Do not credit answers referring to energy</i>
a	ii	hadrons experience strong force OR leptons do not experience the strong force ✓ hadrons made of quarks/not fundamental OR leptons are not made of quarks/are fundamental ✓ hadrons decay «eventually» into protons OR leptons do not decay into protons ✓	<i>Accept leptons experience the weak force</i> <i>Allow "interaction" for "force"</i>
b	i	«high energy particles incident on» thin sample ✓ detect angle/position of deflected particles ✓ reference to interference/diffraction/minimum/maximum/numbers of particles ✓	<i>Allow "foil" instead of thin</i>
b	ii	$\lambda \propto \frac{1}{\sqrt{E}}$ OR $\lambda \propto \frac{1}{E}$ ✓ so high energy gives small λ ✓ to match the small nuclear size ✓ Alternative 2 $E = hf$ /energy is proportional to frequency ✓ frequency is inversely proportional to wavelength/ $c = f\lambda$ ✓ to match the small nuclear size ✓ Alternative 3 higher energy means closer approach to nucleus ✓ to overcome the repulsive force from the nucleus ✓ so greater precision in measurement of the size of the nucleus ✓	<i>Accept inversely proportional</i> <i>Only allow marks awarded from one alternative</i>
c		two analogous situations stated ✓ one element of the analogy equated to an element of physics ✓	<i>eg: moving away from Earth is like climbing a hill where the contours correspond to the equipotentials</i> <i>Atoms in an ideal gas behave like pool balls</i> <i>The forces between them only act during collisions</i>

d	i	$R = 2.7 \times 10^{-15} \times 2^{\frac{1}{3}} \checkmark$ $3.4 - 3.5 \times 10^{-15} \text{ «m» } \checkmark$	Allow use of the Fermi radius from the data booklet
d	ii	correctly plotted $\checkmark$	Allow ECF from (d)(i)
d	iii	single smooth curve passing through both points with decreasing gradient $\checkmark$ through origin $\checkmark$	 nuclear radius / 10^{-15} m carbon-12 magnesium-24 nucleon number



1 - (PHYSI/21_HL_Summer_2017_Q1) - *Mechanics, Thermal Physics*

a	i	$\frac{1}{2}v^2 = 0.24gh$ ✓ $v = 11.9 \text{ «ms}^{-1}\text{»}$ ✓
a	ii	internal energy is the total KE «and PE» of the molecules/particles/atoms in an object ✓ temperature is a measure of the average KE of the molecules/particles/atoms ✓
b	i	arrow vertically downwards from dot labelled weight/W/mg/gravitational force/ F_g / $F_{\text{gravitational}}$ AND arrow vertically upwards from dot labelled reaction force/R/normal contact force/N/ F_N ✓ $W > R$ ✓



b ii **ALTERNATIVE 1**

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓

= 468 «N» ✓

W/640 N (weight) is larger than the centripetal force required, so the skier does not lose contact with the ground ✓

ALTERNATIVE 2

recognition that centripetal acceleration is required / $\frac{v^2}{r}$ seen ✓

a = 7.2 «ms⁻²» ✓

g is larger than the centripetal acceleration required, so the skier does not lose contact with the ground ✓

ALTERNATIVE 3

recognition that to lose contact with the ground centripetal force ≥ weight ✓

calculation that $v \geq 14$ «ms⁻¹» ✓

comment that 12 «ms⁻¹» is less than 14 «ms⁻¹» so the skier does not lose contact with the ground ✓

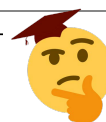
ALTERNATIVE 4

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓

calculation that reaction force = 172 «N» ✓

reaction force > 0 so the skier does not lose contact with the ground ✓

c		ALTERNATIVE 1 $0 = 8.2^2 + 2 \times a \times 24$ therefore $a = \llcorner - \gg 1.40 \llcorner \text{ms}^{-2} \gg$ ✓ friction force $= ma = 65 \times 1.4 = 91 \llcorner \text{N} \gg$ ✓ coefficient of friction $= \frac{91}{65 \times 9.81} = 0.14$ ✓ ALTERNATIVE 2 $KE = \frac{1}{2}mv^2 = 0.5 \times 65 \times 8.2^2 = 2185 \llcorner \text{J} \gg$ ✓ friction force $= KE/\text{distance} = 2185/24 = 91 \llcorner \text{N} \gg$ ✓ coefficient of friction $= \frac{91}{65 \times 9.81} = 0.14$ ✓
d	i	$\llcorner 76 \times 9.6 \gg = 730$ ✓ Ns OR kg ms^{-1} ✓
d	ii	safety net extends stopping time ✓ $F = \frac{\Delta p}{\Delta t}$ therefore F is smaller «with safety net» OR force is proportional to rate of change of momentum therefore F is smaller «with safety net» ✓



2 - (PHYSI/22_HL_Summer_2017_Q1) - Mechanics

a		correct use of kinematic equation/equations ✓ 148.5 or 149 or 150 «m» ✓
b		$a = \frac{27}{11}$ or $2.45 \llcorner \text{ms}^{-2} \gg$ ✓ $F - 160 = 492 \times 2.45$ ✓ 1370 «N» ✓



c

ALTERNATIVE 1

$$\text{«work done to launch glider»} = 1370 \times 149 \text{ «} = 204 \text{ kJ»} \checkmark$$

$$\text{«work done by motor»} = \frac{204 \times 100}{23} \checkmark$$

$$\text{«power input to motor»} = \frac{204 \times 100}{23} \times \frac{1}{11} = 80 \text{ or } 80.4 \text{ or } 81 \text{ k«W»} \checkmark$$

ALTERNATIVE 2

$$\text{use of average speed } 13.5 \text{ m s}^{-1} \checkmark$$

$$\text{«useful power output»} = \text{force} \times \text{average speed} \text{ «} = 1370 \times 13.5 \text{»} \checkmark$$

$$\text{power input} = \text{«} 1370 \times 13.5 \times \frac{100}{23} \text{»} = 80 \text{ or } 80.4 \text{ or } 81 \text{ k«W»} \checkmark$$

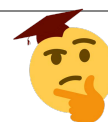
ALTERNATIVE 3

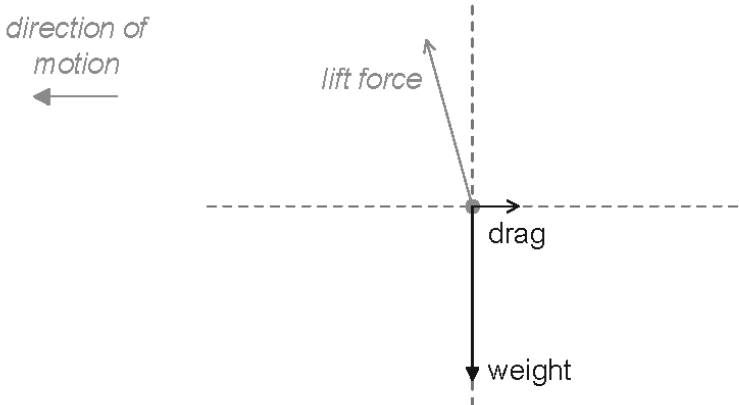
$$\text{work required from motor} = \text{KE} + \text{work done against friction}$$

$$\text{«} = 0.5 \times 492 \times 27^2 + (160 \times 148.5) \text{»} = 204 \text{ «kJ»} \checkmark$$

$$\text{«energy input»} = \frac{\text{work required from motor} \times 100}{23} \checkmark$$

$$\text{power input} = \frac{883000}{11} = 80.3 \text{ k«W»} \checkmark$$



d	direction of motion  lift force drag weight drag correctly labelled and in correct direction ✓ weight correctly labelled and in correct direction AND no other incorrect force shown ✓
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3 - (PHYSI/20_HL_Winter_2017_Q1) - Mechanics

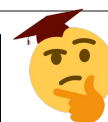
a	arrow vertically downwards labelled weight «of sledge and/or girl»/W/mg/gravitational force/F_g/$F_{\text{gravitational}}$ AND arrow perpendicular to the snow slope labelled reaction force/R/normal contact force/N/F_N ✓ friction force/F/f acting up slope «perpendicular to reaction force» ✓	Do not allow G/g/“gravity”. Do not award MP1 if a “driving force” is included. Allow components of weight if correctly labelled. Ignore point of application or shape of object. Ignore “air resistance”. Ignore any reference to “push of feet on sledge”. Do not award MP2 for forces on sledge on horizontal ground The arrows should contact the object
b	gravitational force/weight from the Earth «downwards» ✓ reaction force from the sledge/snow/ground «upwards» ✓ no vertical acceleration/remains in contact with the ground/does not move vertically as there is no resultant vertical force ✓	Allow naming of forces as in (a) Allow vertical forces are balanced/equal in magnitude/cancel out
c	mention of conservation of momentum OR $5.5 - 4.2 = (55 + 5.5) \langle v \rangle$ ✓ 0.38 m s^{-1} ✓	Allow $p = p'$ or other algebraically equivalent statement Award [0] for answers based on energy
d	same change in momentum/impulse ✓ the time taken «to stop» would be greater «with the snow» ✓ $F = \frac{\Delta p}{\Delta t}$ therefore F is smaller «with the snow» OR force is proportional to rate of change of momentum therefore F is smaller «with the snow» ✓	Allow reverse argument for ice

e	i	«friction force down slope» $\mu mg \cos(6.5)$ «5.9N» ✓ «component of weight down slope» $mg \sin(6.5)$ « 6.1N» ✓ «so $a = \frac{F}{m}$ » acceleration $\frac{12}{5.5}$ 2.2 «ms⁻²» ✓	Ignore negative signs Allow use of $g = 10 \text{ ms}^{-2}$	
e	ii	correct use of kinematics equation ✓ distance 4.4 or 4.0 «m» ✓ Alternative 2 KE lost = work done against friction = GPE ✓ distance 4.4 or 4.0 «m» ✓	Allow ECF from (e)(i) Allow [1 max] for GPE missing leading to 8.2 «m»	
f		calculates a maximum value for the frictional force «μR» 7.5 «N» ✓ sledge will not move as the maximum static friction force is greater than the component of weight down the slope ✓	Allow correct conclusion from incorrect MP1 Allow $7.5 > 6.1$ so will not move	

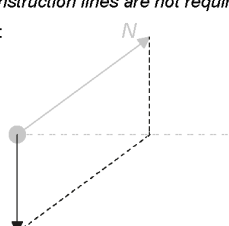
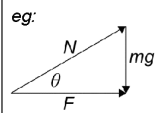
4 - (PHYSI/21_HL_Summer_2018_Q1) - Mechanics

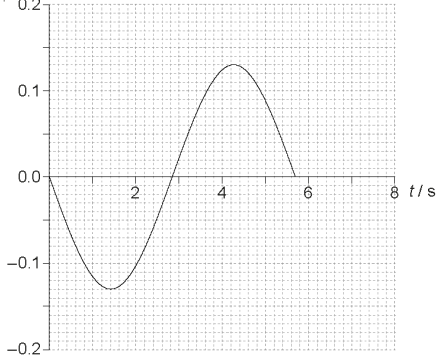
a		use of conservation of energy OR $v^2 = u^2 + 2as$ ✓ $v = \sqrt{2 \cdot 60.0 \cdot 9.81}$ 34.3 «ms⁻¹» ✓		2
b	i	use of impulse $F_{\text{ave}} \cdot \Delta t = \Delta p$ OR use of $F = ma$ with average acceleration OR $F = \frac{80.0 \cdot 34.3}{0.759}$ ✓ 3620 «N» ✓	Allow ECF from (a).	2
b	ii	upwards ✓ clearly longer than weight ✓	For second marking point allow ECF from (b)(i) providing line is upwards.	2
b	iii	$3620 - 80.0 \cdot 9.81$ ✓ 4400 «N» ✓	Allow ECF from (b)(i).	2

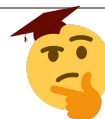
c	i	(loss in) gravitational potential energy (of block) into kinetic energy (of block) ✓	<i>Must see names of energy (gravitational potential energy and kinetic energy) – Allow for reasonable variations of terminology (eg energy of motion for KE).</i>	1
c	ii	(loss in) gravitational potential and kinetic energy of block into elastic potential energy of rope ✓	See note for 1(c)(i) for naming convention. <i>Must see either the block or the rope (or both) mentioned in connection with the appropriate energies.</i>	1
d		k can be determined using EPE $\frac{1}{2}kx^2$ ✓ correct statement or equation showing GPE at A = EPE at C OR (GPE + KE) at B = EPE at C ✓	Candidate must clearly indicate the energy associated with either position A or B for MP2.	2
e	i	$T = 2\pi\sqrt{\frac{80.0}{400}} = 2.81 \text{ s}$ ✓ time $\frac{T}{4} = 0.702 \text{ s}$ ✓	Award [0] for kinematic solutions that assume a constant acceleration.	2
e	ii	ALTERNATIVE 1 $\omega = \frac{2\pi}{2.81} = 2.24 \text{ rad s}^{-1}$ ✓ $v = 2.24 \times 3.50 = 7.84 \text{ ms}^{-1}$ ✓ ALTERNATIVE 2 $\frac{1}{2}kx^2 = \frac{1}{2}mv^2$ OR $\frac{1}{2}400 \times 3.5^2 = \frac{1}{2}80v^2$ ✓ $v = 7.84 \text{ ms}^{-1}$ ✓	Award [0] for kinematic solutions that assume a constant acceleration. Allow ECF for T from (e)(i).	2



5 – (PHYSI/22_HL_Summer_2018_Q1) – Mechanics, Circular Motion & Gravitation

a	i	towards the centre «of the circle» / horizontally to the right ✓	Do not accept towards the centre of the bowl	1
a	ii	downward vertical arrow of any length ✓ arrow of correct length ✓	Judge the length of the vertical arrow by eye. The construction lines are not required. A label is not required eg: 	2
a	iii	ALTERNATIVE 1 $F = N \cos \theta$ ✓ $mg = N \sin \theta$ ✓ dividing/substituting to get result ✓ ALTERNATIVE 2 right angle triangle drawn with F, N and W/mg labelled ✓ angle correctly labelled and arrows on forces in correct directions ✓ correct use of trigonometry leading to the required relationship ✓	eg:  $\tan \theta = \frac{O}{A} = \frac{mg}{F}$ $F = \frac{mg}{\tan \theta}$	3

b	$\frac{mg}{\tan \theta} = m \frac{v^2}{r} \checkmark$ $r = R \cos \theta \checkmark$ $v = \sqrt{\frac{gR \cos^2 \theta}{\sin \theta}} = \sqrt{\frac{gR \cos \theta}{\tan \theta}} = \sqrt{\frac{9.81 \cdot 8.0 \cos 22}{\tan 22}} \checkmark$ $v = 13.4 / 13 \text{ «ms}^{-1}\text{»} \checkmark$	Award [4] for a bald correct answer Award [3] for an answer of 13.9/14 «ms⁻¹». MP2 omitted	4
c	there is no force to balance the weight/N is horizontal $\checkmark$ so no / it is not possible $\checkmark$	Must see correct justification to award MP2	2
d	i	the «restoring» force/acceleration is proportional to displacement $\checkmark$	1
d	ii	$\omega = \sqrt{\frac{g}{R}} = \sqrt{\frac{9.81}{8.0}} = 1.107 \text{ s}^{-1} \checkmark$ $T = \frac{2\pi}{\omega} = \frac{2\pi}{1.107} = 5.7 \text{ «s»} \checkmark$	2
d	iii	sine graph $\checkmark$ correct amplitude «0.13 ms⁻¹» $\checkmark$ correct period and only 1 period shown $\checkmark$ Accept $\pm$ sine for shape of the graph. Accept 5.7 s or 6.0 s for the correct period. Amplitude should be correct to $\pm \frac{1}{2}$ square for MP2 eg: $v / \text{m s}^{-1}$ 	3
e	speed before collision $v = \sqrt{2gR} = 12.5 \text{ «ms}^{-1}\text{»} \checkmark$ «from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed «$v_c = \frac{12.5}{2} = 6.25 \text{ ms}^{-1}$» $\checkmark$ $h = \frac{v_c^2}{2g} = \frac{6.25^2}{2 \cdot 9.81} = 2.0 \text{ «m»} \checkmark$	Allow 12.5 from incorrect use of kinematics equations Award [3] for a bald correct answer Award [0] for $mg(8) = 2mgh$ leading to $h = 4 \text{ m}$ if done in one step Allow ECF from MP1 Allow ECF from MP2	3



6 – (PHYSI/20_HL_Winter_2018_Q1) – Mechanics

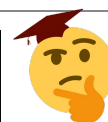


a		change in momentum each second = $6.6 \cdot 10^6 \cdot 5.2 \cdot 10^4 \approx 3.4 \cdot 10^1 \text{ kg ms}^{-1}$ ✓ acceleration = $\frac{3.4 \cdot 10^1}{740} \approx 4.6 \cdot 10^4 \text{ ms}^{-2}$ ✓		2
b	i	ALTERNATIVE 1: (considering the acceleration of the spacecraft) time for acceleration $\frac{30}{5.6 \cdot 10^4} \approx 4.6 \cdot 10^6 \text{ s}$ ✓ max speed «answer to (a)» $4.6 \cdot 10^6 \approx 2.1 \cdot 10^3 \text{ ms}^{-1}$ ✓ ALTERNATIVE 2: (considering the conservation of momentum) (momentum of 30 kg of fuel ions = change of momentum of spacecraft) $30 \cdot 5.2 \cdot 10^4 = 710 \cdot \text{max speed}$ ✓ max speed = $2.2 \cdot 10^3 \text{ ms}^{-1}$ ✓		2
b	ii	as fuel is consumed total mass changes/decreases so acceleration changes/increases OR external forces (such as gravitational) can act on the spacecraft so acceleration isn't constant ✓		1
b	iii	problem may be too complicated for exact treatment ✓ to make equations/calculations simpler ✓ when precision of the calculations is not important ✓ some quantities in the problem may not be known exactly ✓		1 max
c	i	ions have same (sign of) charge ✓ ions repel each other ✓		2
c	ii	the forces between the ions do not affect the force on the spacecraft. ✓ there is no effect on the acceleration of the spacecraft. ✓		2

7 – (PHYSI/20_HL_Winter_2018_Q3) – Mechanics

a		force time OR change in momentum ✓		1
b	i	$E_k = mgh = 0.058 \cdot 9.81 \cdot 1.1 = 0.63 \text{ J}$ ✓	Allow use of $g = 10 \text{ m s}^{-2}$ (which gives 0.64 «J») Substitution and at least 2 SF must be shown	1
b	ii	ALTERNATIVE 1: initial momentum $mv = \sqrt{2 \cdot 0.058 \cdot 0.63} \approx 0.27 \text{ kg ms}^{-1}$ ✓ OR $mv = 0.058 \cdot \sqrt{2 \cdot 9.81 \cdot 1.1} \approx 0.27 \text{ kg ms}^{-1}$ ✓ force « $\frac{\text{change in momentum}}{\text{time}}$ » $\frac{0.27}{0.055}$ ✓ 4.9 «N» ✓ $F = mg = 4.9$ so $F = 5.5 \text{ «N»}$ ✓ ALTERNATIVE 2: $\frac{1}{2}mv^2 = 0.63 \text{ J}$ $v = 4.7 \text{ ms}^{-1}$ ✓ acceleration « $\frac{v}{t}$ » $\frac{4.7}{55 \times 10^{-3}} \approx 85 \text{ ms}^{-2}$ ✓ 4.9 «N» ✓ $F = mg = 4.9$ so $F = 5.5 \text{ «N»}$ ✓	Accept negative acceleration and force.	4

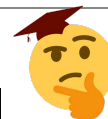
b	iii	ALTERNATIVE 1: concrete reduces the stopping time/distance ✓ impulse/change in momentum same so force greater OR work done same so force greater ✓ ALTERNATIVE 2: concrete reduces the stopping time ✓ deceleration is greater so force is greater ✓	Allow reverse argument for grass.	2
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8 – (PHYSI/21_HL_Summer_2019_Q1) – Mechanics, Electricity & Magnetism

a	i	time taken $\frac{2.0 \times 10^4}{7} \approx 2860 \text{ s} = 2900 \text{ s}$ ✓	Must see at least two s.f.	1
a	ii	use of $E = qV$ OR energy $4.3 \times 10^4 \times 16 \approx 6.88 \times 10^5 \text{ J}$ ✓ power = 241 W ✓	Accept $229 \text{ W} - 241 \text{ W}$ depending on the exact value of t used from ai. Must see at least three s.f.	2
a	iii	use of power = force x speed OR force x distance = power x time ✓ 34 N ✓	Accept $34 \text{ N} - 36 \text{ N}$.	2
b	i	$66 \text{ g} \sin(3^\circ) = 34 \text{ N}$ ✓		1
b	ii	total force $34 + 34 = 88 \text{ N}$ ✓ 3.5 ms^{-1} ✓	Look for ECF from aiii and bi. Accept $3.4 - 3.5 \text{ ms}^{-1}$. Award [0] for solutions involving use of KE.	2
c		«maximum» distance will decrease OWTTE ✓ because opposing/resistive force has increased OR because more energy is transferred to GPE OR because velocity has decreased OR increased mass means more work required «to move up the hill» ✓		2
d		4 V dropped across battery OR $R_{\text{output}} = 1.85 \Omega$ ✓ so internal resistance $\frac{4.0}{6.5} = 0.62 \text{ } \Omega$ ✓		2
e	i	$\frac{16}{5} = 3.2 \text{ V}$ ✓		1
e	ii	ALTERNATIVE 1: $2.5r = 0.62$ ✓ $r = 0.25 \text{ } \Omega$ ✓ ALTERNATIVE 2: $\frac{0.62}{5} = 0.124 \text{ } \Omega$ ✓ $r = 2(0.124) = 0.248 \text{ } \Omega$ ✓	Allow ECF from (d).	2

9 – (PHYSI/21_HL_Summer_2019_Q6) – Mechanics, Oscillations & Waves



a	i	identifies T as 2.25 s ✓ $L = 1.26 \text{ m}$ ✓ $1.3 / 1.26 \text{ «m»}$ ✓	Accept <u>any</u> number of s.f. for MP2. Accept <u>any</u> answer with 2 or 3 s.f. for MP3.	3
a	ii	X labels any point <u>on the curve</u> where $E_k \frac{1}{4}$ of maximum/5 mJ ✓		1
a	iii	$\frac{1}{2}mv^2 = 20 \times 10^{-3}$ seen OR $\frac{1}{2} \times 7.5 \times 10^{-2} \times v^2 = 20 \times 10^{-3}$ ✓ $0.73 \text{ «m s}^{-1}\text{»}$ ✓	Must see at least 2 s.f. for MP2.	2
b	i	$0.40 \text{ «m s}^{-1}\text{»}$ ✓		1
b	ii	initial energy 24 mJ and final energy 12 mJ ✓ energy is lost/unequal /change in energy is 12 mJ ✓ inelastic collisions occur when energy is lost ✓		3
b	iii	graph with same period but inverted ✓ amplitude one half of the original/two boxes throughout (by eye) ✓		2
b	iv	mention of Doppler effect ✓ there is a change in the wavelength of the reflected wave ✓ because the wave speed is constant, there is a change in frequency ✓		3

10 – (PHYSI/22_HL_Summer_2019_Q1) – Mechanics

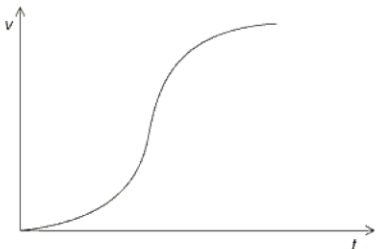
a	i	$F = \frac{\Delta mv}{\Delta t} / m \frac{\Delta v}{\Delta t} / \frac{0.058 \times 64.0}{25 \times 10^{-3}}$ ✓ $F = 148 \text{ «N»} \approx 150 \text{ «N»}$ ✓		2
a	ii	ALTERNATIVE 1 $P = \frac{\frac{1}{2}mv^2}{t} / \frac{\frac{1}{2} \times 0.058 \times 64.0^2}{25 \times 10^{-3}}$ ✓ $P = 4700 / 4800 \text{ «W»}$ ✓ ALTERNATIVE 2 $P = \text{average } Fv / 148 \times \frac{64.0}{2}$ ✓ $P = 4700 / 4800 \text{ «W»}$ ✓		2

b i	horizontal component of velocity is $64.0 \times \cos 7 = 63.52 \text{ ms}^{-1}$ ✓ $t = \frac{11.9}{63.52} = 0.187 / 0.19 \text{ s}$ ✓	2
b ii	ALTERNATIVE 1 $u_y = 64 \sin 7 / 7.80 \text{ ms}^{-1}$ ✓ decrease in height = $7.80 \times 0.187 + \frac{1}{2} \times 9.81 \times 0.187^2 / 1.63 \text{ m}$ ✓ final height = $(2.80 - 1.63) - 1.1 / 1.2 \text{ m}$ ✓ «higher than net so goes over» ALTERNATIVE 2 vertical distance to fall to net = $2.80 - 0.91 = 1.89 \text{ m}$ ✓ time to fall this distance found using $1.89 = 7.8t + \frac{1}{2} \times 9.81 \times t^2$ $t = 0.21 \text{ s}$ ✓ $0.21 \text{ s} > 0.187 \text{ s}$ ✓ «reaches the net before it has fallen far enough so goes over»	3
b iii	ALTERNATIVE 1 Initial KE + PE = final KE / $\frac{1}{2} \times 0.058 \times 64^2 + 0.058 \times 9.81 \times 2.80 = \frac{1}{2} \times 0.058 \times v^2$ ✓ $v = 64.4 \text{ ms}^{-1}$ ✓ ALTERNATIVE 2 $v_y = \sqrt{7.8^2 + 2 \times 9.81 \times 2.8} = 10.8 \text{ ms}^{-1}$ ✓ «$v = \sqrt{63.5^2 - 10.8^2}$» $v = 64.4 \text{ ms}^{-1}$ ✓	2
c	so horizontal velocity component at lift off for clay is smaller ✓ normal force is the same so vertical component of velocity is the same ✓ so bounce angle on clay is greater ✓	3



11 – (PHYSI/20_HL_Winter_2019_Q1) – Mechanics

a	links 0.84 to Δp ✓ $v = \frac{0.84}{5.8 \times 10^{-2}} = 14.5 \text{ ms}^{-1}$ ✓	Award [2] for half correct answer 2
b	use of $\Delta t = (28 - 12) \times 10^{-3} = 16 \times 10^{-3} \text{ s}$ ✓ $\bar{F} = \frac{\Delta p}{\Delta t} = \frac{0.84}{16 \times 10^{-3}}$ OR 53 N ✓	Accept a time interval from 14 to 16 ms Allow ECF from incorrect time interval 2
c	$E_k = \frac{1}{2} \times 5.8 \times 10^{-2} \times 14.5^2$ ✓ $E_k = W$ ✓ $s = \frac{W}{F} = \frac{\frac{1}{2} \times 5.8 \times 10^{-2} \times 14.5^2}{53} = 0.12 \text{ m}$ ✓	Allow ECF from (a) and (b) Allow ECF from MP1 Award [2] max for a calculation without reference to work done. eg: average velocity $\times$ time 3

d			2
	graph must show increasing speed from an initial of zero all the time ✓ overall correct curvature ✓		

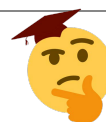


12 – (PHYSI/20_HL_Winter_2020_Q1) – Mechanics

a	i	zero ✓		1
a	ii	Blades exert a downward force on the air ✓ air exerts an equal and opposite force on the blades «by Newton's third law» OR air exerts a reaction force on the blades «by Newton's third law» ✓	Downward direction required for MP1.	2
a	iii	«lift force/change of momentum in one second» 1.7 v ✓ $1.7 \text{ v} = (0.95 \cdot 0.45) \cdot 9.81$ ✓ ✓ $8.1 \text{ «ms}^{-1}\text{»}$ AND answer expressed to 2 sf only ✓	Allow 8.2 from $g = 10 \text{ ms}^{-2}$.	3
a	iv	ALTERNATIVE 1 power = rate of energy transfer to the air $\frac{1}{2} \cdot \frac{\Delta m}{\Delta t} \cdot v^2$ ✓ $\frac{1}{2} \cdot 1.7 \cdot 8.1^2$ ✓ = 56 «W» ✓ ALTERNATIVE 2 Power = Force $\times$ v ave = $(0.45 \cdot 0.45) \cdot 9.81 \cdot \frac{8.1}{2}$ ✓ = 56 «W» ✓		2
b		vertical force = lift force – weight OR $0.45 \cdot 9.81$ OR 4.4 «N» ✓ acceleration $\frac{0.45 \cdot 9.81}{0.95}$ $4.6 \text{ «ms}^{-2}\text{»}$ ✓		2

13 – (PHYSI/21_HL_Summer_2021_Q1) – Mechanics

a	$t = \sqrt{\frac{2d}{g}}$ ✓ 0.22 «s» OR $t = \sqrt{\frac{2 \cdot 0.24}{9.8}}$ ✓	Answer to 2 or more significant figures or formula with variables replaced by correct values.	1
b	increasing straight line from zero up to 0.2 s in v-axis ✓ with gradient 10 ✓		2

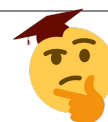


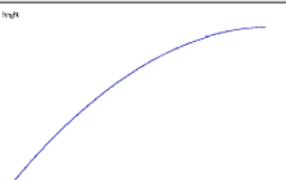
c	ALTERNATIVE 1 $t = \frac{1.37}{12} = 0.114 \text{ s} \checkmark$ $y = \frac{1}{2} \cdot 10 \cdot 0.114^2 = 0.065 \text{ m} \checkmark$ so $(0.24 - 0.065) = 0.175 > 0.15$ OR $0.065 < (0.24 - 0.15)$ «so it goes over the net» $\checkmark$ ALTERNATIVE 2 $0.24 - 0.15 = 0.09 = \frac{1}{2} \cdot 10 \cdot t^2 \text{ so } t = 0.134 \text{ s} \checkmark$ $0.134 \cdot 12 = 1.6 \text{ m} \checkmark$ 1.6 - 1.37 «so ball passed the net already» $\checkmark$	Allow use of $g = 9.8$.	3
d i	ALTERNATIVE 1 $KE = \frac{1}{2}mv^2 = mgh = \frac{1}{2} \cdot 0.0027 \cdot 10.5^2 = 0.0027 \cdot 9.8 = 0.18 \checkmark$ 0.15 «J» $\checkmark$ ALTERNATIVE 2 Use of $v_1 = 10.5$ AND $v_2 = 1.88$ to get $v = \sqrt{10.5^2 + 1.88^2} = 10.67 \text{ m s}^{-1} \checkmark$ $KE = \frac{1}{2} \cdot 0.0027 \cdot 10.67^2 = 0.15 \text{ «J»} \checkmark$		2
d ii	$W = 21 \text{ «N»} \checkmark$ $F = \frac{0.0027 \cdot 21}{0.01}$ OR 5.67 «N» $\checkmark$ any answer to 2 significant figures «N» $\checkmark$		3

14 - (PHYSI/22_HL_Summer_2021_Q1) - Mechanics

a		$A_p = 0.45 \times 19 \text{ OR } a = \frac{19}{0.055} \checkmark$ $\llcorner = F = \frac{0.45 \times 19}{0.055} = 160 \text{ «N»} \checkmark$	Allow [2] marks for a bald correct answer. Allow ECF for MP2 if $19 \sin 22$ OR $19 \cos 22$ used.	2
b	i	horizontal speed = $19 \times \cos 22 = 17.6 \text{ m s}^{-1} \checkmark$ $\text{time} = \frac{\text{distance}}{\text{speed}} = \frac{11}{19 \cos 22} = 0.62 \text{ «s»} \checkmark$	Allow ECF for MP2	2
b	ii	initial vertical speed = $19 \times \sin 22 = 7.1 \text{ m s}^{-1} \checkmark$ $\llcorner 7.12 \times 0.624 - 0.5 \times 9.81 \times 0.624^2 = 2.5 \text{ «m»} \checkmark$ ball does not hit wall OR $2.5 \text{ «m»} > 2.4 \text{ «m»} \checkmark$	Allow ECF from (b)(i) and from MP1 Allow $g = 10 \text{ m s}^{-2}$	3
c		air resistance opposes «direction of» motion OR air resistance opposes velocity $\checkmark$ on the way up «vertical» acceleration is increased OR greater than $g \checkmark$ on the way down «vertical» acceleration is decreased OR smaller than $g \checkmark$	Allow deceleration/acceleration but meaning must be clear	2 max

15 – (PHYSI/20_HL_Winter_2021_Q1) – Mechanics

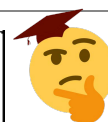


a		$H = \frac{1}{2}gt^2 \Rightarrow 4.9 \text{ «m»} \checkmark$	Accept other methods as area from graph, alternative kinematics equations or conservation of mechanical energy. Award [1] for a bald correct answer in the range 4.9 - 5.1 Award [0] if time used is different than 1.0 s	1
b	i	M at 1.6 s ✓		1
b	ii	$\ll g = \gg 9.80 \text{ «ms}^{-2}\gg \checkmark$	Accept 9.81, 10 or a plain "g" Ignore sign if provided.	1
b	iii	 concave down parabola as shown «with non-zero initial slope and zero final slope» ✓	Award [1] mark if curve starts from a positive time value. Award [0] if the final slope is negative.	1
c		$\ll \text{loss of KE is } \frac{1}{2} \times 0.25 \times (9.8^2 - 5^2) \Rightarrow 8.9 \text{ «J»} \checkmark$	Award [1] mark for an answer in the range 8.7 - 9.5	1
d	i	$\Delta p = 0.250 (9.8 - 5.0) \checkmark$ $F_{\text{net}} = \frac{\Delta p}{\Delta t} = \frac{3.7}{0.1} \Rightarrow 37 \text{ «N»} \checkmark$ $N = 37 - 0.250 \cdot 9.8 = 39.5 \text{ «N»} \checkmark$	Allow ECF for MP2 and MP3	3
d	ii	there is an external force acting on the ball OR some momentum is transferred to the floor ✓	Allow references to impulse instead of force. Do not award references to energy	1

16 – (PHYSI/21_HL_Summer_2022_Q1) – Mechanics

a		direction of motion is different / OWTTE ✓ mv / magnitude of momentum is different «even though v the same» ✓		2
b		use of $ma = mg - T \ll 3.5 \times 2.4 = 3.5g - T \gg$ OR $T = 3.5(g - 2.4) \checkmark$ $26 \text{ «N»} \checkmark$	Accept 27 N from $g = 10 \text{ m s}^{-2}$	2
c		proper use of kinematic equation ✓ $\sqrt{2 \times 2.4 \times 0.95} = 2.14 \text{ «m s}^{-1}\gg \checkmark$	Must see either the substituted values OR a value for v to at least three s.f. for MP2.	2

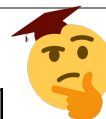
d	ALTERNATIVE 1 $\langle v^2 - u^2 + 2as \rightarrow 0 - 2.1^2 - 2a \times 0.35 \rangle$ leading to $a = 6.3 \text{ m s}^{-2}$ ✓ OR $\langle x = 1/2(u+v)t \rangle$ leading to $t = 0.33 \text{ s}$ ✓ $F_{\text{net}} = \langle ma = 1.5 \times 6.3 = \rangle 9.45 \text{ N} \text{ ✓}$ Weight down ramp = $1.5 \times 9.8 \times \sin(30) = 7.4 \text{ N} \text{ ✓}$ friction force = net force – weight down ramp = $2.1 \text{ N} \text{ ✓}$ ALTERNATIVE 2 kinetic energy initial = work done to stop $0.5 \times 1.5 \times (2.1)^2 = F_{\text{frict}} \times 0.35 \text{ ✓}$ $F_{\text{net}} = 9.45 \text{ N} \text{ ✓}$ Weight down ramp = $1.5 \times 9.8 \times \sin(30) = 7.4 \text{ N} \text{ ✓}$ friction force = net force – weight down ramp = $2.1 \text{ N} \text{ ✓}$	Accept 1.95 N from $g = 10 \text{ m s}^{-2}$. Accept 2.42 N from $u = 2.14 \text{ ms}^{-1}$.	4
e	static coefficient of friction > dynamic/kinetic coefficient of friction / $\mu_s > \mu_k \text{ ✓}$ «therefore» force of dynamic/kinetic friction will be less than the force of static friction ✓ there will be a net / unbalanced forward force once in motion «which results in acceleration» OR reference to net $F = ma \text{ ✓}$		3



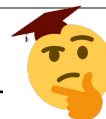
17 – (PHYSI/22_HL_Summer_2022_Q1) – Mechanics

a		ALTERNATIVE 1 there is a force «by the fan» on the air / air is accelerated «to the rear» ✓ by Newton 3 ✓ there is an «equal and» opposite force on the boat ✓ ALTERNATIVE 2 air gains momentum «backward» ✓ by conservation of momentum / force is rate of change in momentum ✓ boat gains momentum in the opposite direction ✓	Accept a reference to Newton's third law, e.g. N'3, or any correct statement of it for MP2 in ALT 1. Allow any reasonable choice of object where the force of the air is acting on, e.g., fan or blades.	3
b	i	πR^2 OR «mass of air through system per unit time =» $Av\rho$ seen ✓ 244 «kg s⁻¹» ✓	Accept use of Energy of air per second = $0.5 \rho Av^3 = 0.5 mv^2$ for MP1.	2
b	ii	«force = Momentum change per sec = $Av^2\rho = \rangle 244 \times 20$ OR 4.9 «kN» ✓	Allow use of 240	1
c	i	resistive forces increase with speed OR resistive forces/drag equal forward thrust ✓ acceleration/net force becomes zero/speed remains constant ✓		2
c	ii	recognition that area under the graph is distance covered ✓ «Distance =» 480 - 560 «m» ✓	Accept graphical evidence or calculation of correct geometric areas for MP1. MP2 is numerical value within range.	2
c	iii	calculation of acceleration as gradient at $t = 0$ «= 1 m s⁻²» ✓ use of $F=ma$ OR $\frac{4900}{1}$ seen ✓ 4900 «kg» ✓	MP1 can be shown on the graph. Allow an acceleration in the range 1 – 1.1 for MP2 and consistent answer for MP3 Allow ECF from MP1. Allow use of average acceleration = $\frac{18}{40}$ or assumption of constant force to obtain 11000 «kg» for [2] Allow use of 4800 or 5000 for MP2	3

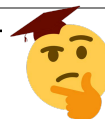
18 – (PHYSI/20_HL_Winter_2022_Q1) – Mechanics



a		g OR 9.81 «m s ⁻² » OR acceleration of gravity/due to free fall ✓	Accept 10 «m s ⁻² », Ignore sign. Do not accept bald "gravity". Accept answer that indicates tangent of the graph at time t=0.	1
b		Identification of air resistance/drag force «acting upwards» ✓ «that» increases with speed ✓ «until» weight and air resistance cancel out OR net force/acceleration becomes zero ✓	A statement as "air resistance increases with speed" scores MP1 and MP2 .	3
c	i	«loss in» GPE $= 3.4 \cdot 10^{-5} \cdot 9.81 \cdot 21 = 7.0 \cdot 10^{-3}$ «J» ✓ OR «gain in» KE $= 0.5 \cdot 3.4 \cdot 10^{-5} \cdot 9.0^2 = 1.4 \cdot 10^{-3}$ «J» ✓ energy transferred to air $= 7.0 \cdot 10^{-3} - 1.4 \cdot 10^{-3} = 5.6 \cdot 10^{-3}$ «J» ✓ any calculated answer to 2 sf ✓	Allow [1] through the use of kinematics assuming constant acceleration. Allow ECF from MP1	3
c	ii	«gravitational» potential energy «of the raindrop» into thermal/internal energy «of the air» ✓	Accept heat for thermal energy Accept into kinetic energy of air particles Ignore sound energy	1

1 - (PHYSI/21_HL_Summer_2017_Q1) - *Mechanics, Thermal Physics*

a	i	$\frac{1}{2}v^2 = 0.24gh$ ✓ $v = 11.9 \text{ «ms}^{-1}\text{»}$ ✓
a	ii	internal energy is the total KE «and PE» of the molecules/particles/atoms in an object ✓ temperature is a measure of the average KE of the molecules/particles/atoms ✓
b	i	arrow vertically downwards from dot labelled weight/W/mg/gravitational force/ F_g / $F_{\text{gravitational}}$ AND arrow vertically upwards from dot labelled reaction force/R/normal contact force/N/ F_N ✓ $W > R$ ✓



b ii **ALTERNATIVE 1**

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓

= 468 «N» ✓

W/640 N (weight) is larger than the centripetal force required, so the skier does not lose contact with the ground ✓

ALTERNATIVE 2

recognition that centripetal acceleration is required / $\frac{v^2}{r}$ seen ✓

a = 7.2 «ms⁻²» ✓

g is larger than the centripetal acceleration required, so the skier does not lose contact with the ground ✓

ALTERNATIVE 3

recognition that to lose contact with the ground centripetal force ≥ weight ✓

calculation that v ≥ 14 «ms⁻¹» ✓

comment that 12 «ms⁻¹» is less than 14 «ms⁻¹» so the skier does not lose contact with the ground ✓

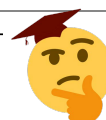
ALTERNATIVE 4

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓

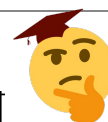
calculation that reaction force = 172 «N» ✓

reaction force > 0 so the skier does not lose contact with the ground ✓

c		ALTERNATIVE 1 $0 = 8.2^2 + 2 \times a \times 24$ therefore $a = \llcorner\llcorner 1.40 \llcorner\llcorner \text{ms}^{-2}$ ✓ friction force = $ma = 65 \times 1.4 = 91 \llcorner\llcorner \text{N}$ ✓ coefficient of friction = $\frac{91}{65 \times 9.81} = 0.14$ ✓ ALTERNATIVE 2 $KE = \frac{1}{2}mv^2 = 0.5 \times 65 \times 8.2^2 = 2185 \llcorner\llcorner \text{J}$ ✓ friction force = $KE/\text{distance} = 2185/24 = 91 \llcorner\llcorner \text{N}$ ✓ coefficient of friction = $\frac{91}{65 \times 9.81} = 0.14$ ✓
d	i	$\llcorner 76 \times 9.6 \llcorner = 730$ ✓ Ns <i>OR</i> kg ms^{-1} ✓
d	ii	safety net extends stopping time ✓ $F = \frac{\Delta p}{\Delta t}$ therefore F is smaller «with safety net» OR force is proportional to rate of change of momentum therefore F is smaller «with safety net» ✓

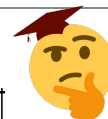


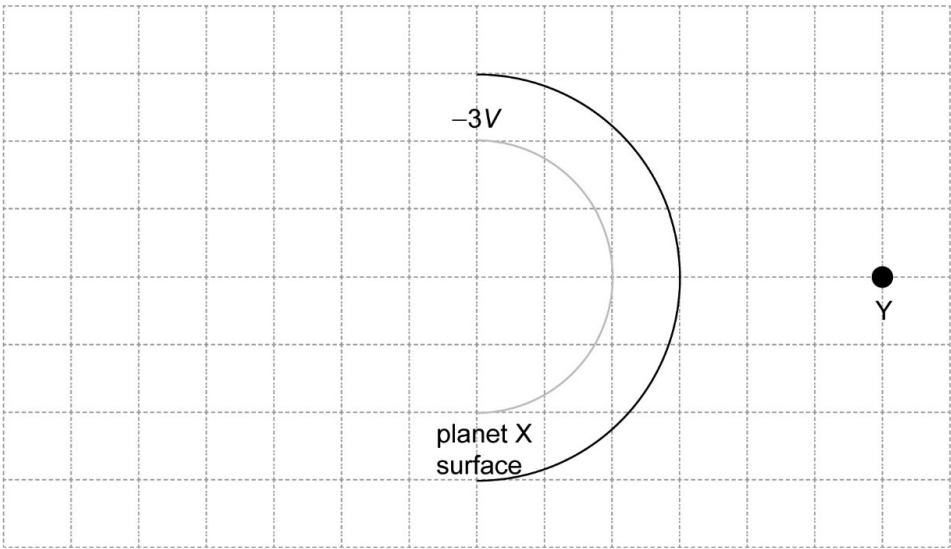
2 - (PHYSI/21_HL_Summer_2017_Q4) - Electricity & Magnetism, Thermal Physics



a	i	$I = \frac{8.5 \times 10^3}{240} = 35 \text{ A} \checkmark$
a	ii	$R = \frac{1.7 \times 10^{-8} \times 10}{6.0 \times 10^{-6}} \checkmark$ $= 0.028 \text{ } \Omega \checkmark$
a	iii	power = $35^2 \times 0.028 = 34 \text{ W} \checkmark$
b		«as temperature increases» there is greater vibration of the metal atoms/lattice/lattice ions OR increased collisions of electrons $\checkmark$ drift velocity decreases «so current decreases» $\checkmark$ «as V constant so» R increases $\checkmark$
c		recognition that power = flow rate $\times c\Delta T \checkmark$ flow rate «= $\frac{\text{power}}{c\Delta T}$ » = $\frac{8.5 \times 10^3}{4200 \times 35} \checkmark$ $= 0.058 \text{ kg s}^{-1} \checkmark$ $\text{kg s}^{-1} / \text{g s}^{-1} / \text{l s}^{-1} / \text{ml s}^{-1} / \text{m}^3 \text{ s}^{-1} \checkmark$

3 - (PHYSI/21_HL_Summer_2017_Q6) - Fields (ahl), Thermal Physics



a		the field lines/arrows are further apart at greater distances from the surface ✓
b		circle centred on Planet X ✓ three units from Planet X centre ✓ 
c		loss in gravitational potential = $\frac{6.67 \times 10^{-11} \times 3.1 \times 10^{21}}{1.2 \times 10^6}$ ✓ «= $1.72 \times 10^5 \text{ J kg}^{-1}$» equate to $\frac{1}{2}v^2$ ✓ $v = 590 \text{ m s}^{-1}$ ✓
d		available energy to melt one kg $1.72 \times 10^5 \text{ J}$ ✓ fraction that melts is $\frac{1.72 \times 10^5}{3.3 \times 10^5} = 0.52$ OR 52 % ✓

4 - (PHYSI/20_HL_Winter_2017_Q5) - Thermal Physics, Oscillations & Waves

a	i	«$v = \frac{\sin i}{\sin r} \times 3 \times 10^8 \frac{\sin(33)}{\sin(46)}$» ✓ $2.3 \times 10^8 \text{ m s}^{-1}$ ✓	
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a	ii	light strikes AB at an angle of 57° ✓ critical angle is $\left\langle \sin^{-1} \left(\frac{2.3}{3} \right) \right\rangle 50.1^\circ$ ✓ angle of incidence is greater than critical angle so total internal reflection OR light strikes AB at an angle of 57° ✓ calculation showing $\sin$ of "refracted angle" 1.1 ✓ statement that since $1.1 > 1$ the angle does not exist and the light does not emerge ✓	49.2° from unrounded value	
a	iii	total internal reflection shown ✓ ray emerges at opposite face to incidence ✓	With sensible refraction in correct direction	
b	i	mass $\langle \text{volume} \cdot \text{density} \rangle (0.75)^3 \cdot 920 \langle 388 \text{ kg} \rangle$ ✓ energy required to raise temperature $388 \cdot 2100 \cdot 20 \langle 1.63 \cdot 10^7 \text{ J} \rangle$ ✓ energy required to melt $388 \cdot 330 \cdot 10^3 \langle 1.28 \cdot 10^8 \text{ J} \rangle$ ✓ $1.4 \cdot 10^8 \langle \text{J} \rangle$ OR $1.4 \cdot 10^5 \langle \text{kJ} \rangle$ ✓	Accept any consistent units Award [3 max] for answer which uses density as 1000 kg m^{-3} ($1.5 \cdot 10^9 \langle \text{J} \rangle$)	
b	ii	in solid state, nearest neighbour molecules cannot exchange places/have fixed positions/are closer to each other/have regular pattern/have stronger forces of attraction ✓ in liquid, bonds between molecules can be broken and re-form ✓	OWTTE Accept converse argument for liquids	

5 - (PHYSI/21_HL_Summer_2018_Q2) - Thermal Physics

a		$\frac{3.0 \cdot 8.31 \cdot 290}{0.15}$ 48 «kPa» ✓		1
b	i	mass $\frac{860}{3100 \cdot 23} \gg 0.012 \langle \text{kg} \rangle$ ✓		1
b	ii	ALTERNATIVE 1 average kinetic energy $\frac{3}{2} 1.38 \cdot 10^{-23} \cdot 313 \cdot 6.5 \cdot 10^{21} \langle \text{J} \rangle$ ✓ number of particles $3.0 \cdot 6.02 \cdot 10^{23} \cdot 1.8 \cdot 10^{24}$ ✓ total kinetic energy $1.8 \cdot 10^{24} \cdot 6.5 \cdot 10^{21} \cdot 12 \langle \text{kJ} \rangle$ ✓ ALTERNATIVE 2 ideal gas so $U = KE$ ✓ $KE = \frac{3}{2} 8.31 \cdot 313 \cdot 3$ ✓ total kinetic energy = 12 «kJ» ✓		3
c		larger temperature implies larger (average) speed/larger (average) KE of molecules/particles/atoms ✓ increased force/momentum transferred to walls (per collision) / more frequent collisions with walls ✓ increased force leads to increased pressure because $P = F/A$ (as area remains constant) ✓	Ignore any mention of $PV = nRT$	3

6 – (PHYSI/22_HL_Summer_2018_Q2) – Thermal Physics

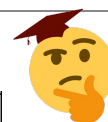


a	i	a gas in which there are no intermolecular forces OR a gas that obeys the ideal gas law/all gas laws at all pressures, volumes and temperatures OR molecules have zero PE/only KE ✓	Accept atoms/particles.	1
a	ii	$N \ll \frac{pV}{kT} = \frac{5.3 \cdot 10^5}{1.38 \cdot 10^{-23} \cdot 310} \gg 2.6 \cdot 10^{22}$ ✓		1
a	iii	«For one atom $U = \frac{3}{2} kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 310 = 6.4 \times 10^{-21} \text{ J}$ » ✓ $U \ll 2.6 \cdot 10^{22} \cdot \frac{3}{2} \cdot 1.38 \cdot 10^{-23} \cdot 310 = 170 \text{ J}$ ✓	Allow ECF from (a)(ii) Award [2] for a bald correct answer Allow use of $U = \frac{3}{2} pV$	2
b	i	$p_2 \ll 5.3 \cdot 10^5 \cdot \frac{2.1 \cdot 10^{-4}}{6.8 \cdot 10^{-4}} \gg 1.6 \cdot 10^5 \text{ Pa}$ ✓		1
b	ii	«volume has increased and» average velocity/KE remains unchanged ✓ «so» molecules collide with the walls less frequently/longer time between collisions with the walls ✓ «hence» rate of change of momentum at wall has decreased ✓ «and so pressure has decreased»	The idea of average must be included Decrease in number of collisions is not sufficient for MP2. Time must be included. Accept atoms/particles.	2 max

7 – (PHYSI/20_HL_Winter_2018_Q9) – Thermal Physics

a		Internal energy is the sum of all the PEs and KEs of the molecules (of the oxygen) ✓ PE of molecules in gaseous state is zero ✓ (At boiling point) average KE of molecules in gas and liquid is the same ✓ gases have a higher internal energy ✓	Molecules/particles/atoms must be included once, if not, award [1 max]	2 max
b	i	ALTERNATIVE 1: flow rate of oxygen = 8 g s^{-1} ✓ $\ll 2.1 \times 10^5 \times 8 \times 10^{-3} \gg = 1.7 \text{ kW}$ ✓ ALTERNATIVE 2: $Q = \ll 0.25 \times 32 \times 10^{-3} \times 2.1 \times 10^5 \gg = 1680 \text{ J}$ ✓ power = $\ll 1680 \text{ W} \gg = 1.7 \text{ kW}$ ✓		2
b	ii	$T = 260 \text{ K}$ ✓ $V = \ll \frac{nRT}{p} \gg = 4.9 \times 10^{-3} \text{ m}^3$ ✓		2
c		ideal gas has point objects ✓ no intermolecular forces ✓ non liquefaction ✓ ideal gas assumes monatomic particles ✓ the collisions between particles are elastic ✓	Allow the opposite statements if they are clearly made about oxygen eg oxygen/this can be liquified	1 max

8 - (PHYSI/21_HL_Summer_2019_Q4) - Thermal Physics



a	weight of cylinder – $Ahg\rho$ ✓ pressure – $\frac{F}{A} = \frac{Ahg\rho}{A}$ ✓		2
b i	use of $PV = nRT$ and $V = \text{Area} \times (0.190)$ seen ✓ substitution of $P = p_0 + p_m$ «re-arrangement to give answer» ✓		2
b ii	recognition that $\frac{nRT}{A}$ is constant OR $190p_0 + 190p_m = 208p_0 + 208p_m$ OR $p_0 = \frac{398}{18} p_m$ ✓ pressure due to mercury $p_m = 0.035 \times 1.36 \times 10^4 \times 9.81 (-4.67 \times 10^3 \text{ Pa})$ ✓ 1.03×10^3 ✓ Pa OR Nm^{-2} OR $\text{kgm}^{-1}\text{s}^{-2}$ ✓	Award MP4 for any correct unit of pressure (eg "mm of mercury / Hg").	4
b iii	same number of particles to collide with a larger surface area OR greater volume with constant rms speed decreases collision frequency ✓		1

9 - (PHYSI/22_HL_Summer_2019_Q2) - Thermal Physics

a	$\frac{1}{2}mv^2 = \frac{3}{2}kT$ / $v = \sqrt{\frac{3kT}{m}}$ / $\sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 320}{6.6 \times 10^{-27}}}$ ✓ $v = 1.4 \times 10^3 \text{ «ms}^{-1}\text{»}$ ✓		2
b	$N = \frac{pV}{kT}$ / $\frac{5.1 \times 10^5 \times 3.2 \times 10^{-6}}{1.38 \times 10^{-23} \times 320}$ OR $N = \frac{pVN_A}{RT}$ / $\frac{5.1 \times 10^5 \times 3.2 \times 10^{-6} \times 6.02 \times 10^{23}}{8.31 \times 320}$ ✓ $N = 3.7 \times 10^{20}$ ✓		2
c i	$\frac{4 \times 10^{20} \times 4.9 \times 10^{-31}}{3.2 \times 10^{-6}} \Rightarrow 6 \times 10^5$ ✓		1
c ii	«For an ideal gas» the size of the particles is small compared to the distance between them/size of the container/gas OR «For an ideal gas» the volume of the particles is negligible/the volume of the particles is small compared to the volume of the container/gas OR «For an ideal gas» particles are assumed to be point objects ✓ calculation/ratio/result in (c)(i) shows that volume of helium atoms is negligible compared to/much smaller than volume of helium gas/container «hence assumption is justified» ✓		2

10 – (PHYSI/20_HL_Winter_2019_Q2) – Thermal Physics



a	i	$N = \frac{pV}{kT}$ OR $N = \frac{1.0 \times 10^5 \times 0.36}{1.38 \times 10^{-23} \times 295}$ ✓ $N = 8.8 \times 10^{24}$ ✓	Allow [1 max] for substitution with T in Celsius. Allow [1 max] for a final answer of $n = 14.7$ or 15 Award [2] for bald correct answer.	2
b	i	use of $\frac{p}{T} = \text{constant}$ OR $p = \frac{nRT}{V}$ OR $\frac{NkT}{V}$ ✓ $p = 9.4 \times 10^4 \text{ «Pa»}$ ✓	Allow ECF from (a) Award [2] for bald correct answer	2
b	ii	$F = A \times p$ ✓ $F = 0.72 \times (1.0 - 0.94) \times 10^5$ OR $4.3 \times 10^5 \text{ «N»}$ ✓	Allow ECF from (b)(i) Allow ECF from MP1	2
b	iii	force is «very» large ✓ there must be a mechanism that makes this force smaller OR assumption used to calculate the force/pressure is unrealistic ✓		2

11 – (PHYSI/20_HL_Winter_2020_Q3) – Thermal Physics

a	i	«15 · 30 · 60» 27000 «J» ✓		1
a	ii	$27 \times 10^3 \cdot 0.32 \times c \times (290 - 250)$ OR 2100 ✓ $\text{J kg}^{-1} \text{ K}^{-1}$ OR $\text{J kg}^{-1} \text{ °C}^{-1}$ ✓	Allow any appropriate unit that is $\frac{\text{energy}}{\text{mass} \cdot \text{temperature}}$	2
b		«intermolecular» bonds are formed during freezing ✓ bond-forming process releases energy OR «intermolecular» PE decreases «and the difference is transferred as heat» ✓ «average random» KE of the molecules does not decrease/change ✓ temperature is related to «average» KE of the molecules «hence unchanged» ✓	To award MP3 or MP4 molecules/particles/atoms must be mentioned	3 max
c		mass of frozen oil « $\frac{27 \cdot 10^3}{130 \cdot 10^3}$ » 0.21 «kg» ✓ unfrozen mass « 0.32 - 0.21 » 0.11 «kg» ✓		2

12 – (PHYSI/21_HL_Summer_2021_Q3) – Thermal Physics, Electricity & Magnetism

a	i	$E_k = \frac{3}{2} (1.38 \times 10^{-23}) (373) = 7.7 \times 10^{-21} \text{ «J»}$ ✓ $v = \sqrt{\frac{3 \cdot 1.38 \cdot 10^{-23} \cdot 6.02 \cdot 10^{23} \cdot 373}{0.018}}$ 720 «m s ⁻¹ » ✓		2
a	ii	particles can be considered points «without dimensions» ✓ no intermolecular forces/no forces between particles «except during collisions» ✓ the volume of a particle is negligible compared to volume of gas ✓ collisions between particles are elastic ✓ time between particle collisions are greater than time of collision ✓ no intermolecular PE/no PE between particles ✓	Accept reference to atoms/molecules for «particle»	1 max
b	i	$\text{«}mL = Pt\text{» so «}L = \frac{1600 \cdot 200}{0.14} \text{ »} = 2.3 \times 10^6 \text{ «J kg}^{-1}\text{»}$ ✓ J kg^{-1} ✓		2
b	ii	«all» of the energy added is used to increase the «intermolecular» potential energy of the particles/break «intermolecular» bonds/OWTTE ✓	Accept reference to atoms/molecules for «particle»	1
c		use of $mc\Delta T$ ✓ $0.86 \cdot 4200 \cdot (100 - T) = 0.3 \cdot 1800 \cdot (T - 10)$ ✓ $T_{\text{eq}} = 85.69 \text{ «°C»} \approx 86 \text{ «°C»}$ ✓	Accept T_{eq} in Kelvin (359 K).	3

d	i	$P = \frac{V^2}{R}$ so $\frac{220^2}{1600}$ so $R = 30.25 \text{ } \Omega$ ✓	Must see either the substituted values OR a value for R to at least three s.f.	1
d	ii	use of parallel resistors addition so $R_{eq} = 15 \text{ } \Omega$ ✓ $P = 3200 \text{ W}$ ✓		2



13 – (PHYSI/22_HL_Summer_2021_Q2) – Thermal Physics

a		«He behaves as ideal gas if» $p \propto T$ «at constant V» ✓ uses two points to show that $p \propto T$ ✓	MP1 can also be described as $\frac{p}{T} = k$ OR $\frac{p}{T} = \frac{nR}{V}$	2
b		$\frac{100 \times 10^{-3} \times 10^{-3}}{250 \times 8.31} = 0.048 \text{ mol}$ ✓ «0.048 x 4 =» 0.19 «g» ✓	Allow any correct data point to be used. Allow ECF from MP1	2
c		recognizes that pressure will double ✓ graph will be steeper OR gradient will be larger ✓ graph will still go through the origin ✓	MP1 can be expressed as e.g. " $p \propto n$ " OR " $\frac{nR}{V}$ will double". Accept $pv = 2nRT$ for MP1.	2 max

14 – (PHYSI/21_HL_Summer_2022_Q2) – Thermal Physics

a		energy required for milk entering in 1 s = mass x specific heat x 73 ✓ 16 kW OR 16000 W ✓	MP1 is for substitution into $mc\Delta T$ regardless of power of ten. Allow any correct unit of power (such as Js^{-1} OR kJ s^{-1}) if paired with an answer to the correct power of 10 for MP2.	2
b		Underestimate / more energy or power required ✓ because energy transferred as heat / thermal energy is lost «to surroundings or electrical components» ✓	Do not allow general term "energy" or "power" for MP2.	2
c		the temperature has increased so the internal energy / « average » KE «of the molecules» has increased OR temperature is proportional to average KE «of the molecules». ✓ «therefore» the «average» speed of the molecules or particles is higher OR more frequent collisions « between molecules » OR spacing between molecules has increased OR average force of collisions is higher OR intermolecular forces are less OR intermolecular bonds break and reform at a higher rate OR molecules are vibrating faster. ✓		2

d	i	conduction/conducting/conductor «through metal» ✓		1
d	ii	use of $P = e\sigma AT^4$ where $T = 357 \text{ K}$ ✓ use of $A = 2\pi r l$ « $= 0.236 \text{ m}^2$ » ✓ $P = 87 \text{ «W»}$ ✓	Allow 85 – 89 W for MP3. Allow ECF for MP3.	3
d	iii	convection «is likely to be a significant loss» ✓ «due to reduction in density of air near pipe surface» hot air rises «and is replaced by cooler air from elsewhere» OR «due to» conduction «of heat or thermal energy» from pipe to air ✓		2



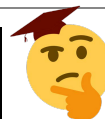
15 – (PHYSI/22_HL_Summer_2022_Q2) – Thermal Physics

a		Correct conversion of T « $T = 310 \text{ K}$ » seen ✓ « use of $N = \frac{pV}{kT}$ to get » 2.3×10^{23} ✓	Allow ECF from MP1 i.e., T in Celsius (Result is 2.7×10^{24}) Allow use of n , R and N_A	2
b	i	density decreases ✓ volume is increased AND mass/number of particles remains constant ✓		2
b	ii	internal energy is constant ✓ internal energy depends on kinetic energy/temperature «only» OR since temperature/kinetic energy is constant ✓	Do not award MP2 for stating that "temperature is constant" unless linked to the correct conclusion, as that is mentioned in the stem. Award MP2 for stating that kinetic energy remains constant.	2

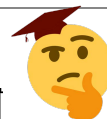
16 – (PHYSI/20_HL_Winter_2022_Q2) – Thermal Physics

a	i	energy required « $250 \cdot 4200 \cdot (30 - 15)$ » ✓ energy available « $0.30 \cdot 680 \cdot t \cdot A$ » ✓ $A = \frac{250 \cdot 4200 \cdot 15}{0.30 \cdot 680 \cdot 60 \cdot 60} = 21 \text{ «m}^2\text{» OR } 22 \text{ «m}^2\text{»}$ ✓	Allow ECF from MP1 and MP2. Accept the correct use of 0.30 in either MP1 or MP2.	3
a	ii	Absorbed intensity « $(1 - 0.2) \cdot 680$ « $= 544$ » « W m^{-2} » OR emitted intensity « $= 0.97 \cdot 5.67 \times 10^{-8} \cdot T^4$ » ✓ $T = \sqrt[4]{\frac{544}{0.97 \cdot 5.67 \cdot 10^{-8}}} = 315 \text{ «K»}$ ✓ 42 «°C» ✓	Allow ECF from MP1 and MP2. Allow MP1 if absorbed or emitted intensity is multiplied by area.	3

b	i	can be liquefied ✓ has intermolecular forces / potential energy ✓ has atoms/molecules that are not point objects / take up volume ✓ does not follow the ideal gas law «for all T and p » ✓ collisions between particles are non-elastic ✓	Accept the converse argument.	1 max
b	ii	ALTERNATIVE 1 «constant p and V imply» $nT = \text{const}$ ✓ T increases hence n decreases ✓ ALTERNATIVE 2 «constant p and n imply» V is proportional to T / air expands as it is heated ✓ «original» air occupies a greater volume OR some air leaves through opening ✓	MP2 in ALT 2 must come from expansion of air, not from expansion of water. Award [0] for an answer based on expansion of water. Award [1] max for an answer based on convection currents.	2
c		photovoltaic cells output electrical energy ✓ electrical is a more versatile form of energy ✓	Accept any reasonable advantage arising from the electrical output..e.g., PV cells allow for the use of a long list of appliances, PV owners can sell excess power back to grid. Accept electrical energy can be stored. Do not accept references to efficiency for MP2.	2



1 - (PHYSI/21_HL_Summer_2017_Q2) - Oscillations & Waves, Wave Phenomena (ahl)

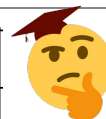


a	when 2 waves meet the resultant displacement ✓ is the «vector» sum of their individual displacements ✓
b	$\lambda = \frac{4.7 \times 10^{-3} \times 0.35 \times 10^{-3}}{2.4}$ ✓ $= 6.9 \times 10^{-7}$ «m» ✓ answer to 2 SF ✓
c	green wavelength smaller than red ✓ fringe separation / distance between maxima decreases ✓
d	bright central maximum ✓ subsidiary maxima «on either side» ✓ the width of the central fringe is twice / larger than the width of the subsidiary/secondary fringes/maxima OR intensity of pattern is decreased ✓

2 - (PHYSI/21_HL_Summer_2017_Q7) - Oscillations & Waves, Measurements & Uncertainties

a	acceleration/restoring force is proportional to displacement ✓ and in the opposite direction/directed towards equilibrium ✓
b	ALTERNATIVE 1 $\frac{T_1^2}{T_2^2} = \frac{m_1}{m_2}$ ✓ mass = 0.38 / 0.39 «kg» ✓ ALTERNATIVE 2 «use of $T = 2\pi\sqrt{\frac{m}{k}}$ » $k = 28$ «Nm ⁻¹ » ✓ «use of $T = 2\pi\sqrt{\frac{m}{k}}$ » $m = 0.38 / 0.39$ «kg» ✓
c	$\omega = \frac{2\pi}{0.74}$ = 8.5 «rads ⁻¹ » ✓ total energy = $\frac{1}{2} \times 0.39 \times 8.5^2 \times (4.8 \times 10^{-2})^2$ ✓ = 0.032 «J» ✓
d	spring constant/k/stiffness would increase ✓ T would be smaller ✓ fractional uncertainty in T would be greater, so fractional uncertainty of mass of block would be greater ✓

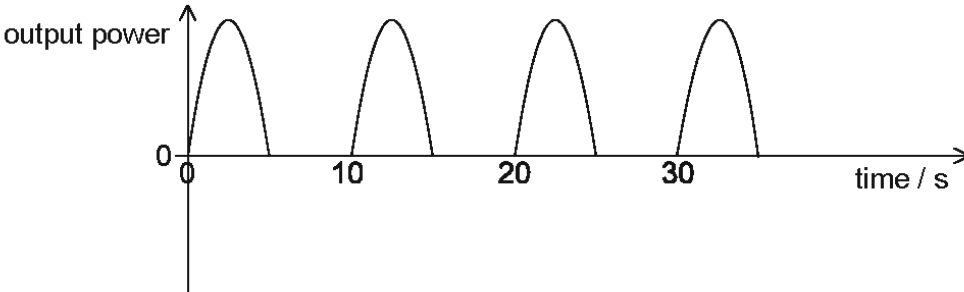
e	i	left ✓
	ii	coils to the right of P move right and the coils to the left move left ✓ hence P at centre of rarefaction ✓

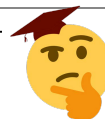


3 - (PHYSI/22_HL_Summer_2017_Q2) - Oscillations & Waves, Energy Production

a		force/acceleration proportional to displacement «from equilibrium position» ✓ and directed towards equilibrium position/point OR and directed in opposite direction to the displacement from equilibrium position/point ✓
b	i	frequency of buoy movement = $\frac{3.4}{35}$ or 0.097 «Hz» OR time period of buoy = $\frac{35}{3.4}$ or 10.3 «s» or 10 «s» ✓ $v = \ll \frac{2\pi x_0}{T} \text{ or } 2\pi f x_0 \gg = \frac{2 \times \pi \times 4.3}{10.3} \text{ or } 2 \times \pi \times 0.097 \times 4.3 \gg$ ✓ 2.6 «ms⁻¹» ✓



b	ii	peaks separated by gaps equal to width of each pulse «shape of peak roughly as shown» ✓ one cycle taking 10 s shown on graph ✓ 
c	i	PE of water is converted to KE of moving water/turbine to electrical energy «in generator/turbine/dynamo» ✓ idea of pumped storage, <i>ie</i>: pump water back during night/when energy cheap to buy/when energy not in demand/when there is a surplus of energy ✓

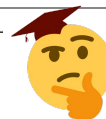


c	ii	specific energy available = «gh» 9.81×270 «$= 2650 \text{ J kg}^{-1}$» OR $mgh = \frac{1}{2}mv^2$ OR $v^2 = 2gh \checkmark$ $v = 73 \text{ «ms}^{-1}\text{» } \checkmark$
c	iii	total energy = «$mgh = 1.5 \times 10^{10} \times 9.81 \times 270$» 4.0×10^{13} «J» OR total energy = «$\frac{1}{2}mv^2 = \frac{1}{2} \times 1.5 \times 10^{10} \times (\text{answer (c)(ii)})^2$» 4.0×10^{13} «J» time = «$\frac{4.0 \times 10^{13}}{4 \times 2.5 \times 10^8}$» 11.1h or 4.0×10^4 s $\checkmark$
c	iv	friction/resistive losses in pipe/fluid resistance/turbulence/turbine or generator «bearings» OR sound energy losses from turbine/water in pipe $\checkmark$ thermal energy/heat losses in wires/components $\checkmark$ water requires kinetic energy to leave system so not all can be transferred $\checkmark$

4 - (PHYSI/20_HL_Winter_2017_Q2) - Circular Motion & Gravitation, Oscillations & Waves, Fields (ahl)

a		«$v = \sqrt{\frac{Gm_E}{r}}$» $\sqrt{\frac{6.67 \cdot 10^{-11} \cdot 6.0 \cdot 10^{24}}{6600 \cdot 10^3}}$ $\checkmark$ 7800 «ms⁻¹» $\checkmark$	Full substitution required Must see 2 : significant figures.
b	i	Y has smaller orbit/orbital speed is greater so time period is less $\checkmark$	Allow answer from appropriate equation Allow converse argument for X

b	ii	to stop Y from getting ahead ✓ to remain stationary with respect to X ✓ otherwise will add tension to cable/damage satellite/pull X out of its orbit ✓	
c		cable is a conductor and contains electrons ✓ electrons/charges experience a force when moving in a magnetic field ✓ use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive» ✓ Alternative 2 cable is a conductor ✓ so current will flow by induction flow when it moves through a B field ✓ use of a suitable hand rule to show current to right so «X becomes positive» ✓	Marks should be awarded from either one alternative or the other. Do not allow discussion of positive charges moving towards X
d		electrons would build up at satellite Y/positive charge at X ✓ preventing further charge flow ✓ by electrostatic repulsion ✓ unless a complete circuit exists ✓	
e		«ϵ $B\ell v$» $31 \cdot 10^{-6} \cdot 7790 \cdot 15000$ ✓ 3600 «V» ✓	Allow 3700 «V» from $v = 8000 \text{ ms}^{-1}$.



f	i	use of $k = \frac{4\pi^2 m}{T^2}$ » $\frac{4 \cdot \pi^2 \cdot 350}{5.2^2}$ ✓ 510 ✓ Nm^{-1} or kg s^{-2} ✓	Allow MP1 and MP2 for a bald correct answer Allow 500 Allow N/m etc
f	ii	E_p in the cable/system transfers to E_k of Y ✓ and back again twice in each cycle ✓	Exclusive use of gravitational potential energy negates MP1

5 - (PHYSI/20_HL_Winter_2017_Q5) - Thermal Physics, Oscillations & Waves

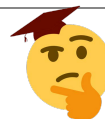
a	i	«$v = c \frac{\sin i}{\sin r}$» $3 \cdot 10^8 \frac{\sin(33)}{\sin(46)}$ ✓ $2.3 \cdot 10^8 \text{ «ms}^{-1}\text{»}$ ✓	
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a	ii	light strikes AB at an angle of 57° ✓ critical angle is $\sin^{-1}\left(\frac{2.3}{3}\right) \approx 50.1^\circ$ ✓ angle of incidence is greater than critical angle so total internal reflection OR light strikes AB at an angle of 57° ✓ calculation showing $\sin$ of "refracted angle" > 1 ✓ statement that since $1.1 > 1$ the angle does not exist and the light does not emerge ✓	49.2° from unrounded value	
a	iii	total internal reflection shown ✓ ray emerges at opposite face to incidence ✓	With sensible refraction in correct direction	
b	i	mass «volume · density» $(0.75)^3 \cdot 920 \approx 388 \text{ kg}$ ✓ energy required to raise temperature $388 \cdot 2100 \cdot 20 \approx 1.63 \cdot 10^7 \text{ J}$ ✓ energy required to melt $388 \cdot 330 \cdot 10^3 \approx 1.28 \cdot 10^8 \text{ J}$ ✓ $1.4 \cdot 10^8 \text{ J}$ OR $1.4 \cdot 10^5 \text{ kJ}$ ✓	Accept any consistent units Award [3 max] for answer which uses density as 1000 kg m^{-3} ($1.5 \cdot 10^9 \text{ J}$)	
b	ii	in solid state, nearest neighbour molecules cannot exchange places/have fixed positions/are closer to each other/have regular pattern/have stronger forces of attraction ✓ in liquid, bonds between molecules can be broken and re-form ✓	OWTTE Accept converse argument for liquids	

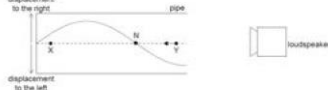
6 - (PHYSI/21_HL_Summer_2018_Q3) - Oscillations & Waves, Wave Phenomena (ahl)

a	i	superposition of light from each slit / interference of light from both slits ✓ with path/phase difference of any half-odd multiple of wavelength/any odd multiple of π (in words or symbols) ✓ producing destructive interference ✓	Ignore any reference to crests and troughs.	3
a	ii	light waves (from slits) must have constant phase difference / no phase difference / be in phase ✓	OWTTE	1
a	iii	evidence of solving for $D \approx D \frac{sd}{\lambda} \rightarrow \checkmark$ $\approx \frac{4.50 \cdot 10^{-3} \cdot 0.300 \cdot 10^{-3}}{633.0 \cdot 10^{-9}} \cdot 2 \approx 4.27 \text{ mm}$ ✓	Award [1] max for 2.13 m.	2

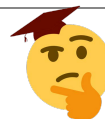
b	i	$\sin \theta = \frac{4 \times 633.0 \times 10^{-9}}{0.300 \times 10^{-3}} \checkmark$ $\theta = 0.0084401... \checkmark$ final answer to three sig figs (eg 0.00844 or 8.44×10^{-3}) $\checkmark$	Allow ECF from (a)(iii). Award [1] for 0.121 rad (can award MP3 in addition for proper sig fig) Accept calculation in degrees leading to 0.481 degrees. Award MP3 for any answer expressed to 3sf.	3
b	ii	use of diffraction formula « $b \frac{\lambda}{d}$ » OR $\frac{633.0 \times 10^{-9}}{0.00844} \checkmark$ « $\approx 7.5 \times 10^{-2}$ mm» $\checkmark$	Allow ECF from (b)(i).	2
c		wavelength increases (so frequency decreases) / light is redshifted $\checkmark$ galaxy is moving away from Earth $\checkmark$	Allow ECF for MP2 (ie wavelength decreases so moving towards).	2
d	i	$\frac{633.0}{1.33} = 476 \text{ nm} \checkmark$		1
d	ii	distance between peaks decreases $\checkmark$ intensity decreases $\checkmark$		2



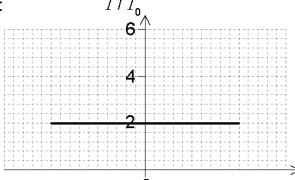
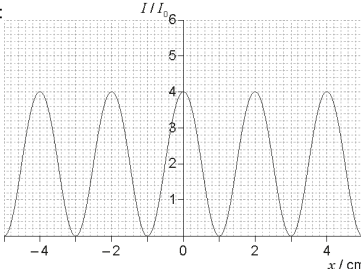
7 - (PHYSI/22_HL_Summer_2018_Q3) - Oscillations & Waves

a	i	the incident wave «from the speaker» and the reflected wave «from the closed end» superpose/combine/interfere $\checkmark$	Allow superimpose/add up Do not allow meet/interact	1
a	ii	Horizontal arrow from X to the right $\checkmark$	MP2 is dependent on MP1 Ignore length of arrow	1
a	iii	P at a node $\checkmark$		1
a	iv	wavelength is $\lambda = \frac{4 \times 0.30}{3} = 0.40 \text{ m} \checkmark$ $f = \frac{340}{0.40} = 850 \text{ Hz} \checkmark$	Award [2] for a bald correct answer Allow ECF from MP1	2

b	i	$\frac{\sin \theta_c}{340} = \frac{1}{1500} \checkmark$ $\theta_c = 13 \text{ «}^\circ \text{»} \checkmark$	Award [2] for a bald correct answer Award [2] for a bald answer of 13.1 Answer must be to 2/3 significant figures to award MP2 Allow 0.23 radians	2
b	ii	correct orientation $\checkmark$ greater separation $\checkmark$	Do not penalize the lengths of A and B in the water Do not penalize a wavefront for C if it is consistent with A and B MP1 must be awarded for MP2 to be awarded eg: 	2



8 - (PHYSI/22_HL_Summer_2018_Q5) - Oscillations & Waves, Wave Phenomena (ahl)

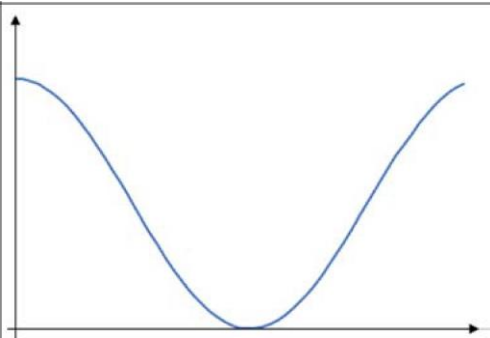
a		horizontal straight line through $I = 2 \checkmark$	eg:  Accept a curve that falls from $I = 2$ as distance increases from centre but not if it falls to zero.	1
b		«standard two slit pattern» general shape with a maximum at $x = 0 \checkmark$ maxima at $4I_0 \checkmark$ maxima separated by « $\frac{D\lambda}{s}$ » 2.0 cm $\checkmark$	Accept single slit modulated pattern provided central maximum is at 4. ie height of peaks decrease as they go away from central maximum. Peaks must be of the same width eg: 	3
c		fringe width/separation decreases OR more maxima seen $\checkmark$		1

9 – (PHYSI/20_HL_Winter_2018_Q4) – Oscillations & Waves



a	i	horizontal line shown in centre of pipe ✓		1
a	ii	«air molecule» moves to the right and then back to the left ✓ returns to X/original position ✓		2
b		wavelength = $2 \times 1.4 = 2.8 \text{ m}$ ✓ $c = \lambda f \Rightarrow 120 \times 2.8 = 340 \text{ ms}^{-1}$ ✓ $K = \frac{1}{2} \rho c^2 = \frac{1}{2} \times 1.3 \times 340^2 = 1.5 \times 10^5$ ✓ $\text{kg m}^{-1} \text{ s}^{-2}$ ✓		4
c	i	construction showing formation of image ✓	Another straight line/ray from image through the wall with line/ray from intersection at wall back to transmitter. Reflected ray must intersect boat.	1
c	ii	interference pattern is observed OR interference/superposition mentioned ✓ maximum when two waves occur in phase/path difference is $n\lambda$ OR minimum when two waves occur 180° out of phase/path difference is $(n + \frac{1}{2})\lambda$ ✓		2

10 – (PHYSI/21_HL_Summer_2019_Q3) – Oscillations & Waves

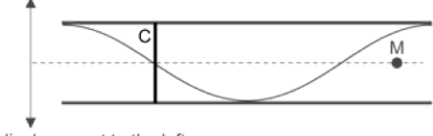
a		two waves superpose/mention of superposition/mention of «constructive» interference ✓ they arrive in phase/there is a path length difference of an integer number of wavelengths ✓		2
b		path difference = 0.062 m ✓ so wavelength = 0.031 m ✓ frequency = $9.7 \times 10^9 \text{ Hz}$ ✓	Award [2 max] for $4.8 \times 10^9 \text{ Hz}$.	3
c		intensity is modulated by a single slit diffraction envelope OR intensity varies with distance OR points are different distances from the slits ✓		1
d		 $\cos^2$ variation shown ✓ with zero at 90° (by eye) ✓	Award [1 max] for an inverted curve with maximum at 90° .	2

11 – (PHYSI/21_HL_Summer_2019_Q6) – Mechanics, Oscillations & Waves



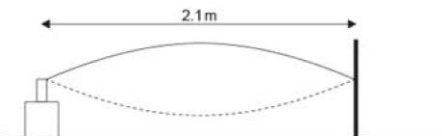
a	i	identifies T as 2.25 s ✓ $L = 1.26 \text{ m}$ ✓ $1.3 / 1.26 \text{ «m»}$ ✓	Accept <u>any</u> number of s.f. for MP2. Accept <u>any</u> answer with 2 or 3 s.f. for MP3.	3
a	ii	X labels any point <u>on the curve</u> where $E_k \frac{1}{4}$ of maximum/5 mJ ✓		1
a	iii	$\frac{1}{2}mv^2 = 20 \times 10^{-3}$ seen OR $\frac{1}{2} \times 7.5 \times 10^{-2} \times v^2 = 20 \times 10^{-3}$ ✓ $0.73 \text{ «m s}^{-1}\text{»}$ ✓	Must see at least 2 s.f. for MP2.	2
b	i	$0.40 \text{ «m s}^{-1}\text{»}$ ✓		1
b	ii	initial energy 24 mJ and final energy 12 mJ ✓ energy is lost/unequal /change in energy is 12 mJ ✓ inelastic collisions occur when energy is lost ✓		3
b	iii	graph with same period but inverted ✓ amplitude one half of the original/two boxes throughout (by eye) ✓		2
b	iv	mention of Doppler effect ✓ there is a change in the wavelength of the reflected wave ✓ because the wave speed is constant, there is a change in frequency ✓		3

12 – (PHYSI/22_HL_Summer_2019_Q3) – Oscillations & Waves

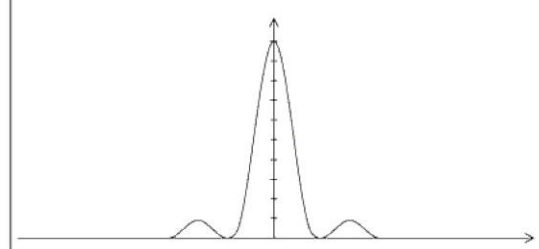
a		Expression or statement showing acceleration is proportional to displacement ✓ so $\text{«}7.9 \times \frac{2.3}{3.2}\text{»} = 5.7 \text{ «ms}^{-2}\text{»}$ ✓		2
b		$\sin \theta = \frac{340}{6010} \times \sin 54^\circ$ ✓ $\theta = 2.6^\circ$ ✓		2
c		$\lambda = \text{«}\frac{340}{250}\text{»} = 1.36 \approx 1.4 \text{ «m»}$ ✓		1
d	i	horizontal arrow «at M» pointing left ✓		1
d	ii	any point labelled C on the vertical line shown below ✓ eg: displacement to the right  displacement to the left		1
e	i	$f' = 2500 \times \frac{340}{340 + 280}$ ✓ $f' = 1371 \approx 1400 \text{ «Hz»}$ ✓		2
e	ii	$\lambda' = \frac{340}{1371} \approx 0.24 / 0.25 \text{ «m»}$ ✓		1

13 – (PHYSI/20_HL_Winter_2019_Q3) – Oscillations & Waves

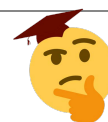


a	i	$v = \frac{0.05}{0.20 \times 10^{-3}} = 250 \text{ m s}^{-1}$ ✓		1
a	ii	$\lambda = 0.30 \text{ m}$ ✓ $f = \frac{250}{0.30} = 830 \text{ Hz}$ ✓	Allow ECF from (a)(i) Allow ECF from wrong wavelength for MP2	2
b		Q ✓ acceleration is proportional to displacement «and Q has larger displacement» ✓		2
c	i	3 «points» ✓		1
c	ii	first harmonic mode drawn ✓ 	Allow if only one curve drawn, either solid or dashed.	1

14 – (PHYSI/20_HL_Winter_2019_Q10) – Oscillations & Waves, Wave Phenomena (ahl)

a		there is a phase change ✓ of π OR as it is reflected off a medium of higher refractive index ✓		2
b	i	$2d$ ✓	Accept $2dn$	1
b	ii	$2dn - \frac{\lambda}{2}$ ✓ $d = \frac{\lambda}{4n} = \frac{656}{4 \times 1.38} = 119 \text{ nm}$ ✓	Award [2] for bald correct answer	2
b	iii	reflection from «front surface of» lens eliminated/reduced OR energy reaching sensor increased ✓ at one wavelength ✓	Accept reference to reduction of glare for MP1	2
c	i	standard single slit diffraction pattern with correct overall shape ✓ secondary maxima of right size ✓ 	Secondary maximum not to exceed 1/5 th of maximum intensity Ignore width of maxima	2
c	ii	use of $\theta = \frac{1.22\lambda}{b}$ ✓ $\theta = 2.9 \times 10^{-4} \text{ rad}$ ✓	Award [2] for bald correct answer	2

15 – (PHYSI/20_HL_Winter_2020_Q4) – Oscillations & Waves, Wave Phenomena (ahl)



a	wavelength = $\frac{340}{850}$ 0.40 «m» ✓ path difference = 1.8 «m» ✓ 1.8 «m» = 4.5 $\times \frac{1}{2} \times \frac{340}{850}$ OR $\frac{1}{2} \times \frac{340}{850}$ «half-wavelengths» ✓ waves meet in antiphase «at P» OR destructive interference/superposition «at P» ✓	Allow approach where path length is calculated in terms of number of wavelengths: along path A (56.25) and path B (60.75) for MP2, hence path difference 4.5 wavelengths for MP3	4
b	«equally spaced» maxima and minima ✓ a maximum at Q ✓ four «additional» maxima «between P and Q» ✓		2 max
c	the amplitude of sound at Q is halved ✓ «intensity is proportional to amplitude squared hence» $\frac{I_Q}{I_P} = \frac{1}{4}$ ✓		2
d i	speed of sound relative to the microphone is less ✓ wavelength unchanged «so frequency is lower» OR fewer waves recorded in unit time/per second «so frequency is lower» ✓		2
d ii	$\frac{845}{850} \times \frac{340}{340}$ ✓ $v = 2.00$ «m s⁻¹» ✓		2

16 – (PHYSI/21_HL_Summer_2021_Q8) – Oscillations & Waves

a	«travelling» wave moves along the length of the string and reflects «at fixed end» ✓ superposition/interference of incident and reflected waves ✓ the superposition of the reflections is reinforced only for certain wavelengths ✓		2 max
b i	$\lambda = 2l = 2 \times 0.62 = 1.24$ m ✓ $v = f\lambda = 195 \times 1.24 = 242$ «m s⁻¹» ✓	Answer must be to 3 or more sf or working shown for MP2.	2
b ii	straight line through origin with negative gradient ✓		1
b iii	max velocity occurs at $x = 0$ ✓ $v = (2\pi)(195)\sqrt{0.004^2} = 4.9$ «m s⁻¹» ✓		2
b iv	$a = (2\pi \times 195)^2 \times 0.004 = 6005$ «m s⁻²» ✓ $\approx 600g$ ✓		2
b v	use of $E \propto A^2$ OR x_0^2 ✓ $A = 0.4\sqrt{2} = 0.57$ «cm» ≈ 0.6 «cm» ✓		2
c	$\frac{62}{3}$ 21 «cm» ✓		1

17 - (PHYSI/22_HL_Summer_2021_Q7) - Oscillations & Waves, Electromagnetic Induction (ahl)



a	i	$\llcorner \frac{15}{110} \times 3300 = \gg 450 \llcorner \text{turns} \gg \checkmark$		1
a	ii	ALTERNATIVE 1 calculates total current = $\frac{35}{15} \times 8 \llcorner = 18.7 \text{ A} \gg \checkmark$ resistance = $\llcorner \frac{15}{18.7} = \gg 0.80 \llcorner \Omega \gg \checkmark$ ALTERNATIVE 2 calculates total power = $35 \times 8 \llcorner = 280 \text{ W} \gg \checkmark$ resistance = $\llcorner \frac{15^2}{280} = \gg 0.80 \llcorner \Omega \gg \checkmark$ ALTERNATIVE 3 calculates individual resistance = $\frac{15^2}{35} \llcorner = 6.43 \Omega \gg \checkmark$ resistance = $\llcorner \frac{6.43}{8} = \gg 0.80 \llcorner \Omega \gg \checkmark$		2
a	iii	total power required = $280 \llcorner \text{W} \gg$ OR uses factor $\frac{3300}{450}$ OR total current = $18.7 \llcorner \text{A} \gg \checkmark$ current = $2.5 \text{ OR } 2.6 \llcorner \text{A} \gg \checkmark$	Award [2] marks for a bald correct answer. Allow ECF from (a)(ii).	2
a	iv	the secondary coil does not enclose all flux $\llcorner \text{lines from core} \gg \checkmark$ induced emf in secondary OR power transferred to the secondary OR efficiency is less than expected $\checkmark$	Award [0] for references to eddy currents/heating of the core as the reason. Award MP2 if no reason stated.	2
b		bob cuts mag field lines OR there is a change in flux linkage $\checkmark$ induced emf across bob $\checkmark$ leading to eddy/induced current in bob $\checkmark$ eddy/induced current produces a magnetic field that opposes $\llcorner \text{direction of} \gg$ motion $\checkmark$ force due to the induced magnetic field decelerates bob $\checkmark$ damping of pendulum increases/there is additional $\llcorner \text{magnetic} \gg$ damping $\checkmark$	MP4 and MP5 can be expressed in terms of energy transfer from kinetic energy of bob to electrical/thermal energy in bob	4 max

18 – (PHYSI/20_HL_Winter_2021_Q2) – Oscillations & Waves



a	$T = 4 \cdot 10^{-3} \text{ s}$ or $f = 250 \text{ Hz}$ ✓ $\lambda = 340 \cdot 4.0 \cdot 10^{-3} = 1.36 \approx 1.4 \text{ m}$ ✓	Allow ECF from MP1. Award [2] for a bald correct answer.	2
b	$\omega = \frac{2\pi}{T} = \frac{2\pi}{4 \cdot 10^{-3}} \text{ OR } 1.57 \cdot 10^3 \text{ s}^{-1}$ ✓ $a = \omega^2 x_c = (1.57 \cdot 10^3)^2 \cdot 6 \cdot 10^{-6} = 14.8 \approx 15 \text{ ms}^{-2}$ ✓ «opposite to displacement so» to the right ✓		3
c i	$\phi = \frac{\pi}{2} / 90 \text{ OR } \frac{3\pi}{2} / 270$ ✓		1
c ii	1.5 ms ✓		1
c iii	$8.0 \text{ OR } 8.5 \text{ }\mu\text{m}$ ✓	From the graph on the paper, value is 8.0. From the calculated correct trig functions, value is 8.49	1
d i	$L = \frac{v}{f} = 0.90 \text{ m}$ ✓		1
d ii	to the right ✓ displacement is getting less negative OR change of displacement is positive ✓		2
d iii	horizontal line drawn at the equilibrium position ✓		1

19 – (PHYSI/22_HL_Summer_2022_Q3) – Oscillations & Waves

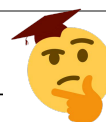
a i	«incident and reflected» waves superpose/interfere/combine ✓ «that leads to» standing waves formed OR nodes and antinodes present ✓ at antinodes / maxima there is maximum intensity / constructive interference / «displacement» addition / louder sound ✓ at nodes / minima there is minimum intensity / destructive interference / «displacement» cancellation / quieter sound ✓	OWTTE Allow a sketch of a standing wave for MP2 Allow a correct reference to path or phase differences to identify constructive / destructive interference	3 max
a ii	wavelength = 0.24 m ✓ $f = \frac{340}{0.24} \approx 1.4 \text{ kHz}$ OR 1400 Hz ✓	Allow ECF from MP1	2
b	relates intensity to amplitude ✓ antinodes / maximum intensity will be decreased / quieter ✓ nodes / minimum will be increased / louder ✓ difference in intensities will be less ✓ maxima and minima are at the same positions ✓	OWTTE	3 max

20 – (PHYSI/20_HL_Winter_2022_Q3) – Oscillations & Waves



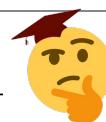
a	i	oscillation in antiphase ✓ smaller amplitude than P ✓ displacement 0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 t/ms		2
a	ii	wavelength = $\frac{2}{3} \times 0.80 = 0.53$ «m» ✓ speed = $\frac{0.53}{2.8 \times 10^{-3}} = 190$ «m s⁻¹» ✓	Allow ECF from incorrect wavelength	2
b	i	kg m s⁻² OR m² s⁻² seen ✓ kg m⁻¹ ✓	Award [2] for a BCA	2
b	ii	speed increases hence frequency increases ✓ by factor $\sqrt{2}$ ✓		2
c	i	travelling waves transfer energy OR standing waves don't ✓ amplitude of oscillation varies along a standing wave OR is constant along a travelling wave ✓ standing waves have nodes / antinodes OR travelling waves don't ✓ points in an internodal region have same phase in standing waves OR different phase in travelling waves ✓		1 max
c	ii	ALTERNATIVE 1 $\sin \theta_c = \frac{340}{1500}$ ✓ critical angle = 13° «from $\frac{340}{1500}$» ✓ the angle of incidence is greater than θ_c hence the sound can't enter water ✓ ALTERNATIVE 2 $\sin \theta_c = \frac{1500}{340} \sin 30^\circ$ ✓ sine value greater than one hence the sound can't enter water ✓	Conclusion must be justified, award [0] for BCA	2

1 - (PHYSI/21_HL_Summer_2017_Q3) - Energy Production, Electricity & Magnetism



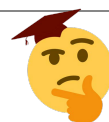
a		solar heating panel converts solar/radiation/photon/light energy into thermal energy AND photovoltaic cell converts solar/radiation/photon/light energy into electrical energy ✓
b		power received = $240 \times 25000 = \llcorner 6.0 \text{ MW} \llcorner$ ✓ efficiency $\llcorner = \frac{1.6}{6.0} \llcorner = 0.27 / 27\%$ ✓
c	i	area = $\pi \times 17^2 \llcorner = 908 \text{ m}^2 \llcorner$ ✓ power = $\frac{1}{2} \times 908 \times 1.3 \times 7.5^3 \llcorner = 0.249 \text{ MW} \llcorner$ ✓ number of turbines $\llcorner = \frac{1.6}{0.249} = 6.4 \llcorner = 7$ ✓
	ii	«efficiency is less than 100 % as» not all KE of air can be transferred to KE of blades OR air needs to retain KE to escape ✓ thermal energy is lost due to friction in turbine/dynamo/generator ✓

2 - (PHYSI/21_HL_Summer_2017_Q4) - Electricity & Magnetism, Thermal Physics



a	i	$I = \frac{8.5 \times 10^3}{240} = 35 \text{ A} \checkmark$
a	ii	$R = \frac{1.7 \times 10^{-8} \times 10}{6.0 \times 10^{-6}} \checkmark$ $= 0.028 \text{ } \Omega \checkmark$
a	iii	power = $35^2 \times 0.028 = 34 \text{ W} \checkmark$
b		«as temperature increases» there is greater vibration of the metal atoms/lattice/lattice ions OR increased collisions of electrons $\checkmark$ drift velocity decreases «so current decreases» $\checkmark$ «as V constant so» R increases $\checkmark$
c		recognition that power = flow rate $\times c\Delta T \checkmark$ flow rate «= $\frac{\text{power}}{c\Delta T}$» = $\frac{8.5 \times 10^3}{4200 \times 35} \checkmark$ $= 0.058 \text{ kg s}^{-1} \checkmark$ $\text{kg s}^{-1} / \text{g s}^{-1} / \text{l s}^{-1} / \text{ml s}^{-1} / \text{m}^3 \text{ s}^{-1} \checkmark$

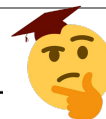
3 - (PHYSI/22_HL_Summer_2017_Q3) - Electromagnetic Induction (ahl), Electricity & Magnetism



a		$\left\langle \frac{1}{2} CV^2 = \frac{1}{2} \times 0.022 \times 24^2 \right\rangle = 6.3 \text{ «J»} \checkmark$
b		$\frac{1}{100} = e^{-\frac{t}{8.0 \times 0.022}} \checkmark$ $\ln 0.01 = -\frac{t}{8.0 \times 0.022} \checkmark$ $0.81 \text{ «s»} \checkmark$
c	i	$c = \frac{Q}{m \times \Delta T}$ OR $\frac{6.3}{0.00061 \times 28} \checkmark$ $370 \text{ J kg}^{-1} \text{ K}^{-1} \checkmark$

c	ii	ALTERNATIVE 1 some thermal energy will be transferred to surroundings/along connecting wires/to thermometer ✓ estimate «of specific heat capacity by student» will be larger «than accepted value» ✓ ALTERNATIVE 2 not all energy transferred as capacitor did not fully discharge ✓ so estimate «of specific heat capacity by student» will be larger «than accepted value» ✓
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4 – (PHYSI/20_HL_Winter_2017_Q4) – Electricity & Magnetism



a	i	$\llcorner \frac{RA}{\rho} \frac{82}{4.1 \cdot 10^{-5}} \cdot 2 \cdot 10^{-6} \gg$ $0.032 \llcorner \text{m} \gg \checkmark$	
a	ii	power $1500 \cdot 8 \cdot 10^{-3} \cdot 0.032 \llcorner 0.384 \gg \checkmark$ $\llcorner \text{current} \cdot \sqrt{\frac{\text{power}}{\text{resistance}}} \sqrt{\frac{0.384}{82}} \gg$ $0.068 \llcorner \text{A} \gg \checkmark$	Be aware of ECF from (a)(i) Award [1] for 4.3 «A» where candidate has not calculated area
a	iii	quantities such as resistivity depend on the material OR they allow the selection of the correct material OR they allow scientists to compare properties of materials ✓	
b		as area is larger and length is smaller ✓ resistance is «very much» smaller ✓	Award [1 max] for answers that involve a calculation

5 – (PHYSI/21_HL_Summer_2018_Q4) – Electricity & Magnetism

a		$1.7 \cdot 10^{-8} \cdot \frac{0.10}{(0.02 \cdot 10^{-2})^2} \checkmark$ $0.043 \llcorner \Omega \gg \checkmark$		2
b		$v \llcorner \frac{I}{neA} \gg \frac{2.0}{8.5 \cdot 10^{22} \cdot 1.60 \cdot 10^{-19} \cdot 0.02^2} \checkmark$ $0.37 \llcorner \text{cms}^{-1} \gg \checkmark$		2
c	i	$V = RI \llcorner 0.086 \llcorner \text{V} \gg \checkmark$ $\llcorner \frac{V}{d} \gg \frac{0.086}{0.10} \gg 0.86 \llcorner \text{Vm}^{-1} \gg \checkmark$	Allow ECF from 4(a). Allow ECF from MP1.	2
c	ii	ALTERNATIVE 1 clear use of Ohm's Law ($V=IR$) ✓ clear use of $R = \frac{\rho L}{A}$ ✓ combining with $I = nAve$ and $V = EL$ to reach result. ✓ ALTERNATIVE 2 attempts to substitute values into equation. ✓ correctly calculates LHS as 4.3×10^9. ✓ correctly calculates RHS as 4.3×10^9. ✓	For ALTERNATIVE 1 look for: $V = IR$ $R = \frac{\rho L}{A}$ $V = EL$ $I = nAve$ $V = I \frac{\rho L}{A}$ $EL = I \frac{\rho L}{A}$ $E = I \frac{\rho}{A}$ $E = nAve \frac{\rho}{A} = nev\rho$ $\frac{v}{E} = \frac{1}{nev\rho}$	3

6 – (PHYSI/21_HL_Summer_2018_Q5) – Electricity & Magnetism, Circular Motion & Gravitation



a		out of the page plane / $\odot$ ✓	Do not accept just "up" or "outwards".	1
b		$1.60 \cdot 10^{-18} \cdot 6.8 \cdot 10^5 \cdot 8.5 \cdot 9.2 \cdot 10^{-13} \text{ «N»}$ ✓		1
c	i	the magnetic force does not do work on the electron hence does not change the electron's kinetic energy OR the magnetic force/acceleration is at right angles to velocity ✓		1
c	ii	the velocity of the electron is at right angles to the magnetic field ✓ (therefore) there is a centripetal acceleration / force acting on the charge ✓	OWTTE	2

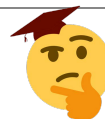
7 – (PHYSI/22_HL_Summer_2018_Q4) – Electricity & Magnetism

a		the work done per unit charge ✓ in moving charge from one terminal of a cell to the other / all the way round the circuit ✓	Award [1] for "energy per unit charge provided by the cell" / "power per unit current" Award [1] for "potential difference across the terminals of the cell when no current is flowing" Do not accept "potential difference across terminals of cell"	2
b	i	the resistance is proportional to length / see 0.35 AND 1 «.00» ✓ so it equals $0.35 \cdot 80$ ✓ $\text{« } 28 \Omega \text{ »}$		2
b	ii	current leaving 12 V cell is $\frac{12}{80} = 0.15 \text{ «A»}$ OR $E = \frac{12}{80} \cdot 28$ ✓ $E = 0.15 \cdot 28 = 4.2 \text{ «V»}$ ✓	Award [2] for a bald correct answer Allow a 1sf answer of 4 if it comes from a calculation. Do not allow a bald answer of 4 «V» Allow ECF from incorrect current	2
c		since the current in the cell is still zero there is no potential drop across the internal resistance ✓ and so the length would be the same ✓	OWTTE	2

8 – (PHYSI/20_HL_Winter_2018_Q2) – Electricity & Magnetism

a		ALTERNATIVE 1: $r = \sqrt{\frac{\rho l}{\pi R}}$ OR $\sqrt{\frac{7.2 \cdot 10^{-7} \cdot 12.5}{\pi \cdot 0.1}}$ ✓ $r = 5.352 \cdot 10^{-3}$ ✓ $5.4 \cdot 10^{-3} \text{ «m»}$ ✓ ALTERNATIVE 2: $A = \frac{7.2 \cdot 10^{-7} \cdot 12.5}{0.1}$ ✓ $r = 5.352 \cdot 10^{-3}$ ✓ $5.4 \cdot 10^{-3} \text{ «m»}$ ✓	For MP2 accept any SF For MP3 accept only 2 SF For MP3 accept ANY answer given to 2 SF For MP2 accept any SF For MP3 accept only 2 SF For MP3 accept ANY answer given to 2 SF	3
b		current in lamp $\frac{5}{24} \text{ «= 0.21» «A»}$ OR $n = 24 \cdot \frac{8}{5}$ ✓ so «38.4 and therefore» 38 lamps ✓	Do not award ECF from MP1	2

c		when adding more lamps in parallel the brightness stays the same ✓ when adding more lamps in parallel the pd across each remains the same/at the operating value/24 V ✓ when adding more lamps in parallel the current through each remains the same ✓ lamps can be controlled independently ✓ the pd across each bulb is larger in parallel ✓ the current in each bulb is greater in parallel ✓ lamps will be brighter in parallel than in series ✓ In parallel the pd across the lamps will be the operating value/24 V ✓	Accept converse arguments for adding lamps in series: when adding more lamps in series the brightness decreases when adding more lamps in series the pd decreases when adding more lamps in series the current decreases lamps can't be controlled independently the pd across each bulb is smaller in series the current in each bulb is smaller in series in series the pd across the lamps will less than the operating value/24 V Do not accept statements that only compare the overall resistance of the combination of bulbs.	1 max
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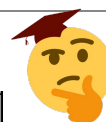


d	i	«as flux linkage change occurs in core, induced emfs appear so» current is induced ✓ induced currents give rise to resistive forces ✓ eddy currents cause thermal energy losses «in conducting core» ✓ power dissipated by eddy currents is drawn from the primary coil/reduces power delivered to the secondary ✓		2 max
d	ii	power = 190 OR 192 «W» ✓ required power = $190 \times \frac{100}{95}$ «= 200 or 202 W» ✓ so $\frac{200}{240} = 0.83$ OR 0.84 «A rms» ✓ peak current = «$0.83 \times \sqrt{2}$ OR $0.84 \times \sqrt{2}$» = 1.2/1.3 «A» ✓		4

9 - (PHYSI20_HL_Winter_2018_Q7) - Electricity & Magnetism

a		charge stored on capacitor $12 \cdot 10^{-3} \cdot 7.5 \cdot 0.09$ «C» ✓		1
b		energy stored in capacitor «$\frac{1}{2} CV^2$ or $\frac{1}{2} QV$» $\frac{1}{2} \cdot 12 \cdot 10^{-3} \cdot 7.5^2$ « 0.338 J» ✓ height «$\frac{1}{3} \cdot \frac{0.338}{9.81 \cdot 4.5 \cdot 10^{-2}}$» 0.25/0.26 «m» ✓	Allow use of $g = 10 \text{ m s}^{-2}$ which gives 0.25 «m»	2
c		C halved ✓ so energy stored is halved/reduced so rises «less than» half height ✓ discharge time/raise time less as RC halved/reduced ✓	Allow 6 mF	3

10 - (PHYSI/21_HL_Summer_2019_Q1) - Mechanics, Electricity & Magnetism



a	i	time taken $\frac{2.0 \times 10^4}{7} \approx 2860 \text{ s} = 2900 \text{ s} \checkmark$	Must see at least two s.f.	1
a	ii	use of $E = qV$ OR energy $4.3 \times 10^4 \times 16 \approx 6.88 \times 10^5 \text{ J} \checkmark$ power $= 241 \text{ «W»} \checkmark$	Accept 229 W – 241 W depending on the exact value of t used from ai. Must see at least three s.f.	2
a	iii	use of power = force x speed OR force x distance = power x time $\checkmark$ $34 \text{ «N»} \checkmark$	Accept 34 N – 36 N.	2
b	i	$66 \text{ g} \sin(3^\circ) = 34 \text{ «N»} \checkmark$		1
b	ii	total force $34 + 34 = 68 \text{ «N»} \checkmark$ $3.5 \text{ «ms}^{-1}\text{»} \checkmark$	Look for ECF from aii and bi. Accept 3.4 – 3.5 «ms ⁻¹ ». Award [0] for solutions involving use of KE.	2
c		«maximum» distance will decrease OWTTE $\checkmark$ because opposing/resistive force has increased OR because more energy is transferred to GPE OR because velocity has decreased OR increased mass means more work required «to move up the hill» $\checkmark$		2
d		4 V dropped across battery OR $R_{\text{output}} = 1.85 \Omega \checkmark$ so internal resistance $\frac{4.0}{6.5} = 0.62 \text{ «}\Omega\text{»} \checkmark$		2
e	i	$\frac{16}{5} = 3.2 \text{ «V»} \checkmark$		1
e	ii	ALTERNATIVE 1: $2.5r = 0.62 \checkmark$ $r = 0.25 \text{ «}\Omega\text{»} \checkmark$ ALTERNATIVE 2: $\frac{0.62}{5} = 0.124 \text{ «}\Omega\text{»} \checkmark$ $r = 2(0.124) = 0.248 \text{ «}\Omega\text{»} \checkmark$	Allow ECF from (d).	2

11 – (PHYSI/21_HL_Summer_2019_Q8) – Electromagnetic Induction (ahl), Electricity & Magnetism



a	i	length $\times \frac{d \times C}{\text{width} \times \epsilon_0}$ ✓ = 0.33 «m» ✓ so 0.66/0.67 «m» «as two lengths required» ✓	3
a	ii	$1.5 \times 10^6 \times 55 \times 10^{-6} = 83$ «V» ✓ $q = CV = 5.6 \times 10^{-6}$ «C» ✓	2
b	i	$0.5 = e^{-\frac{t}{RC}} = e^{-\frac{t}{220 \times 6.8 \times 10^{-9}}}$ ✓ $t = \ln 0.5 \times 220 \times 6.8 \times 10^{-9} \times \ln 0.5$ ✓ 5.7×10^{-5} «s» ✓ OR use of $t_1 = RC \times \ln 2$ ✓ $220 \times 6.8 \times 10^{-9} \times 0.693$ ✓ 5.7×10^{-5} «s» ✓	3
b	ii	mention of Faraday's law ✓ indicating that changing current in discharge circuit leads to change in flux in coil/change in magnetic field «and induced emf» ✓	2
b	iii	decrease/reduce ✓ resistance (R) OR capacitance (C) ✓	2

12 – (PHYSI/22_HL_Summer_2019_Q4) – Electricity & Magnetism

a		total resistance of circuit is 8.0 «Ω» ✓ $P = \frac{12^2}{8.0} = 18$ «W» ✓	2
b	i	«a resistor is now connected in parallel» reducing the total resistance OR current through YZ unchanged and additional current flows through X ✓	1
b	ii	evidence in calculation or statement that pd across Y/current in Y is the same as before ✓ so ratio is 1 ✓	2
c		$E = \frac{1}{2} CV^2 = \frac{1}{2} \times 6 \times 10^{-6} \times 12^2 = 4.3 \times 10^{-4}$ «J» ✓	1
d	i	ALTERNATIVE 1 capacitance doubles and voltage halves ✓ since $E = \frac{1}{2} CV^2$ energy halves ✓ so change is « 2.2×10^{-4} «J» » ✓ ALTERNATIVE 2 $E = \frac{1}{2} CV^2$ and $Q = CV$ so $E = \frac{Q^2}{2C}$ ✓ capacitance doubles and charge unchanged so energy halves ✓ so change is « 2.2×10^{-4} «J» » ✓	3
d	ii	it is the work done when inserting the dielectric into the capacitor ✓	1

13 – (PHYSI/22_HL_Summer_2019_Q5) – Electricity & Magnetism, Circular Motion & Gravitation



a	i	F towards centre ✓		1
a	ii	v tangent to circle and in the direction shown in the diagram ✓		1
b	i	$qvB = \frac{mv^2}{R} \Rightarrow R = \frac{mv}{qB} = \frac{1.673 \times 10^{-27} \times 2.16 \times 10^6}{1.60 \times 10^{-19} \times 0.042} \checkmark$ $R = 0.538 \text{ «m»} \checkmark$ $R = 0.54 \text{ «m»} \checkmark$		3
b	ii	$T = \frac{2\pi R}{v} = \frac{2\pi \times 0.54}{2.16 \times 10^6} \checkmark$ $T = 1.6 \times 10^{-6} \text{ «s»} \checkmark$		2

14 – (PHYSI/20_HL_Winter_2019_Q4) – Electricity & Magnetism, Circular Motion & Gravitation

a		magnetic force is to the left «at the instant shown» OR explains a rule to determine the direction of the magnetic force ✓ force is perpendicular to velocity/«direction of» motion OR force is constant in magnitude ✓ force is centripetal/towards the centre ✓	Accept reference to acceleration instead of force. 2 max
b	i	$qvB = \frac{mv^2}{R} \checkmark$ $R = \frac{1.67 \times 10^{-27} \times 2.0 \times 10^6}{1.6 \times 10^{-19} \times 0.35} \text{ OR } 0.060 \text{ «m»}$	Award MP2 for full replacement or correct answer to at least 2 significant figures 2
b	ii	$T = \frac{2\pi R}{v} \checkmark$ $T = \frac{2\pi \times 0.06}{2.0 \times 10^6} = 1.9 \times 10^{-7} \text{ «s»} \checkmark$	Award [2] for bald correct answer 2
c		ALTERNATIVE 1 work done by force is change in kinetic energy ✓ work done is zero/force perpendicular to velocity ✓ ALTERNATIVE 2 proton moves at constant speed ✓ kinetic energy depends on speed ✓	Award [2] for a reference to work done is zero hence E_k remains constant Accept mention of speed or velocity indistinctly in MP2 2

15 – (PHYSI/20_HL_Winter_2019_Q5) – Electricity & Magnetism



a		$E = \frac{k \times q}{r^2} \checkmark$ $E = \frac{8.99 \times 10^9 \times 6.0 \times 10^{-3}}{0.4^2} \text{ OR } E = 3.37 \times 10^6 \text{ «NC}^{-1}\text{»} \checkmark$	Ignore any negative sign. 2
b	i	$F = q \times E \text{ OR } F = 1.6 \times 10^{-19} \times 3.4 \times 10^6 = 5.4 \times 10^{-11} \text{ «N»} \checkmark$ $a = \frac{5.4 \times 10^{-11}}{9.1 \times 10^{-31}} = 5.9 \times 10^{19} \text{ «ms}^{-2}\text{»} \checkmark$	Ignore any negative sign. Award [1] for a calculation leading to $a = 3.7 \times 10^{18} \text{ «ms}^{-2}\text{»}$ Award [2] for bald correct answer 2
b	ii	the electron moves away from the point charge/to the right «along the line joining them» $\checkmark$ decreasing acceleration $\checkmark$ increasing speed $\checkmark$	Allow ECF from MP1 if a candidate mistakenly evaluates the force as attractive so concludes that the acceleration will increase 3

16 – (PHYSI/20_HL_Winter_2020_Q5) – Electricity & Magnetism

a		current is not «directly» proportional to the potential difference OR resistance of X is not constant OR resistance of X changes «with current/voltage» $\checkmark$	1
b	i	ALTERNATIVE 1 voltage across X = 2.3 «V» $\checkmark$ voltage across R « 4.0 - 2.3 » 1.7 «V» $\checkmark$ resistance of variable resistor « $\frac{1.7}{0.020}$ » 85 « Ω » $\checkmark$ ALTERNATIVE 2 overall resistance « $\frac{4.0}{0.020}$ » 200 « Ω » $\checkmark$ resistance of X « $\frac{2.3}{0.020}$ » 115 « Ω » $\checkmark$ resistance of variable resistor « 200 - 115 » 85 « Ω » $\checkmark$	3
b	ii	power « 4.0 - 0.020 » 0.080 «W» $\checkmark$	1
c	i	from 0 to 60 mA $\checkmark$	1
c	ii	ALTERNATIVE 1 current from the cell is greater «than 20 mA» $\checkmark$ because some of the current must flow through section SQ of the potentiometer $\checkmark$ overall power greater «than in part (b)» $\checkmark$ ALTERNATIVE 2 total/overall resistance decreases $\checkmark$ because SQ and X are in parallel $\checkmark$ overall power greater «than in part (b)» $\checkmark$	Allow the reverse argument 3

17 – (PHYSI/21_HL_Summer_2021_Q3) – Thermal Physics, Electricity & Magnetism



a	i	$E_k = \frac{3}{2} (1.38 \times 10^{-23})(373) = 7.7 \times 10^{-21} \text{ J} \checkmark$ $v = \sqrt{\frac{3 \cdot 1.38 \cdot 10^{-23} \cdot 6.02 \cdot 10^{23} \cdot 373}{0.018}} = 720 \text{ m s}^{-1} \checkmark$		2
a	ii	particles can be considered points «without dimensions» ✓ no intermolecular forces/no forces between particles «except during collisions» ✓ the volume of a particle is negligible compared to volume of gas ✓ collisions between particles are elastic ✓ time between particle collisions are greater than time of collision ✓ no intermolecular PE/no PE between particles ✓	Accept reference to atoms/molecules for "particle"	1 max
b	i	$mL = Pt$ so $L = \frac{1600 \cdot 200}{0.14} = 2.3 \times 10^6 \text{ J kg}^{-1} \checkmark$ $\text{J kg}^{-1} \checkmark$		2
b	ii	«all» of the energy added is used to increase the «intermolecular» potential energy of the particles/break «intermolecular» bonds/OWTTE ✓	Accept reference to atoms/molecules for "particle"	1
c		use of $mc\Delta T$ ✓ $0.86 \cdot 4200 \cdot (100 - T) = 0.3 \cdot 1800 \cdot (T - 10) \checkmark$ $T_{\text{eq}} = 85.69^\circ\text{C} \approx 86^\circ\text{C} \checkmark$	Accept T_{eq} in Kelvin (359 K).	3
d	i	$P = \frac{V^2}{R}$ so $\frac{220^2}{1600}$ so $R = 30.25 \text{ } \Omega \checkmark$	Must see either the substituted values OR a value for R to at least three s.f.	1
d	ii	use of parallel resistors addition so $R_{\text{eq}} = 15 \text{ } \Omega \checkmark$ $P = 3200 \text{ W} \checkmark$		2

18 – (PHYSI/22_HL_Summer_2021_Q3) – Electricity & Magnetism

a		identifies units of ϵ as $\text{C m}^{-2} \checkmark$ $\frac{\text{C}}{\text{m}^2} \cdot \frac{\text{Nm}^2}{\text{C}^2}$ seen and reduced to $\text{N C}^{-1} \checkmark$	Accept any analysis (eg dimensional) that yields answer correctly	2
b	i	horizontal force F on ball = $T \sin 30 \checkmark$ $T = \frac{mg}{\cos 30} \checkmark$ $F = mg \tan 30 = 0.025 \times 9.8 \times \tan 30 = 0.14 \text{ N} \checkmark$	Allow $g = 10 \text{ N kg}^{-1}$ Award [3] marks for a bald correct answer. Award [1max] for an answer of zero, interpreting that the horizontal force refers to the horizontal component of the net force.	3
b	ii	$E = \frac{0.14}{1.2 \times 10^{-5}} = 1.2 \times 10^4 \checkmark$ $\sigma = \frac{2 \times 8.85 \times 10^{-12} \times 0.14}{1.2 \times 10^{-5}} = 2.1 \times 10^{-6} \text{ C m}^{-2} \checkmark$	Allow ECF from the calculated F in (b)(i) Award [2] for a bald correct answer.	2
c		horizontal/repulsive force and vertical force/pull of gravity act on the ball ✓ so ball has constant acceleration/constant net force ✓ motion is in a straight line ✓ at 30° to vertical away from wall/along original line of thread ✓		3 max
d	i	$\frac{Q}{0.22^2} = \frac{1.2 \times 10^{-6}}{0.18^2} \checkmark$ «+» $1.8 \times 10^{-6} \text{ C} \checkmark$ 2sf ✓	Do not award MP2 if charge is negative Any answer given to 2 sig figs scores MP3	3

d	ii	work must be done to move a «positive» charge from infinity to P «as both charges are positive» OR reference to both potentials positive and added OR identifies field as gradient of potential and with zero value ✓ therefore, point P is at a positive / non-zero potential ✓	Award [0] for baid answer that P has non-zero potential	2
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19 - (PHYSI/22_HL_Summer_2021_Q5) - Electricity & Magnetism

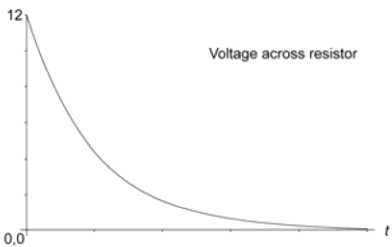
a		energy is not propagated by standing waves ✓ amplitude constant for travelling waves OR amplitude varies with position for standing waves OR standing waves have nodes / antinodes ✓ phase varies with position for travelling waves OR phase constant inter-node for standing waves ✓ travelling waves can have any wavelength OR standing waves have discrete wavelengths ✓	OWTTE	2 max
b	i	«sound» wave «travels down tube and» is reflected ✓ incident and reflected wave superpose/combine/interfere ✓	OWTTE Do not award MP1 if the reflection is quoted at the walls/container	2
b	ii	nodes shown at water surface AND $\frac{2}{3}$ way up tube (by eye) ✓	Accept drawing of displacement diagram for correct harmonic without nodes specifically identified. Award [0] if waveform is shown below the water surface	1
b	iii	$\lambda = 0.74 \text{ «m»} \checkmark$ $f = \frac{c}{\lambda} = \frac{320}{0.74} = 430 \text{ «Hz»} \checkmark$	Allow ECF from MP1	2

20 – (PHYSI/22_HL_Summer_2021_Q6) – Electricity & Magnetism, Energy Production



a	there is a potential difference across the internal resistance OR there is energy/power dissipated in the internal resistance ✓ when there is current «in the cell»/as charge flows «through the cell» ✓	Allow full credit for answer based on $V = \mathcal{E} - Ir$	2
b	ALTERNATIVE 1 pd dropped across cell = 6.5 «V» ✓ internal resistance = $\frac{6.5}{0.9}$ ✓ 7.2 «Ω» ✓ ALTERNATIVE 2 $\mathcal{E} = I(R + r)$ so $\mathcal{E} = V + Ir$ ✓ 21.0 = 14.5 + 0.9 × r ✓ 7.2 «Ω» ✓	Alternative solutions are possible Award [3] marks for a bald correct answer	3
c	power arriving at cell = 680 × 0.35 × 0.45 = «107 W» ✓ power in external circuit = 14.5 × 0.9 = «13.1 W» ✓ efficiency = 0.12 OR 12 % ✓	Award [3] marks for a bald correct answer Allow ECF for MP3	3
d	«energy from Sun/photovoltaic cells» is renewable OR non-renewable are running out ✓ non-polluting/clean ✓ no greenhouse gases OR does not contribute to global warming/climate change ✓	OWTTE Do not allow economic aspects (e.g. free energy)	2 max

21 – (PHYSI/20_HL_Winter_2021_Q3) – Electricity & Magnetism

a	i	«electric field at P from one charge is $\frac{kQ}{r^2} \Rightarrow \frac{8.99 \cdot 10^3 \cdot 44 \cdot 10^{-6}}{0.48^2}$ OR 1.7168 · 10 ⁶ «NC ⁻¹ » ✓ «net field is » 2 · 1.7168 · 10 ⁶ · cos30° = 2.97 · 10 ⁶ «NC ⁻¹ » ✓		2
a	ii	directed vertically up «on plane of the page» ✓	Allow an arrow pointing up on the diagram	1
b	i	force «on q» is proportional to the displacement ✓ and opposite to the displacement / directed towards equilibrium ✓		2
b	ii	«a $\frac{F}{m}$ » «v ² x $\frac{115x}{0.25}$ ✓ T « $\frac{2\pi}{T}$ » «0.29 «s» ✓	Award [2] marks for a bald correct answer. Allow ECF for MP2	2
c	i	decreasing from 12 ✓ correct shape as shown ✓ 	Do not penalize if the graph does not touch the t axis.	2
c	ii	$\frac{1}{2} = e^{-\frac{5.0}{20 \cdot 10^{-6}}}$ ✓ C = 3.6 × 10 ⁻⁷ «F» ✓	Award [2] for a bald correct answer.	2

22 – (PHYSI/20_HL_Winter_2021_Q7) – Electricity & Magnetism

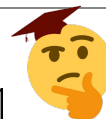


a		$Q = \frac{VR}{k} = \frac{3.4 \cdot 10^7 \cdot 0.48}{8.99 \cdot 10^9}$ OR $Q = 18.2 \text{ «}\mu\text{C»} \checkmark$		1
b	i	electrons leave the small sphere «making it positively charged» ✓		1
b	ii	$k \frac{q_1}{48} - k \frac{q_2}{24} > q_2 \cdot 2q \checkmark$ $q_1 \cdot q_2 = 18 \checkmark$ so $q_1 = 12 \text{ «}\mu\text{C»}, q_2 = 6.0 \text{ «}\mu\text{C»} \checkmark$	Award [3] marks for a bald correct answer.	3

23 – (PHYSI/21_HL_Summer_2022_Q4) – Electricity & Magnetism

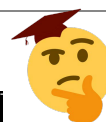
a		ALTERNATIVE 1 attempt to use potential divider equation or similar method ✓ $«6.0 \times \frac{40}{(40 + 60)}» = 2.4 \text{ «V»} \checkmark$ ALTERNATIVE 2 «current = $\frac{6}{60 - 40}$ » = 0.06 «A» ✓ $40 \times 0.06 = 2.4 \text{ «V»} \checkmark$		2
b		ALTERNATIVE 1 Pd across Q = 2.4 V so $I = 0.15 \text{ «A»} \checkmark$ and pd across S is $6.0 - 2.4 = 3.6 \text{ «V»} \checkmark$ $R = \frac{V}{I} = \frac{3.6}{0.15} = 24 \text{ «}\Omega\text{»} \checkmark$ ALTERNATIVE 2 pd at PR junction = pd at QS junction ✓ so $\frac{S}{Q} = \frac{R}{P}$ OR $S = \frac{16 \times 60}{40} \checkmark$ $24 \text{ «}\Omega\text{»} \checkmark$ ALTERNATIVE 3 $I = \frac{40 \times 0.06}{16} = 0.15 \text{ «A»} \checkmark$ $6.0 = (16 + S)(0.15)$ OR $2.4 = (6)(\frac{16}{S + 16}) \checkmark$ $R = 24 \text{ «}\Omega\text{»} \checkmark$	Allow ECF for MP3 from incorrect MP1 or MP2	3
c	i	recognition that $4L$ leads to $4R$ / « $\frac{4L}{A}$ » = $4R \checkmark$ «because the volume of S is constant new area is» $\frac{A}{4} \checkmark$ $16 \times 24 = 384 \text{ «}\Omega\text{»} \checkmark$		3
c	ii	«total» power has decreased ✓ Because current in the branch has decreased «and $P = I^2 R$ » OR Because resistance has increased in branch «and $P = \frac{V^2}{R}$ » ✓	Allow opposite argument as ECF from (c)(i) (if candidate deduces a lower resistance). Allow «power doesn't change» if candidate has no change of resistance from (b) to (c)(i).	2

24 – (PHYSI/22_HL_Summer_2022_Q4) – Electricity & Magnetism



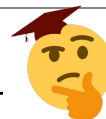
a		« conservation of » charge ✓ « conservation of » energy ✓	Allow [1] max if they explicitly refer to Kirchhoff's laws linking them to the conservation laws incorrectly.	2
b	i	12 V ✓		1
b	ii	$I = 2.0 \text{ A}$ OR $12 = I(r+4)$ OR $4 = Ir$ OR $8 = 4I$ ✓ «Correct working to get » $r = 2.0 \text{ }\Omega$ » ✓	Allow any valid method. Allow ECF from (b)(i)	2
c	i	Loop equation showing EITHER correct voltages, i.e., $10 - 4$ on one side or both emf's positive on different sides of the equation OR correct resistances, i.e. $I(1 + 2)$ ✓ $10 - 4 = I(1 + 2)$ OR $I = 2.0 \text{ A}$ seen ✓ $V = 8.0 \text{ V}$ ✓	Allow any valid method	3
c	ii	Charge is being driven through the 4.0 V cell OR it is being (re-)charged ✓		1
d	i	is generated from primary/other sources ✓		1
d	ii	«a fuel » that can be replenished/replaced within a reasonable time span OR «a fuel » that can be replaced faster than the rate at which it is consumed OR renewables are limitless/never run out OR «a fuel » produced from renewable sources OR gives an example of a renewable (biofuel, hydrogen, wood, wind, solar, tidal, hydro etc...) ✓	OWTTE	1
e	i	ALTERNATIVE 1 «energy output of the panel =» VIt OR $6 \times 5 \times 0.25 \times 3600$ OR 27000 J ✓ «available power =» $380 \times 0.4 \times 0.15 \times 0.18$ OR 4.1 W ✓ $t = \frac{27000}{4.1} = 6600 \text{ s}$ ✓ ALTERNATIVE 2 «energy needed from Sun =» $\frac{VIt}{\text{eff}}$ OR $\frac{6 \times 5 \times 0.25 \times 3600}{0.18}$ OR 150000 J ✓ « incident power =» $380 \times 0.4 \times 0.15$ OR 22.8 W ✓ $t = \frac{150000}{22.8} = 6600 \text{ s}$ ✓	Allow ECF for MP3 Accept final answer in minutes (110) or hours (1.8).	3
e	ii	coherent reason ✓ e.g., to improve efficiency, is non-polluting, is renewable, does not produce greenhouse gases, reduce use of fossil fuels,	Do not allow economic reasons	1

25 – (PHYSI/20_HL_Winter_2022_Q5) – Electricity & Magnetism



a		infinite resistance <i>OR</i> no current is flowing through it ✓		1
b	i	$\frac{1.47}{50.0} = 29.4 \text{ «mA»} \checkmark$		1
b	ii	$29.4(50.0 \cdot r) = 139(10.0 \cdot r) \checkmark$ attempt to solve for r , e.g. $29.4 \cdot 50.0 = 139 \cdot 10.0 \quad r(139 - 29.4)$ <i>OR</i> $0.73 \text{ «}\Omega\text{»} \checkmark$	<i>Do not allow working backwards from 0.7Ω.</i>	2
b	iii	$139 \cdot 10^{-5}(10.0 - 0.73)$ <i>OR</i> $29.4 \cdot 10^{-3}(50.0 + 0.73) \checkmark$ $1.49 \text{ «V»} \checkmark$	<i>Watch for ECF from 5(b)(i)</i>	2
c	i	charge/carriers are moving in a magnetic field ✓ there is a magnetic force on them / quote $F = qvB$ <i>OR</i> this creates a magnetic field that interacts with the external magnetic field ✓	<i>Accept electrons</i> <i>For MP2, the force must be identified as acting on charge / carriers</i>	2
c	ii	into the plane «of the paper» ✓		1

1 - (PHYSI/22_HL_Summer_2017_Q8) - Circular Motion & Gravitation



a		potential is defined to be zero at infinity ✓ so a positive amount of work needs to be supplied for a mass to reach infinity ✓
b	i	$V_S = -\frac{GM}{r}$ so $r \times V_S \llcorner -GM \llcorner = \text{constant because } G \text{ and } M \text{ are constants} \checkmark$
b	ii	$GM = 1.33 \times 10^{20} \llcorner \text{J m kg}^{-1} \llcorner \checkmark$ $\text{GPE at Earth orbit} \llcorner = -\frac{1.33 \times 10^{20} \times 6.0 \times 10^{24}}{1.5 \times 10^{11}} \llcorner = \llcorner - \llcorner 5.3 \times 10^{33} \llcorner \text{J} \llcorner \checkmark$
b	iii	ALTERNATIVE 1 work leading to statement that kinetic energy $= \frac{GMm}{2r}$, AND kinetic energy evaluated to be $\llcorner + \llcorner 2.7 \times 10^{33} \llcorner \text{J} \llcorner \checkmark$ energy $\llcorner = \text{PE} + \text{KE} = \text{answer to (b)(ii)} + 2.7 \times 10^{33} \llcorner = \llcorner - \llcorner 2.7 \times 10^{33} \llcorner \text{J} \llcorner \checkmark$ ALTERNATIVE 2 statement that kinetic energy is $= -\frac{1}{2}$ gravitational potential energy in orbit ✓ so energy $\llcorner = \frac{\text{answer to (b)(ii)}}{2} \llcorner = \llcorner - \llcorner 2.7 \times 10^{33} \llcorner \text{J} \llcorner \checkmark$
b	iv	$\llcorner \text{KE will initially decrease so} \llcorner \text{ total energy decreases}$ OR $\llcorner \text{KE will initially decrease so} \llcorner \text{ total energy becomes more negative} \checkmark$ Earth moves closer to Sun ✓ new orbit with greater speed $\llcorner \text{but lower total energy} \llcorner \checkmark$ changes ellipticity of orbit ✓



c		centripetal force is required ✓ and is provided by gravitational force between Earth and Sun ✓
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2 - (PHYSI/20_HL_Winter_2017_Q2) - Circular Motion & Gravitation, Oscillations & Waves, Fields (ahl)

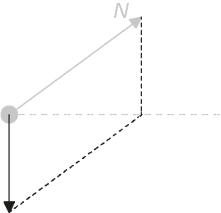
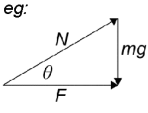
a		$v = \sqrt{\frac{Gm_E}{r}} = \sqrt{\frac{6.67 \cdot 10^{-11} \cdot 6.0 \cdot 10^{24}}{6600 \cdot 10^3}} \checkmark$ $7800 \text{ «ms}^{-1}\text{»} \checkmark$	Full substitution required Must see 2 : significant figures.
b	i	Y has smaller orbit/orbital speed is greater so time period is less ✓	Allow answer from appropriate equation Allow converse argument for X
b	ii	to stop Y from getting ahead ✓ to remain stationary with respect to X ✓ otherwise will add tension to cable/damage satellite/pull X out of its orbit ✓	
c		cable is a conductor and contains electrons ✓ electrons/charges experience a force when moving in a magnetic field ✓ use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive» ✓ Alternative 2 cable is a conductor ✓ so current will flow by induction flow when it moves through a B field ✓ use of a suitable hand rule to show current to right so «X becomes positive» ✓	Marks should be awarded from either one alternative or the other. Do not allow discussion of positive charges moving towards X
d		electrons would build up at satellite Y/positive charge at X ✓ preventing further charge flow ✓ by electrostatic repulsion ✓ unless a complete circuit exists ✓	
e		$\epsilon = Blv = 31 \cdot 10^{-6} \cdot 7790 \cdot 15000 \checkmark$ $3600 \text{ «V»} \checkmark$	Allow 3700 «V» from $v = 8000 \text{ ms}^{-1}$.
f	i	use of $k = \frac{4\pi^2 m}{T^2} = \frac{4 \cdot \pi^2 \cdot 350}{5.2^2} \checkmark$ 510 ✓ N m⁻¹ or kg s⁻² ✓	Allow MP1 and MP2 for a bald correct answer Allow 500 Allow N/m etc
f	ii	E_p in the cable/system transfers to E_k of Y ✓ and back again twice in each cycle ✓	Exclusive use of gravitational potential energy negates MP1

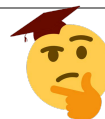
3 - (PHYSI/21_HL_Summer_2018_Q5) - Electricity & Magnetism, Circular Motion & Gravitation

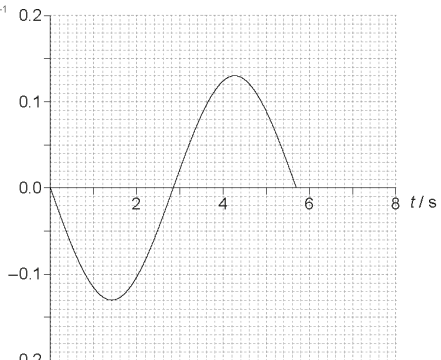


a		out of the page plane / $\odot$ ✓	Do not accept just "up" or "outwards".	1
b		$1.60 \cdot 10^{-18} \cdot 6.8 \cdot 10^5 \cdot 8.5 \cdot 9.2 \cdot 10^{-13} \text{ «N»}$ ✓		1
c	i	the magnetic force does not do work on the electron hence does not change the electron's kinetic energy OR the magnetic force/acceleration is at right angles to velocity ✓		1
c	ii	the velocity of the electron is at right angles to the magnetic field ✓ (therefore) there is a centripetal acceleration / force acting on the charge ✓	OWTTE	2

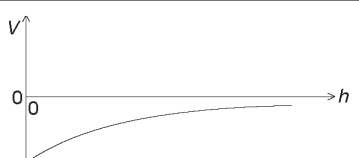
4 - (PHYSI/22_HL_Summer_2018_Q1) - Mechanics, Circular Motion & Gravitation

a	i	towards the centre «of the circle» / horizontally to the right ✓	Do not accept towards the centre of the bowl	1
a	ii	downward vertical arrow of any length ✓ arrow of correct length ✓	Judge the length of the vertical arrow by eye. The construction lines are not required. A label is not required eg: 	2
a	iii	ALTERNATIVE 1 $F = N \cos \theta$ ✓ $mg = N \sin \theta$ ✓ dividing/substituting to get result ✓ ALTERNATIVE 2 right angle triangle drawn with F , N and W/mg labelled ✓ angle correctly labelled and arrows on forces in correct directions ✓ correct use of trigonometry leading to the required relationship ✓	eg:  $\tan \theta = \frac{O}{A} = \frac{mg}{F}$ $F = \frac{mg}{\tan \theta}$	3
b		$\frac{mg}{\tan \theta} = m \frac{v^2}{r}$ ✓ $r = R \cos \theta$ ✓ $v = \sqrt{\frac{gR \cos^2 \theta}{\sin \theta}} = \sqrt{\frac{gR \cos \theta}{\tan \theta}} = \sqrt{\frac{9.81 \cdot 8.0 \cos 22}{\tan 22}}$ ✓ $v = 13.4 / 13 \text{ «ms}^{-1}\text{»}$ ✓	Award [4] for a bald correct answer Award [3] for an answer of $13.9/14 \text{ «ms}^{-1}\text{»}$. MP2 omitted	4
c		there is no force to balance the weight/N is horizontal ✓ so no / it is not possible ✓	Must see correct justification to award MP2	2



d	i	the «restoring» force/acceleration is proportional to displacement ✓	<i>Direction is not required</i>	1
d	ii	$\omega = \sqrt{\frac{g}{R}} = \sqrt{\frac{9.81}{8.0}} = 1.107 \text{ s}^{-1}$ ✓ $T = \frac{2\pi}{\omega} = \frac{2\pi}{1.107} = 5.7 \text{ s}$ ✓	Allow use of $g = 9.8$ or 10 Award [0] for a substitution into $T = 2\pi \sqrt{\frac{l}{g}}$	2
d	iii	sine graph ✓ correct amplitude «0.13 ms ⁻¹ » ✓ correct period and only 1 period shown ✓	Accept $\pm$ sine for shape of the graph. Accept 5.7 s or 6.0 s for the correct period. Amplitude should be correct to $\pm \frac{1}{2}$ square for MP2 eg: $v / \text{m s}^{-1}$ 	3
e		speed before collision $v = \sqrt{2gR} = 12.5 \text{ ms}^{-1}$ ✓ «from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed « $v_c = \frac{12.5}{2} = 6.25 \text{ ms}^{-1}$ » ✓ $h = \frac{v_c^2}{2g} = \frac{6.25^2}{2 \times 9.81} = 2.0 \text{ m}$ ✓	Allow 12.5 from incorrect use of kinematics equations Award [3] for a bald correct answer Award [0] for $mg(8) = 2mgh$ leading to $h = 4 \text{ m}$ if done in one step. Allow ECF from MP1 Allow ECF from MP2	3

5 - (PHYSI/22_HL_Summer_2018_Q6) - Circular Motion & Gravitation, Fields (ahl)

a	i	the «gravitational» force per unit mass exerted on a point/small/test mass ✓		1
a	ii	at height h potential is $V = -\frac{GM}{(R+h)}$ ✓ field is $g = \frac{GM}{(R+h)^2}$ ✓ «dividing gives answer»	Do not allow an answer that starts with $g = -\frac{\Delta V}{\Delta r}$ and then cancels the deltas and substitutes $R+h$	2
a	iii	correct shape and sign ✓ non-zero negative vertical intercept ✓	eg: V 	2
b		$V = -(2.2 \times (3.1 \times 10^6 + 2.4 \times 10^7)) = -6.0 \times 10^7 \text{ J kg}^{-1}$ ✓	Unit is essential Allow eg MJ kg^{-1} if power of 10 is correct Allow other correct SI units eg $\text{m}^2 \text{s}^{-2}$, Nm kg^{-1}	1

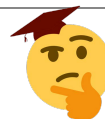
c	total energy at P = 0 / KE gained = GPE lost ✓ $\frac{1}{2}mv^2 = mV - 0 \Rightarrow v = \sqrt{2V}$ ✓ $v = \sqrt{2 \cdot 6.0 \cdot 10^7} \approx 1.1 \cdot 10^4 \text{ ms}^{-1}$ ✓	Award [3] for a bald correct answer ignore negative sign errors in the workings Allow ECF from 6(b)	3
d	ALTERNATIVE 1 force on asteroid is $6.2 \cdot 10^{12} \cdot 2.2 \approx 1.4 \cdot 10^{13} \text{ N}$ ✓ «by Newton's third law» this is also the force on the planet ✓ ALTERNATIVE 2 mass of planet = $2.4 \times 10^{26} \text{ kg}$ «from $V = \frac{GM}{(R+h)}$ » ✓ force on planet = $\frac{GMm}{(R+h)^2} \approx 1.4 \cdot 10^{13} \text{ N}$ ✓	MP2 must be explicit	2



6 - (PHYSI/20_HL_Winter_2018_Q8) - Circular Motion & Gravitation

a	i	force per unit mass ✓ acting on a small/test/point mass «placed at the point in the field» ✓		2
a	ii	Mars is spherical/a sphere «and of uniform density so behaves as a point mass» ✓ satellite has a much smaller mass/diameter/size than Mars «so approximates to a point mass» ✓		2
b	i	$\frac{mv^2}{r} = \frac{GMm}{r^2}$ hence $v = \sqrt{\frac{GM}{R}}$. Also $v = \frac{2\pi R}{T}$ OR $m\omega^2 r = \frac{GMm}{r^2}$ hence $\omega^2 = \frac{GM}{R^3}$ ✓ uses either of the above to get $T^2 = \frac{4\pi^2}{GM} R^3$ OR uses $k = \frac{4\pi^2}{GM}$ ✓ $k = 9.2 \cdot 10^{-13} / 9.3 \cdot 10^{-13}$ ✓	Unit not required	3

b	ii	$R^3 = \frac{T^2}{k} = \frac{(8.9 \times 10^4)^2}{9.25 \times 10^{-13}} \quad R = 2.04 \times 10^7 \text{ «m» } \checkmark$ $v = \omega r = \frac{2\pi \times 2.04 \times 10^7}{89000} = 1.4 \times 10^3 \text{ «ms}^{-1}\text{»}$ OR $v = \sqrt{\frac{GM}{R}} = \sqrt{\frac{6.67 \times 10^{-11} \times 6.4 \times 10^{23}}{2.04 \times 10^7}} = 1.4 \times 10^3 \text{ «ms}^{-1}\text{» } \checkmark$	2
c	i	use of $I \propto \frac{1}{r^2}$ « $1.36 \times 10^3 \times \frac{1}{1.5^2}$ » $\checkmark$ 604 «W m ⁻² » $\checkmark$	2
c	ii	use of $\frac{600}{4}$ for mean intensity $\checkmark$ temperature/K = « $\sqrt{\frac{600}{4 \times 5.67 \times 10^{-8}}}$ » = 230 $\checkmark$	2
c	iii	reference to greenhouse gas/effect $\checkmark$ recognize the link between molecular density/concentration and pressure $\checkmark$ low pressure means too few molecules (to produce a significant heating effect) $\checkmark$ OR low pressure means too little radiation re-radiated back to Mars $\checkmark$	3



7 - (PHYSI/21_HL_Summer_2019_Q5) - Circular Motion & Gravitation

a	i	gravitational attraction/force/field «of the planet/Mars» $\checkmark$	Do not accept "gravity".	1
a	ii	the force/field and the velocity/displacement are at 90° to each other OR there is no change in GPE of the moon/Phobos $\checkmark$		1
b	i	ALTERNATE 1 «using fundamental equations» use of Universal gravitational force/acceleration/orbital velocity equations $\checkmark$ equating to centripetal force or acceleration. $\checkmark$ rearranges to get $k = \frac{G}{4\pi^2}$ $\checkmark$ ALTERNATE 2 «starting with $\frac{R^3}{T^2} = kM$ » substitution of proper equation for T from orbital motion equations $\checkmark$ substitution of proper equation for M OR R from orbital motion equations $\checkmark$ rearranges to get $k = \frac{G}{4\pi^2}$ $\checkmark$		3
b	ii	$m_{\text{Mars}} = \left(\frac{R_{\text{Mars}}^3}{R_{\text{Earth}}^3} \right)^{\frac{1}{2}} \left(\frac{T_{\text{Earth}}}{T_{\text{Mars}}} \right)^{\frac{2}{3}} m_{\text{Earth}}$ or other consistent re-arrangement $\checkmark$ 6.4 × 10 ²³ «kg» $\checkmark$		2
c		read off separation at maximum potential 0.9 $\checkmark$ equating of gravitational field strength of earth and moon at that location OR $\frac{M_E}{0.9^2} = \frac{M_M}{0.1^2}$ $\checkmark$ 7.4 × 10 ²² «kg» $\checkmark$	Allow ECF from MP1	3

8 - (PHYSI/22_HL_Summer_2019_Q5) - Electricity & Magnetism, Circular Motion & Gravitation



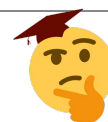
a	i	F towards centre ✓		1
a	ii	v tangent to circle and in the direction shown in the diagram ✓		1
b	i	$qvB = \frac{mv^2}{R} \Rightarrow R = \frac{mv}{qB} = \frac{1.673 \times 10^{-27} \times 2.16 \times 10^6}{1.60 \times 10^{-19} \times 0.042} \checkmark$ $R = 0.538 \text{ «m»} \checkmark$ $R = 0.54 \text{ «m»} \checkmark$		3
b	ii	$T = \frac{2\pi R}{v} = \frac{2\pi \times 0.54}{2.16 \times 10^6} \checkmark$ $T = 1.6 \times 10^{-6} \text{ «s»} \checkmark$		2

9 - (PHYSI/20_HL_Winter_2019_Q4) - Electricity & Magnetism, Circular Motion & Gravitation

a		magnetic force is to the left «at the instant shown» OR explains a rule to determine the direction of the magnetic force ✓ force is perpendicular to velocity/«direction of» motion OR force is constant in magnitude ✓ force is centripetal/towards the centre ✓	Accept reference to acceleration instead of force.	2 max
b	i	$qvB = \frac{mv^2}{R} \checkmark$ $R = \frac{1.67 \times 10^{-27} \times 2.0 \times 10^6}{1.6 \times 10^{-19} \times 0.35} \text{ OR } 0.060 \text{ «m»}$	Award MP2 for full replacement or correct answer to at least 2 significant figures	2
b	ii	$T = \frac{2\pi R}{v} \checkmark$ $T = \frac{2\pi \times 0.06}{2.0 \times 10^6} = 1.9 \times 10^{-7} \text{ «s»} \checkmark$	Award [2] for bald correct answer	2
c		ALTERNATIVE 1 work done by force is change in kinetic energy ✓ work done is zero/force perpendicular to velocity ✓ ALTERNATIVE 2 proton moves at constant speed ✓ kinetic energy depends on speed ✓	Award [2] for a reference to work done is zero hence E_k remains constant Accept mention of speed or velocity indistinctly in MP2	2

10 - (PHYSI/20_HL_Winter_2020_Q2) - Circular Motion & Gravitation

a		arrow downwards labelled weight/ W/mg and arrow upwards labelled friction/ F ✓ arrow horizontally to the left labelled «normal» reaction/ N ✓ 	Ignore point of application of the forces but do not allow arrows that do not touch the object. Do not allow horizontal force to be labelled 'centripetal' or R .	2
b		See $F = \mu N$ AND $N = mR\omega^2$ ✓ «substituting for N » $\mu m\omega^2 R = mg$ ✓		2



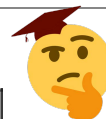
c	ALTERNATIVE 1 minimum required angular velocity $\omega = \sqrt{\frac{9.81}{0.40 \cdot 3.5}} = 2.6 \text{ rad s}^{-1}$ ✓ actual angular velocity $\omega = \frac{2\pi}{60} = 2.9 \text{ rad s}^{-1}$ ✓ actual angular velocity is greater than the minimum, so the person does not slide ✓ ALTERNATIVE 2 minimum friction force $= mg = 1 \text{ m}$ ✓ actual friction force $= \mu m R \omega^2 = 0.40 \text{ m} \cdot 3.5 \left(\frac{2\pi}{60} \right)^2 = 12.0 \text{ m}$ ✓ actual friction force is greater than the minimum frictional force so the person does not slide ✓	Allow 2.7 from $g = 10 \text{ ms}^{-2}$.
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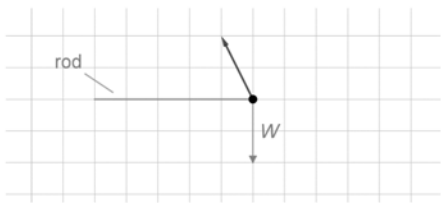
3

11 – (PHYSI/21_HL_Summer_2021_Q2) – Circular Motion & Gravitation, Fields (ahl)

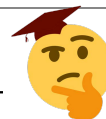
a	«circular motion» involves a changing velocity ✓ «Tangential velocity» is «always» perpendicular to centripetal force/acceleration ✓ there must be a force/acceleration towards centre/star ✓ without a centripetal force the planet will move in a straight line ✓		2 max
b	$F = \frac{(6.67 \times 10^{-11})(8 \times 10^{24})(3.2 \times 10^{24})}{(4.4 \times 10^{13})^2} = 8.8 \times 10^{23} \text{ N} \checkmark$		1
c	i $V_{\text{planet}} = \omega r = \frac{(6.67 \times 10^{-11})(8 \times 10^{24})}{9.1 \times 10^8} = 5.9 \times 10^3 \text{ J kg}^{-1} \checkmark$ $V_{\text{star}} = \omega r = \frac{(6.67 \times 10^{-11})(3.2 \times 10^{24})}{4.4 \times 10^{13}} = 4.9 \times 10^3 \text{ J kg}^{-1} \checkmark$ $V_{\text{planet}} - V_{\text{star}} = 4.9 \times 10^3 \text{ J kg}^{-1} \checkmark$	Must see substitutions and not just equations.	3
c	ii use of $v_{\text{esc}} = \sqrt{2V}$ ✓ $v = 9.91 \times 10^4 \text{ m s}^{-1} \checkmark$		2

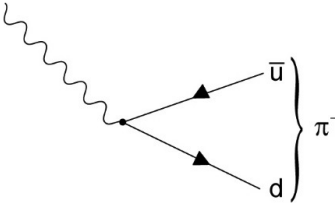
12 – (PHYSI/20_HL_Winter_2022_Q4) – Circular Motion & Gravitation



a	horizontal component of any length to the left ✓ vertical component two squares long upwards ✓ E.g. 	Ignore point of application. Award [1] max if arrowhead not present.	2
b	ALTERNATIVE 1 the net/centripetal force has constant magnitude ✓ the direction of the net/centripetal force constantly changes ✓ this is achieved by «vector-» adding weight and the force from the rod OR the force from the rod is «vector» difference of the centripetal force and weight ✓ ALTERNATIVE 2 at the top $F_{\text{rod}} = F_c - W$ ✓ at the bottom, $F_{\text{rod}} = F_c + W$ ✓ net F/F_c is constant so the force from the rod is different «hence is changing» ✓	Accept reference to centripetal or net force indistinctly. Allow reference to centripetal acceleration.	3

1 - (PHYSI/21_HL_Summer_2017_Q5) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)

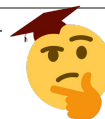


a		<i>Meson</i>: quark-antiquark pair ✓ <i>Baryon</i>: 3 quarks ✓
b	i	Alternative 1 strange quark changes «flavour» to an up quark ✓ changes in quarks/strangeness happen only by the weak interaction ✓ Alternative 2 Strangeness is not conserved in this decay «because the strange quark changes to an up quark» ✓ Strangeness is not conserved during the weak interaction ✓
	ii	arrows drawn in the direction shown ✓ 
	iii	W^- ✓
c		it lowers the cost to individual nations, as the costs are shared ✓ international co-operation leads to international understanding OR historical example of co-operation OR co-operation always allows science to proceed ✓ large quantities of data are produced that are more than one institution/research group can handle ✓ co-operation allows effective analysis\collaboration of able scientists ✓

2 - (PHYSI/20_HL_Winter_2017_Q3) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl), Measurements & Uncertainties

a	i	«electron» neutrino ✓ it has a lepton number of 1 «as lepton number is conserved» ✓ it has a charge of zero/is neutral «as charge is conserved» OR it has a baryon number of 0 «as baryon number is conserved» ✓	<i>Do not allow antineutrino</i> <i>Do not credit answers referring to energy</i>
a	ii	hadrons experience strong force OR leptons do not experience the strong force ✓ hadrons made of quarks/not fundamental OR leptons are not made of quarks/are fundamental ✓ hadrons decay «eventually» into protons OR leptons do not decay into protons ✓	<i>Accept leptons experience the weak force</i> <i>Allow "interaction" for "force"</i>

b	i	«high energy particles incident on» thin sample ✓ detect angle/position of deflected particles ✓ reference to interference/diffraction/minimum/maximum/numbers of particles ✓	Allow "foil" instead of thin
b	ii	$\lambda \propto \frac{1}{\sqrt{E}}$ OR $\lambda \propto \frac{1}{E}$ ✓ so high energy gives small λ ✓ to match the small nuclear size ✓ Alternative 2 $E = hf$ /energy is proportional to frequency ✓ frequency is inversely proportional to wavelength/ $c = f\lambda$ ✓ to match the small nuclear size ✓ Alternative 3 higher energy means closer approach to nucleus ✓ to overcome the repulsive force from the nucleus ✓ so greater precision in measurement of the size of the nucleus ✓	Accept inversely proportional Only allow marks awarded from one alternative
c		two analogous situations stated ✓ one element of the analogy equated to an element of physics ✓	eg: moving away from Earth is like climbing a hill where the contours correspond to the equipotentials Atoms in an ideal gas behave like pool balls The forces between them only act during collisions



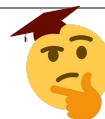
d	i	$R = 2.7 \times 10^{-15} \times 2^{\frac{1}{3}}$ ✓ $3.4 - 3.5 \times 10^{-15}$ «m» ✓	Allow use of the Fermi radius from the data booklet
d	ii	correctly plotted ✓	Allow ECF from (d)(i)
d	iii	single smooth curve passing through both points with decreasing gradient ✓ through origin ✓	

3 - (PHYSI/21_HL_Summer_2018_Q6) - Atomic, nuclear & Particle Physics



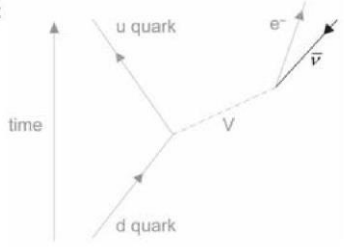
a		${}^{10}_4\text{Be} \rightarrow {}^{10}_5\text{B} + {}^0_{-1}\text{e} + {}^0_0\bar{\nu}_e$ antineutrino AND charge AND mass number of electron ${}^0_{-1}\text{e}$, $\bar{\nu}$ ✓ conservation of mass number AND charge ${}^{10}_5\text{B}$, ${}^{10}_4\text{Be}$ ✓	Do not accept $\bar{\nu}$. Accept $\bar{\nu}$ without subscript e.	2
b	i	correct shape <i>ie</i> increasing from 0 to about $0.80N_0$ ✓ crosses given line at $0.50N_0$ ✓ number of nuclei 		2
b	ii	ALTERNATIVE 1 fraction of Be $\frac{1}{8}$, 12.5%, or 0.125 ✓ therefore 3 half lives have elapsed ✓ $t_{1/2} = \frac{4.3 \cdot 10^6}{3} = 1.43 \cdot 10^6 \approx 1.4 \cdot 10^6 \text{ «y»} \checkmark$ ALTERNATIVE 2 fraction of Be $\frac{1}{8}$, 12.5%, or 0.125 ✓ $\frac{1}{8} = e^{-(4.3 \cdot 10^6) \lambda}$ leading to $\lambda = 4.836 \cdot 10^{-7} \text{ «y}^{-1}\text{»} \checkmark$ $\frac{\ln 2}{\lambda} = 1.43 \cdot 10^6 \text{ «y»} \checkmark$	Must see at least one extra sig fig in final answer.	3
b	iii	$\lambda = \frac{\ln 2}{1.4 \cdot 10^6} = 4.95 \cdot 10^{-7} \text{ «y}^{-1}\text{»} \checkmark$ rearranging of $A = \lambda N_0 e^{-\lambda t}$ to give $\lambda t = \ln \frac{8.0 \cdot 10^3 \cdot 365 \cdot 24 \cdot 60 \cdot 60}{4.95 \cdot 10^{-7} \cdot 7.6 \cdot 10^{11}} \approx 0.400 \checkmark$ $t = \frac{0.400}{4.95 \cdot 10^{-7}} = 8.1 \cdot 10^5 \text{ «y»} \checkmark$	Allow ECF from MP1	3

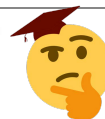
c	i	emission of (infrared) electromagnetic/infrared energy/waves/radiation. ✓		1
c	ii	the (peak) wavelength of emitted em waves depends on temperature of emitter/reference to Wein's Law ✓ so frequency/color depends on temperature ✓		2
c	iii	$\lambda = \frac{2.90 \cdot 10^{-3}}{253}$ ✓ $1.1 \cdot 10^{-5}$ «m» ✓	Allow ECF from MP1 (incorrect temperature).	2
c	iv	from the laboratory to the sample ✓ conduction – contact between ice and lab surface. OR convection – movement of air currents ✓	Must clearly see direction of energy transfer for MP1. Must see more than just words "conduction" or "convection" for MP2.	2
c	v	correct units for Intensity (allow W, Nms^{-1} OR Js^{-1} in numerator) ✓ rearrangement into proper SI units = $kg s^{-3}$ ✓	Allow ECF for MP2 if final answer is in fundamental units.	2



4 – (PHYSI/22_HL_Summer_2018_Q9) – Quantum & Nuclear Physics (ahl), Atomic,nuclear & Particle Physics

a		«most of» the mass of the atom is confined within a very small volume/nucleus ✓ «all» the positive charge is confined within a very small volume/nucleus ✓ electrons orbit the nucleus «in circular orbits» ✓		2 max
b		the electrons accelerate and so radiate energy ✓ they would therefore spiral into the nucleus/atoms would be unstable ✓ electrons have discrete/only certain energy levels ✓ the only orbits where electrons do not radiate are those that satisfy the Bohr condition « $mvr = n \frac{h}{2\pi}$ » ✓		3 max
c	i	$\frac{m_e v^2}{r} = \frac{ke^2}{r^2}$ OR KE = $\frac{1}{2}$ PE hence $\frac{1}{2} m_e v^2 = \frac{1}{2} \frac{ke^2}{r}$ ✓ «solving for v to get answer»	Answer given – look for correct working	1
c	ii	combining $v = \sqrt{\frac{ke^2}{m_e r}}$ with $m_e v r = \frac{h}{2\pi}$ using correct substitution ✓ «eg $m_e^2 \frac{ke^2}{m_e r} = \frac{h^2}{4\pi^2}$ » correct algebraic manipulation to gain the answer ✓	Answer given – look for correct working Do not allow a bald statement of the answer for MP2. Some further working eg cancellation of m or r must be shown	2
c	iii	« $r = \frac{(6.63 \cdot 10^{-34})^2}{4\pi^2 \cdot 8.99 \cdot 10^9 \cdot 9.11 \cdot 10^{-31} \cdot (1.6 \cdot 10^{-19})^2}$ » $r = 5.3 \cdot 10^{-11}$ «m» ✓		1
d	i	the energy released is $3.54 - 0.48 = 3.06$ «MeV» ✓ this is shared by the electron and the antineutrino ✓ so the electron's energy varies from 0 to 3.06 «MeV» ✓		3
d	ii	the palladium nucleus emits the photon when it decays into the ground state «from the excited state» ✓		1

d	iii	Photon energy $E = 0.48 \times 10^6 \times 1.6 \times 10^{-19} = 7.68 \times 10^{-14} \text{ J}$ ✓ $\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{7.68 \times 10^{-14}} = 2.6 \times 10^{-12} \text{ m}$ ✓	Award [2] for a bald correct answer Allow ECF from incorrect energy	2
e	i	line <u>with arrow</u> as shown labelled anti-neutrino/ $\bar{\nu}$ ✓ eg. 	Correct direction of the "arrow" is essential The line drawn must be "upwards" from the vertex in the time direction i.e. above the horizontal	1
e	ii	$V = W^-$ ✓		1



5 - (PHYSI/20_HL_Winter_2018_Q5) - Atomic, nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)

a	i	identifies $\lambda = 435 \text{ nm}$ ✓ $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4.35 \times 10^{-7}} = 4.6 \times 10^{-19} \text{ J}$ ✓		3
a	ii	-0.605 OR -0.870 OR -1.36 to -5.44 AND arrow pointing downwards ✓	Arrow MUST match calculation in (a)(i) Allow ECF from (a)(i)	1
a	iii	Difference in energy levels is equal to the energy of the photon ✓ Downward arrow as energy is lost by hydrogen/energy is given out in the photon/the electron falls from a higher energy level to a lower one ✓		2
b	i	$\frac{\lambda}{2.12} = \frac{656.20}{1813} \times 1813 \text{ nm}$ ✓ so spacing is $\frac{3.5 \times 10^{-3}}{1813} = 1.9 \times 10^{-6} \text{ m}$ ✓	Allow use of either wavelength or the mean value Must see at least 2 SF for a bald correct answer	2
b	ii	$2.41 \times 10^{-7} = 1.9 \times 10^{-6} \sin \theta_v$ seen OR $6.6 \times 10^{-7} = 1.9 \times 10^{-6} \sin \theta_r$ seen ✓ $\theta_v = 24 - 26^\circ$ ✓ OR $\theta_r = 19 - 20^\circ$ ✓ $\theta = 5 - 6^\circ$ ✓	For MP3 answer must follow from answers in MP2 For MP3 do not allow ECF from incorrect angles	3
b	iii	centre of pattern is white ✓ coloured fringes are formed ✓ blue/violet edge of order is closer to centre of pattern OR red edge of order is furthest from centre of pattern ✓ the greater the order the wider the pattern ✓ there are gaps between «first and second order» spectra ✓		3 max

6 – (PHYSI/20_HL_Winter_2018_Q6) – Atomic,nuclear & Particle Physics

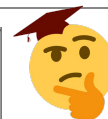


a	i	it is constant ✓		1
a	ii	$R = 1.20 \cdot 10^{-16} \cdot 31 = 3.8 \cdot 10^{-15} \text{ «m»} \checkmark$	Must see working and answer to at least 2SF	1
b	i	separation for interaction $5.3 \text{ or } 5.5 \text{ «fm»} \checkmark$		1
b	ii	energy required $\frac{15e^2}{4\pi\epsilon_0} = 5.3 \cdot 10^{-15} \checkmark$ $6.5 / 6.6 \cdot 10^{-13} \text{ OR } 6.3 \cdot 10^{-13} \text{ «J»} \checkmark$	Allow ecf from (b)(i)	2
c		«electron» antineutrino also emitted ✓ energy split between electron and «anti»neutrino ✓		2
d	i	probability of decay of a nucleus ✓ OR the fraction of the number of nuclei that decay in one/the next second OR per unit time ✓		2
d	ii	$1 \text{ week} = 6.05 \cdot 10^5 \text{ «s»} \checkmark$ $17 \cdot 24e^{-2.61 \cdot 10^{-10}} \checkmark$ $5.7 \cdot 10^{-7} \text{ «s}^{-1}\text{»} \checkmark$	Award [2 max] if answer is not in seconds If answer not in seconds and no unit quoted award [1 max] for correct substitution into equation (MP2)	3

7 – (PHYSI/21_HL_Summer_2019_Q2) – Atomic,nuclear & Particle Physics

a	i	read off between 17 and 19 «deg» ✓ correct use of $d = \frac{\lambda}{\sin(\theta)} = 7.8 \cdot 10^{-15} \text{ «m»} \checkmark$ so radius $= \frac{7.8}{2} \text{ «fm»} = 3.9 \text{ «fm»} \checkmark$	Award ecf for wrong angle in MP1. Answer for MP3 must show at least 2 sf.	3
a	ii	$R_{Tn} = R_{Sn} \left(\frac{A_{Tn}}{A_{Sn}}\right)^{1/3}$ or substitution ✓ $7.4 \text{ «fm»} \checkmark$		2
a	iii	electron wavelength shorter than alpha particles (thus increased resolution) OR electron is not subject to strong nuclear force ✓		1
a	iv	nuclear forces act ✓ nuclear recoil occurs ✓ significant penetration into nucleus / probing internal structure of individual nucleons ✓ incident particles are relativistic ✓		2 max

b	i	${}_{15}^{30}\text{P} \rightarrow ({}_{14}^{30}\text{Si}) \checkmark$ $+ {}_{+1}^0\text{e} + \nu_e \checkmark$		2
b	ii	correct change of either u to d $\checkmark$ W^+ shown $\checkmark$ correct arrow directions for positron and electron neutrino $\checkmark$		3
b	iii	quarks cannot be directly observed as free particles/must remain bound to other quarks/quarks cannot be isolated $\checkmark$ because energy given to nucleon creates other particles rather than freeing quarks/ <i>OWTTE</i> $\checkmark$		2
c		models need testing/new information may change models/new technology may bring new information/Models can be revised/ <i>OWTTE</i> $\checkmark$		1


8 – (PHYSI/22_HL_Summer_2019_Q6) – Atomic,nuclear & Particle Physics

a		proton / ${}^1_1\text{H}$ / p $\checkmark$	1
b	i	$\ll 3 \times 2.78 - 2 \times 2 \times 1.12 \gg$ See $3 \times 2.78 / 8.34$ OR $2 \times 2 \times 1.12 / 4.48 \checkmark$ $3.86 \ll \text{MeV} \gg \checkmark$	2
b	ii	the deuterium nuclei are positively charged/repel $\checkmark$ high KE/energy is required to overcome «Coulomb/electrostatic» repulsion /potential barrier OR high KE/energy is required to bring the nuclei within range of the strong nuclear force $\checkmark$ high temperatures are required to give high KEs/energies $\checkmark$	2 max
c	i	-1 / $-e \checkmark$	1
c	ii	$-3 \checkmark$	1

9 - (PHYSI/20_HL_Winter_2019_Q7) - Atomic,nuclear & Particle Physics



a		random: it cannot be predicted which nucleus will decay OR it cannot be predicted when a nucleus will decay ✓ spontaneous: the decay cannot be influenced/modified in any way ✓	OWTTE	2
b	i	234×7.6 OR 4×7.07 ✓ $BE_U \approx 234 \times 7.6 + 4 \times 7.07 - 4.27 \approx 1802 \text{ «MeV»}$ ✓ $\frac{BE_U}{A} \approx \frac{1802}{238} \approx 7.57 \text{ «MeV»}$ ✓	Allow ECF from MP2 Award [3] for bald correct answer Allow conversion to J. final answer is 1.2×10^{-12}	3
b	ii	states or applies conservation of momentum ✓ ratio is $\frac{E_{\alpha}}{E_{\text{in}}} = \frac{2m_{\alpha}}{m_{\alpha} + m_{\text{in}}} = \frac{234}{4} \approx 58.5$ ✓	Award [2] for bald correct answer	2

10 - (PHYSI/20_HL_Winter_2020_Q6) - Atomic,nuclear & Particle Physics, Energy Production

a	i	energy required to «completely» separate the nucleons OR energy released when a nucleus is formed from its constituent nucleons ✓	Allow protons AND neutrons.	1
a	ii	the values «in SI units» would be very small ✓		1
a	iii	$140 + 8.29 + 94 + 8.59 + 235 + 7.59$ OR 184 «MeV» ✓		1
b	i	see «energy» $180 \cdot 10^6 + 1.60 \cdot 10^{14}$ AND «mass» $235 + 1.66 \cdot 10^{27}$ ✓ $7.4 \cdot 10^{13} \text{ «J kg}^{-1}\text{»}$ ✓		2
b	ii	energy produced in one day $\frac{1.2 \cdot 10^{11} \cdot 24 \cdot 3600}{0.36} = 2.9 \cdot 10^{14} \text{ «J»}$ ✓ mass $= \frac{2.9 \cdot 10^{14}}{7.4 \cdot 10^{13}} = 3.9 \text{ «kg»}$ ✓		2
b	iii	«specific energy of uranium is much greater than that of coal, hence» more energy can be produced from the same mass of fuel / per kg OR less fuel can be used to create the same amount of energy ✓		1
c	i	39 ✓	Do not allow ${}_{39}^{92}\text{X}$ unless the proton number is indicated.	1
c	ii	75 «s» ✓		1
c	iii	ALTERNATIVE 1 10 min – 8 h. ✓ mass remaining $= 1.0 \cdot \left(\frac{1}{2}\right)^5 = 3.9 \cdot 10^{-2} \text{ «kg»}$ ✓ ALTERNATIVE 2 decay constant $= \frac{\ln 2}{75} \approx 9.24 \cdot 10^{-3} \text{ «s}^{-1}\text{»}$ ✓ mass remaining $= 1.0 \cdot e^{-9.24 \cdot 10^{-3} \cdot 800} = 3.9 \cdot 10^{-2} \text{ «kg»}$ ✓		2

11 - (PHYSI/20_HL_Winter_2020_Q10) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



a		$\lambda = \frac{6.63 \cdot 10^{-34} \cdot 3 \cdot 10^8}{1.60 \cdot 10^{-16} \cdot 4.2 \cdot 10^6}$ OR $2.96 \cdot 10^{-11}$ «m» ✓	Answer to at least 2 s.f. (i.e. 3.0)	1
b	i	«the shape of the graph suggests that» electrons undergo diffraction «with carbon nuclei» ✓ only waves diffract ✓		2
b	ii	$\sin \theta_n = \frac{2.96 \cdot 10^{-11}}{4.94 \cdot 10^{-10}}$ «-0.599» ✓ 37 «degrees» OR 0.64/0.65 «rad» ✓		2
b	iii	the de Broglie wavelength of electrons is «much» longer than the size of a nucleus ✓ hence electrons would not undergo diffraction OR no diffraction pattern would be observed ✓		2
c		volume of a nucleus proportional to $A^{\frac{1}{3}}$ - A AND mass proportional to A ✓ the ratio $\frac{\text{mass}}{\text{volume}}$ independent of A «hence density the same for all nuclei» ✓	Both needed for MP1	2

12 - (PHYSI/21_HL_Summer_2021_Q7) - Atomic,nuclear & Particle Physics

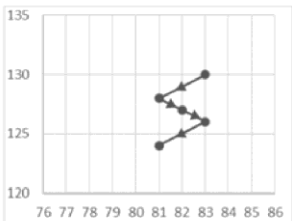
a		${}_{92}^{233}\text{U} \rightarrow {}_{90}^{209}\text{Th} + {}_2^4\text{He}$ ✓	Allow He for alpha.	1
b		udd → uud OR down quark changes to up quark ✓		1
c		measure «radio»activity/«radioactive» decay/A for either OR take measurements with a Geiger counter. ✓ for Uranium measure number/N of radioactive atoms/OWTTE ✓ for Thallium measure «rate of» change in activity over time. ✓ correct connection for either Uranium or Thallium to determine half life ✓		4
d	i	links temperature to kinetic energy/speed of particles ✓ energy required to overcome «Coulomb» electrostatic repulsion ✓		2
d	ii	«energy is released when» binding energy per nucleon increases		1
d	iii	any use of (value from graph) x (number of nucleons) ✓ «235 · 7.6 - (89 · 8.6 + 144 · 8.2) · » 160 «MeV» ✓		2

13 - (PHYSI/21_HL_Summer_2021_Q9) - Atomic,nuclear & Particle Physics

a		they express fundamental principles of nature ✓ allow to model situations ✓ allow to calculate unknown variables ✓ allow to predict possible outcomes ✓ allow to predict missing quantities/particles ✓ allow comparison of different system states ✓		1 max
b		three correct conservation laws listed ✓ at least one conservation law correctly demonstrated ✓ all three conservation laws correctly demonstrated ✓		3

14 - (PHYSI/22_HL_Summer_2021_Q4) - Atomic,nuclear & Particle Physics



a	i	$^{206}_{82}\text{Pb}$ ✓ $^0_{-1}\text{e}$ AND $^0_{+1}\text{e}$ ✓		2
a	ii	calculates $\lambda = \frac{\ln 2}{15 \cdot 10^3}$ «= 4.62 x 10 ⁻⁵ year ⁻¹ » ✓ calculates nuclei remaining = 0.50 x 10 ⁶ x 6.0 x 10 ²³ «= 3.0 x 10 ¹⁷ » ✓ activity = « $\lambda N = 1.4 \times 10^{10}$ nuclei per year» = 440 «nuclei per second» ✓	Accept conversion to seconds at any stage. Award [3] marks for a bald correct answer. Allow ECF from MP1 and MP2 Allow use of decay equation.	3
b		Reference to proton repulsion OR nucleon attraction ✓ strong force is short range OR electrostatic/electromagnetic force is long range ✓ more neutrons «than protons» needed «to hold nucleus together» ✓		2 max
c		 any α change correct ✓ any β change correct ✓ diagram fully correct ✓	Award [2] max for a correct diagram without arrows drawn. For MP1 accept a (-2, -2) line with direction indicated, drawn at any position in the graph. For MP2 accept a (1, -1) line with direction indicated, drawn at any position in the graph. Award [1] max for a correct diagram with all arrows in the opposite direction.	3

15 - (PHYSI/20_HL_Winter_2021_Q4) - Atomic,nuclear & Particle Physics

a	i	the energy needed to «completely» separate the nucleons of a nucleus OR the energy released when a nucleus is assembled from its constituent nucleons ✓	Accept reference to protons and neutrons.	1
a	ii	curve rising to a maximum between 50 and 100 ✓ curve continued and decreasing ✓	ignore starting point. ignore maximum at alpha particle	2
a	iii	At a point on the peak of their graph ✓		1
a	iv	beta minus «decay» ✓		1
b	i	correct mass numbers for uranium (234) and alpha (4) ✓ $234 \cdot 7600 \cdot 4 \cdot 7074 \cdot 238 \cdot 7568$ «MeV» ✓ energy released 5.51 «MeV» ✓	ignore any negative sign	3
b	ii	$\frac{KE}{KE_U} \gg \frac{2m_U}{2m_U} \gg \frac{m_U}{m_e}$ OR $\frac{m_U}{m_e}$ ✓ $\frac{234}{4} \gg 58.5$ ✓	Award [2] marks for a bald correct answer Accept $\frac{117}{2}$ for MP2.	2

c	i	number of nuclei present $\frac{33 \cdot 10^3}{238} \cdot 6.02 \cdot 10^{23} \approx 8.347 \cdot 10^{25} \checkmark$ initial activity is $\lambda N_0 = 2.5 \cdot 10^{10} \cdot 8.347 \cdot 10^{25} \approx 2.08 \cdot 10^{36} \text{ Bq} \checkmark$ power is $2.08 \cdot 10^{11} \cdot 5.51 \cdot 10^{-13} \cdot 1.6 \cdot 10^{-13} \approx 18 \text{ kW} \checkmark$	Allow: a final answer of 20 kW if 6 MeV used Allow: ECF from MP1 and MP2.	3
c	ii	available power after time t is $P_0 e^{-\lambda t} \checkmark$ $18e^{-2.5 \cdot 10^{10} \cdot 238 \cdot 3600} \approx 17.0 \text{ kW} \checkmark$	MP1 may be implicit. Allow: ECF from (c)(i) Allow: 17.4 kW from unrounded power from (c)(i) Allow: 18.8 kW from 6 MeV	2
d	i	stays the same $\checkmark$ as energy depends on the frequency of light $\checkmark$	Allow reference to wavelength for MP2 Award MP2 only to answers stating that KE decreases due to Doppler effect.	2
d	ii	decreases $\checkmark$ as number of photons incident decreases $\checkmark$		2



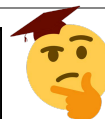
16 – (PHYSI/21_HL_Summer_2022_Q5) – Atomic,nuclear & Particle Physics

a	3 quarks / example with three quarks «eg up up down» $\checkmark$ integer / zero / 1 / no fractional «electron» charge OR held together by the strong force / gluons OR half integer spin OR baryon number = 1 OR colour neutral $\checkmark$		2
b	A «Decay of the strange antiquark is a» weak «interaction» $\checkmark$ B «Decay of the u to a gluon and eventually to d and anti-d is a» strong «interaction» $\checkmark$		2
c	weak «interaction» $\checkmark$ strangeness is not conserved and this is possible only in weak interactions OR the weak interaction allows change of quark flavour OR only the weak interaction has a boson / an exchange particle / a W^+ to conserve the charge OR neutrinos are only produced via the weak interaction $\checkmark$		2

17 – (PHYSI/21_HL_Summer_2022_Q9) – Atomic,nuclear & Particle Physics

a	${}^{40}_{20}\text{Ca} \checkmark$ ${}^0_1\text{e} + \bar{\nu}_e$ OR ${}^0_{-1}\beta + \bar{\nu}_e \checkmark$	Full equation ${}^{40}_{19}\text{K} \rightarrow {}^{40}_{20}\text{Ca} + {}^0_1\text{e} + \bar{\nu}_e$	2
b	i	total K-40 decayed = $\frac{12 \mu\text{mol}}{0.11} = 109 \mu\text{mol} \checkmark$ so total K-40 originally was $109 + 340 = 449 \mu\text{mol} \checkmark$	2

b	ii	ALTERNATIVE 1 $\lambda = \frac{\ln(2)}{t_{1/2}} \text{ used to give } \lambda = 5.3 \times 10^{-10} \text{ per year } \checkmark$ $340 = (449)(e^{-5.3 \times 10^{-10} \cdot t})$ OR $\ln\left(\frac{340}{449}\right) = -5.3 \times 10^{-10} \times t \checkmark$ $t = 5.2 \times 10^8 \text{ «years» } \checkmark$ ALTERNATIVE 2 $p = \frac{340}{449} = 0.76 \text{ «remaining» } \checkmark$ $n = \frac{\ln(p)}{0.693} = \frac{\ln(0.76)}{0.693} = -0.40 \checkmark$ $t = 0.40 \times 1.3 \times 10^9 = 5.2 \times 10^8 \text{ «years» } \checkmark$ ALTERNATIVE 3 $p = \frac{340}{449} = 0.76 \text{ «remaining»}$ $0.76 = \left(\frac{1}{2}\right)^{t/1.3 \times 10^9}$ $t = 0.40 \times 1.3 \times 10^9 = 5.2 \times 10^8 \text{ «years»}$	Allow 5.3×10^8 years for final answer. Allow ECF for MP3 for an incorrect number of half-lives.	3
c		«use the mass of the sample to» determine number of potassium-40 atoms / nuclei in sample $\checkmark$ «use a counter to» determine (radio)activity / A of sample $\checkmark$ use $A = \lambda N$ «to determine the decay constant / λ» $\checkmark$		3



18 – (PHYSI/22_HL_Summer_2022_Q5) – Atomic,nuclear & Particle Physics

a		background count rate is subtracted «from each reading» $\checkmark$	OWTTE	1
b		thickness is 0.25 «mm» $\checkmark$ 380 «count min⁻¹» $\checkmark$	MP1 and MP2 can be shown on the graph Allow a range of 0.23 to 0.27 mm for MP1 Allow ECF from MP1. Accept a final answer in the range 350 – 420	2

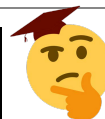
c	lead better absorber than copper ✓ not alpha ✓ as it does not go through the foil / it is easily stopped / it is stopped by paper ✓ there is gamma ✓ as it goes through lead ✓ ALTERNATIVE 1 can be beta ✓ as it is attenuated by «thin» metal / can go through «thin» metal ✓ ALTERNATIVE 2 not beta ✓ it is stopped by «thin» metal ✓		4 max
d	${}_{55}^{137}\text{Cs} \rightarrow {}_{56}^{137}\text{Ba} + {}_{-1}^0\beta + \bar{\nu}_e$ ✓ $\bar{\nu}_e$ ✓	Accept β or e in MP1. Do not penalize if proton / nucleon numbers or electron subscript in antineutrino are missing.	2



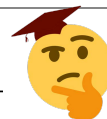
19 – (PHYSI/20_HL_Winter_2022_Q6) – Atomic,nuclear & Particle Physics

a	according to $\Delta E = \Delta mc^2$ / identifies mass energy equivalence ✓ energy is released when nucleons come together / a nucleus is formed «so nucleus has less mass than individual nucleons» OR energy is required to «completely» separate the nucleons / break apart a nucleus «so individual nucleons have more mass than nucleus» ✓	Accept protons and neutrons	2
b	i $\{m_{{}_{55}^{137}\text{Cs}}, m_{{}_{56}^{137}\text{Ba}}, m_e\}c^2$ OR $\{209.93676 - 205.92945 - 4.00151\}$ OR mass difference = 5.8×10^{-3} ✓ conversion to MeV using 931.5 to give 5.4 «MeV» ✓	Allow ECF from MP1 Award [2] for a BCA Award [1] for 8.6×10^{-13} J	2
b	ii ALTERNATIVE 1 energy ratio expressed in terms of momentum, e.g. $\frac{E_{\alpha}}{E_{\text{lead}}} = \frac{p_{\alpha}^2 / 2m_{\alpha}}{p_{\text{lead}}^2 / 2m_{\text{lead}}}$ ✓ $p_{\alpha} = p_{\text{lead}}$ hence $\frac{E_{\alpha}}{E_{\text{lead}}} = \frac{m_{\text{lead}}}{m_{\alpha}}$ ✓ $\frac{m_{\text{lead}}}{m_{\alpha}} = \frac{206}{4} = 51.5 \rightarrow E_{\alpha} = 51.5 E_{\text{lead}}$ «so α has a much greater KE» OR m_{lead} «much» greater than m_{α} «so α has a much greater KE» ✓ ALTERNATIVE 2 alpha particle and lead particle have equal and opposite momenta ✓ so their velocities are inversely proportional to mass ✓ but $\text{KE} \propto v^2$ «so α has a much greater KE» ✓		3

b	iii	photon energy is determined by its wavelength ✓ photons are emitted when nucleus undergoes transitions between its «nuclear» energy levels OR photon energy equals the difference between «nuclear» energy levels ✓ photons have the same energy / a fixed value OR energy is quantized / discrete ✓		3
c		undecayed mass = $5.0 \times 10^{-4} \text{ kg}$ «g» ✓ mass of decayed polonium «= $5.0 - \text{undecayed mass}$» = 4.2 «g» ✓ mass of lead «= $\frac{206}{210} \cdot 4.2$» = 4.1 «g» ✓	Allow [2] max for answers that ignore mass difference between Pb and Po (4.2 g) Allow calculations in number of particles or moles for MP1 and MP2 Allow ECF from MP1 and MP2	3



1 - (PHYSI/21_HL_Summer_2017_Q3) - Energy Production, Electricity & Magnetism

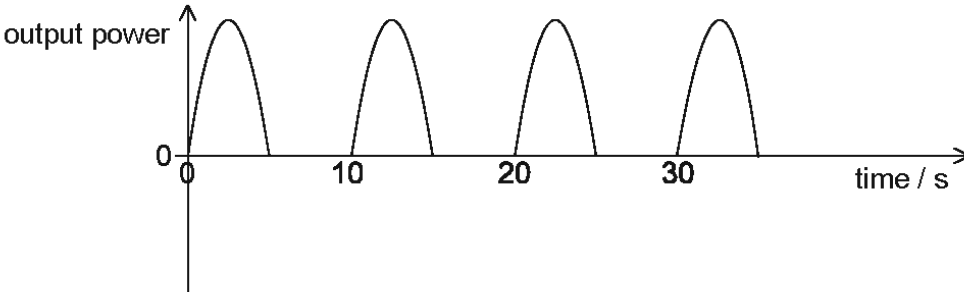


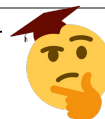
a		solar heating panel converts solar/radiation/photon/light energy into thermal energy AND photovoltaic cell converts solar/radiation/photon/light energy into electrical energy ✓
b		power received = $240 \times 25000 = \llcorner 6.0 \text{ MW} \llcorner$ ✓ efficiency $\llcorner \frac{1.6}{6.0} \llcorner = 0.27 / 27\%$ ✓
c	i	area = $\pi \times 17^2 \llcorner 908 \text{ m}^2 \llcorner$ ✓ power = $\frac{1}{2} \times 908 \times 1.3 \times 7.5^3 \llcorner 0.249 \text{ MW} \llcorner$ ✓ number of turbines $\llcorner \frac{1.6}{0.249} = 6.4 \llcorner = 7$ ✓
	ii	«efficiency is less than 100 % as» not all KE of air can be transferred to KE of blades OR air needs to retain KE to escape ✓ thermal energy is lost due to friction in turbine/dynamo/generator ✓

2 - (PHYSI/22_HL_Summer_2017_Q2) - Oscillations & Waves, Energy Production

a		force/acceleration proportional to displacement «from equilibrium position» ✓ and directed towards equilibrium position/point OR and directed in opposite direction to the displacement from equilibrium position/point ✓
b	i	frequency of buoy movement = $\frac{3.4}{35}$ or 0.097 «Hz» OR time period of buoy = $\frac{35}{3.4}$ or 10.3 «s» or 10 «s» ✓ $v = \llcorner \frac{2\pi x_0}{T} \text{ or } 2\pi f x_0 \llcorner = \frac{2 \times \pi \times 4.3}{10.3} \text{ or } 2 \times \pi \times 0.097 \times 4.3$ ✓ 2.6 «ms ⁻¹ » ✓



b	ii	peaks separated by gaps equal to width of each pulse «shape of peak roughly as shown» ✓ one cycle taking 10 s shown on graph ✓ 
c	i	PE of water is converted to KE of moving water/turbine to electrical energy «in generator/turbine/dynamo» ✓ idea of pumped storage, <i>ie</i>: pump water back during night/when energy cheap to buy/when energy not in demand/when there is a surplus of energy ✓



c	ii	specific energy available = «gh» = 9.81×270 «$= 2650 \text{ J kg}^{-1}$» OR $mgh = \frac{1}{2}mv^2$ OR $v^2 = 2gh \checkmark$ $v = 73 \text{ «ms}^{-1}\text{»} \checkmark$
c	iii	total energy = «$mgh = 1.5 \times 10^{10} \times 9.81 \times 270$» = 4.0×10^{13} «J» OR total energy = «$\frac{1}{2}mv^2 = \frac{1}{2} \times 1.5 \times 10^{10} \times (\text{answer (c)(ii)})^2$» = 4.0×10^{13} «J» time = «$\frac{4.0 \times 10^{13}}{4 \times 2.5 \times 10^8}$» = 11.1h or 4.0×10^4 s ✓
c	iv	friction/resistive losses in pipe/fluid resistance/turbulence/turbine or generator «bearings» OR sound energy losses from turbine/water in pipe ✓ thermal energy/heat losses in wires/components ✓ water requires kinetic energy to leave system so not all can be transferred ✓

3 - (PHYSI/20_HL_Winter_2017_Q7) - Energy Production

a	i	$T \ll \frac{2.90 \times 10^{-3}}{\lambda_{\text{max}}} \gg \frac{2.90 \times 10^{-3}}{10.1 \times 10^{-6}} \checkmark$ 287 «K» or 14 «°C» ✓	Award [0] for any use of wavelength from Sun Do not accept 287 °C
a	ii	wavelength of radiation from the Sun is shorter than that emitted from Earth «and is not absorbed by the atmosphere» ✓ infrared radiation emitted from Earth is absorbed by greenhouse gases in the atmosphere ✓ this radiation is re-emitted in all directions «including back to Earth» ✓	
b		peer review ✓ international collaboration ✓ full details of experiments published so that experiments can be repeated ✓	

4 - (PHYSI/22_HL_Summer_2018_Q7) - Energy Production



a	i	Average height = 127 «m» ✓ Specific energy « $\frac{mgh}{m}$ » gh 9.81 127» 1.2 10 ³ J kg ⁻¹ ✓	Unit is essential Allow g = 10 gives 1.3 10 ³ J kg ⁻¹ Allow ECF from 110 m (1.1 10 ³ J kg ⁻¹) or 144 m (1.4 10 ³ J kg ⁻¹)	2
a	ii	mass per second leaving dam is $\frac{1.2 \cdot 10^3}{60} \cdot 10^3$ «2.0 · 10 ⁶ kg s ⁻¹ » ✓ rate of decrease of GPE is 2.0 10 ⁶ 9.81 127 ✓ 2.49 10 ⁹ «W» / 2.49 «GW» ✓	Do not award ECF for the use of 110 m or 144 m Allow 2.4 GW if rounded value used from (a)(i) or 2.6 GW if g = 10 is used	3
a	iii	efficiency is « $\frac{1.8}{2.5}$ » 0.72 / 72% ✓		1
b		water is pumped back up at times when the demand for/price of electricity is low ✓		1

5 - (PHYSI/21_HL_Summer_2019_Q7) - Energy Production

a	i	$T = \left(\frac{1360}{\sigma} \right)^{0.25}$ ✓ 390 «K» ✓	Must see 1360 (from data booklet) used for MP1. Must see at least 2 s.f.	2
a	ii	energy/Power/Intensity lower at B ✓ connection made between energy/power/intensity and temperature of blackbody ✓		2
b		(28%) of sun's energy is scattered/reflected by earth's atmosphere OR only 72% of incident energy gets absorbed by blackbody ✓	Must be clear that the energy is being scattered by the atmosphere.	1

6 - (PHYSI/22_HL_Summer_2019_Q7) - Energy Production

a		$5.67 \times 10^{-8} \times 289^4$ OR $= 396 \text{ «W m}^{-2}\text{»}$ ✓ «≈ 400 W m ⁻² »		1
b		«most of the radiation emitted by the oceans is in the» infrared ✓ «this radiation is» absorbed by greenhouse gases/named greenhouse gas in the atmosphere ✓ «the gases» reradiate/re-emit ✓ partly back towards oceans/in all directions/awareness that radiation in other directions is also present ✓		3 max
c	i	water loses $396 - 330 / 66 \text{ «W m}^{-2}\text{»}$ ✓ extra intensity that must be lost is «170 - 66» = 104 ≈ 100 W m ⁻² ✓ OR absorbed by water $330 + 170 / 500 \text{ «W m}^{-2}\text{»}$ ✓ extra intensity that must be lost is «500 - 396» = 104 ≈ 100 W m ⁻² ✓		2

c	ii	conduction to the air above OR «mainly» evaporation OR melting ice at the poles OR reflection of sunlight off the surface of the ocean ✓	Do not accept convection or radiation.	1
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7 – (PHYSI/20_HL_Winter_2019_Q6) – Energy Production

a		$P = \frac{1}{2} \times A \times 1.2 \times 8^3$ OR $P = \frac{1}{2} \times A \times 1.32 \times 4^3$ ✓ P «in incoming beam» = 1.4×10^5 «W» OR P «in outgoing beam» = 1.9×10^4 «W» ✓ subtracts both P to obtain 1.2×10^5 «W» ✓	Condone use of a wrong area or use of circumference in MP1. Allow ECF from MP2. Award [1] max for any attempt to use the formula for wind power which cubes the difference of velocities Award [3] for a bald correct answer	3
b		because some power is lost due to inefficiencies in the system/transfers to the surroundings ✓	Accept power or energy indistinctly	1

8 – (PHYSI/20_HL_Winter_2020_Q6) – Atomic, nuclear & Particle Physics, Energy Production

a	i	energy required to «completely» separate the nucleons OR energy released when a nucleus is formed from its constituent nucleons ✓	Allow protons AND neutrons.	1
a	ii	the values «in SI units» would be very small ✓		1
a	iii	$140 \div 8.29 = 94 \div 8.59 = 235 \div 7.59$ OR 184 «MeV» ✓		1
b	i	see «energy» $180 \div 10^9 = 1.80 \times 10^{11}$ AND «mass» $235 \div 1.66 \times 10^{-27}$ ✓ 7.4×10^{13} «J kg ⁻¹ » ✓		2
b	ii	energy produced in one day = $\frac{1.2 \times 10^{11} \times 24 \times 3600}{0.36} = 2.9 \times 10^{14}$ «J» ✓ mass = $\frac{2.9 \times 10^{14}}{7.4 \times 10^{13}} = 3.9$ «kg» ✓		2
b	iii	«specific energy of uranium is much greater than that of coal, hence» more energy can be produced from the same mass of fuel / per kg OR less fuel can be used to create the same amount of energy ✓		1
c	i	39 ✓	Do not allow ${}_{39}^{92}\text{X}$ unless the proton number is indicated.	1
c	ii	75 «s» ✓		1
c	iii	ALTERNATIVE 1 $10 \text{ min} = 8 \text{ h}$ ✓ $\text{mass remaining} = 1.0 \times \left(\frac{1}{2}\right)^8 = 3.9 \times 10^{-2}$ «kg» ✓ ALTERNATIVE 2 $\text{decay constant} = \frac{\ln 2}{75} = 9.24 \times 10^{-3}$ «s ⁻¹ » ✓ $\text{mass remaining} = 1.0 \times e^{-9.24 \times 10^{-3} \times 800} = 3.9 \times 10^{-2}$ «kg» ✓		2

9 - (PHYSI/21_HL_Summer_2021_Q4) - Energy Production



a	i	$\frac{P}{4\pi d^2}$ is the power received by the planet/at a distance d «from star» ✓ $\frac{A}{4}$ is the projected area/cross sectional area of the planet ✓		2
a	ii	use of $\epsilon \sigma A T^4$ OR $\frac{P}{4\pi d^2} \cdot \frac{A}{4} (1 - \alpha_p)$ ✓ with correct manipulation to show the result ✓		2
b		$\sqrt{\frac{1.36 \cdot 10^{-16} \cdot 0.87}{4 \cdot 5.67 \cdot 10^{-8}}}$ ✓ $T = 268.75 \text{ «K»} \approx 270 \text{ «K»}$ ✓		2

10 - (PHYSI/22_HL_Summer_2021_Q6) - Electricity & Magnetism, Energy Production

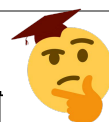
a		there is a potential difference across the internal resistance OR there is energy/power dissipated in the internal resistance ✓ when there is current «in the cell»/as charge flows «through the cell» ✓	Allow full credit for answer based on $V = \epsilon - Ir$	2
b		ALTERNATIVE 1 pd dropped across cell = 6.5 «V» ✓ internal resistance = $\frac{6.5}{0.9}$ ✓ 7.2 «Ω» ✓ ALTERNATIVE 2 $\epsilon = I(R + r)$ so $\epsilon = V + Ir$ ✓ 21.0 = 14.5 + 0.9 x r ✓ 7.2 «Ω» ✓	Alternative solutions are possible Award [3] marks for a bald correct answer	3
c		power arriving at cell = $680 \times 0.35 \times 0.45 = \text{«107 W»}$ ✓ power in external circuit = $14.5 \times 0.9 = \text{«13.1 W»}$ ✓ efficiency = 0.12 OR 12 % ✓	Award [3] marks for a bald correct answer Allow ECF for MP3	3
d		«energy from Sun/photovoltaic cells» is renewable OR non-renewable are running out ✓ non-polluting/clean ✓ no greenhouse gases OR does not contribute to global warming/climate change ✓	OWTTE Do not allow economic aspects (e.g. free energy)	2 max

11 – (PHYSI/20_HL_Winter_2021_Q6) – Energy Production



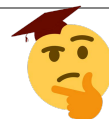
a	i	incident intensity $\frac{1360}{9.3^2}$ OR $15.7 \approx 16 \text{ W m}^{-2}$ ✓	Allow the use of 1400 for the solar constant.	1
a	ii	exposed surface is $\frac{1}{4}$ of the total surface ✓ absorbed intensity = $(1.022) \times$ incident intensity ✓ $0.78 \times 0.25 \times 15.7$ OR 3.07 W m^{-2} ✓	Allow 3.06 from rounding and 3.12 if they use 16 W m^{-2}	3
a	iii	$\sigma T^4 = 3.07$ OR $T = 36 \text{ K}$ ✓		1
b		$v = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{0.025}{0.404}} = 11.2$ OR 2.79 km s^{-1} ✓		1
c	i	correct equating of gravitational force / acceleration to centripetal force / acceleration ✓ correct rearrangement to reach the expression given ✓	Allow use of $\sqrt{\frac{GM}{R}} = \frac{2\pi R}{T}$ for MP1	2
c	ii	$T = 15.9 \times 24 \times 3600 \text{ s}$ ✓ $M = \frac{4\pi^2 (1.2 \times 10^7)^3}{6.67 \times 10^{-11} (15.9 \times 24 \times 3600)^2} = 5.4 \times 10^{25} \text{ kg}$ ✓	Award [2] marks for a bald correct answer. Allow ECF from MP1	2
d	i	$m = \frac{28 \times 10^7}{6.02 \times 10^{23}}$ OR $4.65 \times 10^{-26} \text{ kg}$ ✓		1
d	ii	$\frac{1}{2}mv^2 = \frac{3}{2}kT \Rightarrow v = \sqrt{\frac{3kT}{m}}$ ✓ $v = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 90}{4.651 \times 10^{-26}}} = 283 \approx 300 \text{ m s}^{-1}$ ✓	Award [2] marks for a bald correct answer. Allow 282 from a rounded mass.	2
e		no, molecular speeds much less than escape speed ✓	Allow ECF from incorrect (d)(ii)	1

1 - (PHYSI/21_HL_Summer_2017_Q2) - Oscillations & Waves, Wave Phenomena (ahl)



a	when 2 waves meet the resultant displacement ✓ is the «vector» sum of their individual displacements ✓
b	$\lambda = \frac{4.7 \times 10^{-3} \times 0.35 \times 10^{-3}}{2.4}$ ✓ $= 6.9 \times 10^{-7}$ «m» ✓ answer to 2 SF ✓
c	green wavelength smaller than red ✓ fringe separation / distance between maxima decreases ✓
d	bright central maximum ✓ subsidiary maxima «on either side» ✓ the width of the central fringe is twice / larger than the width of the subsidiary/secondary fringes/maxima OR intensity of pattern is decreased ✓

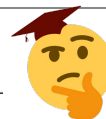
2 - (PHYSI/22_HL_Summer_2017_Q4) - Wave Phenomena (ahl)



a		«light» superposes/interferes ✓ pattern consists of «intensity» maxima and minima OR consisting of constructive and destructive «interference» ✓ voltage peaks correspond to interference maxima ✓
b	i	$s = \frac{\lambda D}{d} = \frac{6.3 \times 10^{-7} \times 5.0}{1.5 \times 10^{-3}} = 2.1 \times 10^{-3} \text{ «m» } \checkmark$
b	ii	correct read-off from graph of 25 ms ✓ $v = \frac{x}{t} = \frac{2.1 \times 10^{-3}}{25 \times 10^{-3}} = 8.4 \times 10^{-2} \text{ «ms}^{-1}\text{» } \checkmark$
c	i	angular width of diffraction minimum = $\frac{0.13}{5.0}$ «= 0.026 rad» ✓ slit width = $\frac{\lambda}{d} = \frac{6.3 \times 10^{-7}}{0.026} = 2.4 \times 10^{-5} \text{ «m» } \checkmark$
c	ii	«beyond the first diffraction minimum» average voltage is smaller ✓ «voltage minimum» spacing is «approximately» same OR rate of variation of voltage is unchanged ✓

d		«reflection at barrier» leads to two waves travelling in opposite directions ✓ mention of formation of standing wave ✓ maximum corresponds to antinode/maximum displacement «of air molecules» OR complete cancellation at node position ✓
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3 – (PHYSI/20_HL_Winter_2017_Q6) – Wave Phenomena (ahl)



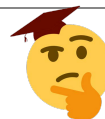
a	i	the diagram shows the combined effect of «single slit» diffraction and «double slit» interference ✓ recognition that there is a minimum of the single slit pattern OR a missing maximum of the double slit pattern at A ✓ waves «from the single slit» are in antiphase/cancel/have a path difference of $(n + \frac{1}{2})\lambda$ /destructive interference at A ✓	
a	ii	$\theta = \frac{4.1 \cdot 10^{-2}}{7.0}$ OR $b = \frac{\lambda}{\theta} = \frac{7.0 \cdot 5.9 \cdot 10^{-7}}{4.1 \cdot 10^{-2}}$ ✓ $1.0 \cdot 10^{-4}$ «m» ✓	Award [0] for use of double slit formula (which gives the correct answer so do not award BCA) Allow use of sin or tan for small angles
a	iii	use of $s = \frac{\lambda D}{d}$ with 3 fringes « $\frac{590 \cdot 10^{-9} \cdot 7.0}{4.1 \cdot 10^{-2}}$ » ✓ $3.0 \cdot 10^{-4}$ «m» ✓	Allow ECF.

b	i	fringes are further apart because the separation of slits is «much» less intensity does not change «significantly» across the pattern OR diffraction envelope is broader because slits are «much» narrower the fringes are narrower/sharper because the region/area of constructive interference is smaller/there are more slits intensity of peaks has increased because more light can pass through	Award [1 max] for stating one or more differences with no explanation Award [2 max] for stating one difference with its explanation Award [MP3] for a second difference with its explanation Allow "peaks" for "fringes"
b	ii	$\Delta\lambda = 589.592 - 588.995$ OR $\Delta\lambda = 0.597$ «nm» ✓ $N = \frac{\lambda}{m\Delta\lambda} = \frac{589}{2 \cdot 0.597}$ «493» ✓ beam width « $\frac{493}{600}$ » $8.2 \cdot 10^{-4}$ «m» OR 0.82 «mm» ✓	

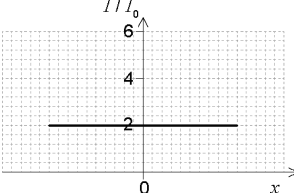
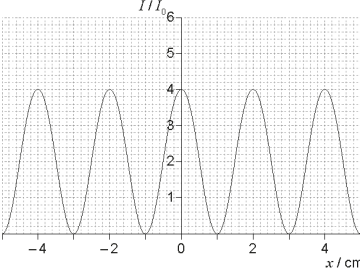
4 – (PHYSI/21_HL_Summer_2018_Q3) – Oscillations & Waves, Wave Phenomena (ahl)

a	i	superposition of light from each slit / interference of light from both slits ✓ with path/phase difference of any half-odd multiple of wavelength/any odd multiple of π (in words or symbols) ✓ producing destructive interference ✓	Ignore any reference to crests and troughs.	3
a	ii	light waves (from slits) must have constant phase difference / no phase difference / be in phase ✓	OWTTE	1
a	iii	evidence of solving for $D = D \frac{sd}{\lambda} > \lambda$ ✓ « $\frac{4.50 \cdot 10^{-3} \cdot 0.300 \cdot 10^{-3}}{633.0 \cdot 10^{-9}}$ » $2 > 4.27$ «m» ✓	Award [1] max for 2.13 m.	2

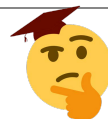
b	i	$\sin \theta = \frac{4.633.0 \cdot 10^{-3}}{0.300 \cdot 10^{-3}} \checkmark$ $\theta = 0.0084401... \checkmark$ final answer to three sig figs (eg 0.00844 or 8.44×10^{-3}) $\checkmark$	Allow ECF from (a)(iii). Award [1] for 0.121 rad (can award MP3 in addition for proper sig fig) Accept calculation in degrees leading to 0.481 degrees. Award MP3 for <u>any</u> answer expressed to 3sf.	3
b	ii	use of diffraction formula « $b \frac{\lambda}{d}$ » OR $\frac{633.0 \cdot 10^{-3}}{0.00844} \checkmark$ « $\approx 7.5 \cdot 10^{-2}$ mm» $\checkmark$	Allow ECF from (b)(i).	2
c		wavelength increases (so frequency decreases) / light is redshifted $\checkmark$ galaxy is moving away from Earth $\checkmark$	Allow ECF for MP2 (ie wavelength decreases so moving towards).	2
d	i	$\frac{633.0}{1.33} = 476 \text{ nm} \checkmark$		1
d	ii	distance between peaks decreases $\checkmark$ intensity decreases $\checkmark$		2



5 - (PHYSI/22_HL_Summer_2018_Q5) - Oscillations & Waves, Wave Phenomena (ahl)

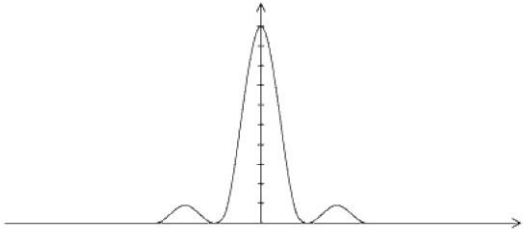
a		horizontal straight line through $I = 2 \checkmark$	eg:  Accept a curve that falls from $I = 2$ as distance increases from centre but not if it falls to zero.	1
b		«standard two slit pattern» general shape with a maximum at $x = 0 \checkmark$ maxima at $4I_0 \checkmark$ maxima separated by « $\frac{D\lambda}{s}$ » $\approx 2.0 \text{ cm} \checkmark$	Accept single slit modulated pattern provided central maximum is at 4, ie height of peaks decrease as they go away from central maximum. Peaks must be of the same width eg: 	3
c		fringe width/separation decreases OR more maxima seen $\checkmark$		1

6 – (PHYSI/22_HL_Summer_2019_Q8) – Wave Phenomena (ahl)



a		there is constructive interference at M OR the amplitude doubles at M ✓ intensity is «proportional to» amplitude ² ✓ 88 «W m ⁻² » ✓		3
b		« $s = \frac{\lambda D}{d} \rightarrow \lambda = \frac{sd}{D} = \frac{0.12 \times 10^{-3} \times 7.0 \times 10^{-2}}{1.5}$ » ✓ $\lambda = 560$ «nm» ✓		2
c	i	«the interference pattern will be modulated by» single slit diffraction ✓ «envelope and so it will be less»		1
c	ii	ALTERNATIVE 1 the angular position of this point is $\theta = \frac{28 \times 10^{-3}}{1.5} = 0.01867$ «rad» ✓ which coincides with the first minimum of the diffraction envelope $\theta = \frac{\lambda}{b} = \frac{560 \times 10^{-9}}{0.030 \times 10^{-3}} = 0.01867$ «rad» ✓ «so intensity will be zero» ALTERNATIVE 2 the first minimum of the diffraction envelope is at $\theta = \frac{\lambda}{b} = \frac{560 \times 10^{-9}}{0.030 \times 10^{-3}} = 0.01867$ «rad» ✓ distance on screen is $y = 1.50 \times 0.01867 = 28$ «mm» ✓ «so intensity will be zero»		2

7 – (PHYSI/20_HL_Winter_2019_Q10) – Oscillations & Waves, Wave Phenomena (ahl)

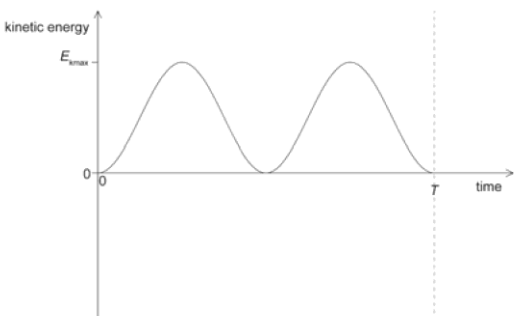
a		there is a phase change ✓ of π OR as it is reflected off a medium of higher refractive index ✓		2
b	i	$2d$ ✓	Accept $2dn$	1
b	ii	$2dn = \frac{\lambda}{2}$ ✓ $d = \frac{\lambda}{4n} = \frac{656}{4 \times 1.38} \rightarrow 119$ «nm» ✓	Award [2] for bald correct answer	2
b	iii	reflection from «front surface of» lens eliminated/reduced OR energy reaching sensor increased ✓ at one wavelength ✓	Accept reference to reduction of glare for MP1	2
c	i	standard single slit diffraction pattern with correct overall shape ✓ secondary maxima of right size ✓ 	Secondary maximum not to exceed 1/5 th of maximum intensity Ignore width of maxima	2
c	ii	use of $\theta = \frac{1.22\lambda}{b}$ ✓ $\theta = 2.9 \times 10^{-4}$ «rad» ✓	Award [2] for bald correct answer	2

8 – (PHYSI/20_HL_Winter_2020_Q4) – Oscillations & Waves, Wave Phenomena (ahl)



a	wavelength = $\frac{340}{850} = 0.40$ «m» ✓ path difference = 1.8 «m» ✓ 1.8 «m» = 4.5λ OR $\frac{1.8}{0.40} = 4.5$ «half-wavelengths» ✓ waves meet in antiphase «at P» ✓ OR destructive interference/superposition «at P» ✓	Allow approach where path length is calculated in terms of number of wavelengths: along path A (56.25) and path B (60.75) for MP2, hence path difference 4.5 wavelengths for MP3	4
b	«equally spaced» maxima and minima ✓ a maximum at Q ✓ four «additional» maxima «between P and Q» ✓		2 max
c	the amplitude of sound at Q is halved ✓ «intensity is proportional to amplitude squared hence» $\frac{I_2}{I_1} = \frac{1}{4}$ ✓		2
d i	speed of sound relative to the microphone is less ✓ wavelength unchanged «so frequency is lower» ✓ OR fewer waves recorded in unit time/per second «so frequency is lower» ✓		2
d ii	$845 - 850 = \frac{340}{340} = 1$ ✓ $v = 2.00$ «m s⁻¹» ✓		2

9 – (PHYSI/20_HL_Winter_2020_Q7) – Wave Phenomena (ahl)

a	the «restoring» force/acceleration is proportional to displacement ✓	Allow use of symbols i.e. $F \propto -x$ or $a \propto -x$	1
b	Evidence of equating $m\omega^2 x = \rho A g x$ «to obtain» $\frac{\rho A g}{m} = \omega^2$ » ✓ $\omega = \sqrt{\frac{1.03 \cdot 10^3 \cdot 2.29 \cdot 10^{-4} \cdot 9.81}{118}}$ OR 4.43 «rad s⁻¹» ✓	Answer to at least 3 s.f.	2
c i	«E_k is a maximum when $x = 0$ hence» $E_{k \max} = \frac{1}{2} \cdot 118 \cdot 4.4^2 (0.250^2 - 0^2)$ ✓ 71.4 «J» ✓		2
c ii	energy never negative ✓ correct shape with two maxima ✓ 		2

10 – (PHYSI/21_HL_Summer_2021_Q6) – Wave Phenomena (ahl)



a		«change is» $\pi / 180^\circ$ ✓	1
b		«to eliminate reflection» destructive interference is required ✓ phase change is the same at both boundaries / no relative phase change due to reflections ✓ therefore $2wn_{\text{coating}} = \left(m + \frac{1}{2}\right)\lambda_{\text{eff}}$ OR $w = \frac{\lambda_{\text{coating}}}{4}$ OR $w = \frac{\lambda_{\text{air}}}{4n_{\text{coating}}}$ ✓	3
c	i	central maximum of one diffraction pattern lies over the central/first minimum of the other diffraction pattern ✓	1
c	ii	$\theta = \left\langle 1.22 \frac{\lambda}{b} = 1.22 \frac{700 \times 10^{-9}}{4 \times 10^{-5}} \right\rangle = 2.14 \times 10^{-2} \text{ «rad»} \checkmark$ $D = 14 \text{ «0.05 m»} \checkmark$	2

11 – (PHYSI/22_HL_Summer_2021_Q8) – Wave Phenomena (ahl)

a	i	0 OR 2π OR 360° ✓	1
a	ii	4λ ✓	1
a	iii	$\sin \theta = \left\langle \frac{XZ}{VX} \right\rangle = \frac{4\lambda}{2d}$ ✓	Do not award ECF from (a)(ii). 1
b		identifies gradient with $\frac{\lambda}{d}$ OR use of $d \sin \theta = n\lambda$ ✓ gradient = 0.08 OR correct replacement in equation with coordinates of a point ✓ $d = \frac{633 \times 10^{-9}}{0.080} = \text{«}7.91 \times 10^{-6} \text{ m»} \checkmark$ 1.26×10^2 OR $1.27 \times 10^2 \text{ «mm}^{-1}\text{»} \checkmark$	Allow ECF from MP3 4
c	i	gradient smaller ✓	1
c	ii	no change ✓	1

12 – (PHYSI/20_HL_Winter_2021_Q8) – Wave Phenomena (ahl)

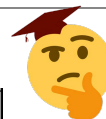


a	the change in the observed frequency ✓ when there is relative motion between the source and the observer ✓	Do not award MP1 if they refer to wavelength.	2
b	use of $2\pi f A$ ✓ maximum speed is $2\pi \cdot 39 \cdot 0.080 = 19.6 \text{ «ms»}$ ✓	Award [2] for a bald correct answer.	2
c	frequency at plate $2400 \cdot \frac{340 - 19.6}{340} \approx 2538 \text{ Hz}$ ✓ at source $2538 \cdot \frac{340}{340 - 19.6} = 2694 \approx 2700 \text{ «Hz»}$ ✓	Award [2] marks for a bald correct answer. Award [1] mark when the effect is only applied once.	2
d i	stays the same ✓		1
d ii	decreases ✓		1
d iii	decreases ✓		1

13 – (PHYSI/21_HL_Summer_2022_Q3) – Wave Phenomena (ahl)

a	movement of B means that path distance is different « between BM and AM » OR movement of B creates a path difference «between BM and AM» ✓ interference OR superposition «of waves» ✓ maximum when waves arrive in phase / path difference = $n \times \text{lambda}$ OR minimum when waves arrive «180° or π » out of phase / path difference = $(n + \frac{1}{2}) \times \text{lambda}$ ✓		3
b	wavelength = 26 cm ✓ peak to peak distance is the path difference which is one wavelength OR this is the distance B moves to be back in phase «with A» ✓	Allow 25 – 27 cm for MP1.	2
c	$\frac{\lambda}{2} = 13 \text{ cm}$ ✓ $f = \frac{c}{\lambda} = \frac{340}{0.13} \rightarrow 2.6 \text{ «kHz»}$ ✓	Allow $\frac{1}{2}$ of wavelength from (b) or data from graph for MP1. Allow ECF from MP1.	2
d	ALTERNATIVE 1 use of $f' = f \frac{v}{v + u_0}$ (+ sign must be seen) OR $f' = 2987 \text{ «Hz»}$ ✓ « Δf » = 13 «Hz» ✓ ALTERNATIVE 2 Attempted use of $\frac{\Delta f}{f} \approx \frac{v}{c}$ « Δf » = 13 «Hz» ✓		2

14 – (PHYSI/21_HL_Summer_2022_Q6) – Wave Phenomena (ahl)

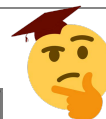


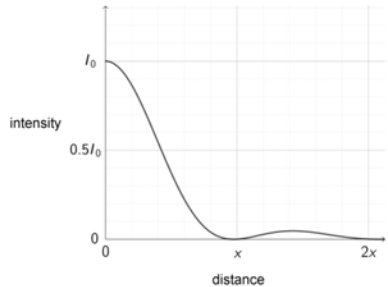
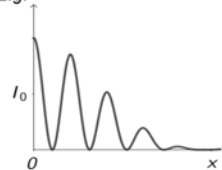
a		For both models: displacement is x to acceleration/force «because graph is straight and through origin» ✓ displacement and acceleration / force in opposite directions «because gradient is negative» OR acceleration/«restoring» force is always directed to equilibrium ✓		2
b		attempted use of $\omega^2 = \left(\frac{a}{x}\right)$ ✓ suitable read-offs leading to gradient of line = 28 «s⁻²» ✓ $T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{28}}$ ✓ $T = 1.2$ s ✓		4
c		time period increases ✓ because average ω «for whole cycle» is smaller OR slope / acceleration / force at large x is smaller OR area under graph B is smaller so average speed is smaller. ✓		2
d		same curve OR shape for small amplitudes «to about 0.05 m» ✓ for large amplitudes «outside of 0.05 m» E_p smaller for model B / values are lower than original / spread will be wider ✓ OWTTE	Accept answers drawn on graph – e.g.	2

15 – (PHYSI/22_HL_Summer_2022_Q6) – Wave Phenomena (ahl)

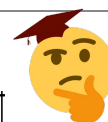
a	i	1.3 «Hz» ✓		1
a	ii	$k \propto m$ OR $\frac{m_1}{k_1} = \frac{m_2}{k_2}$ ✓ 0.25 OR $\frac{1}{4}$ ✓		2
a	iii	$v_{max} = 4.8$ «m s⁻¹» ✓ $x_c = \frac{v}{\omega} = \frac{vT}{2\pi} = \frac{4.8 \times 0.80}{2\pi} = 0.61$ «m» ✓	Allow a range of 4.7 to 4.9 for MP1 Allow a range of 0.58 to 0.62 for MP2 Allow ECF from (a)(i) Allow ECF from MP1.	2
a	iv	all energy shown positive ✓ curve starting and finishing at $E = 0$ with two peaks with at least one at 44 J OR curve starting and finishing at $E = 0$ with one peak at 44 J ✓	Do not accept straight lines or discontinuous curves for MP2	2
b		read off of 9.4 «m s⁻¹» ✓ use of $f' = f \left(\frac{v}{v \pm u_s} \right)$ OR $f' = f \left(\frac{v \pm u_o}{v} \right)$ ✓ $f = 36$ «kHz» OR 34 «kHz» ✓ «recognition that there are two shifts so» change in $f = 2$ «kHz» OR $f = 37$ «kHz» OR 33 «kHz» ✓	Allow a range of 9.3 to 9.5 for MP1 Allow ECF from MP1. MP4 can also be found by applying the Doppler effect twice.	4

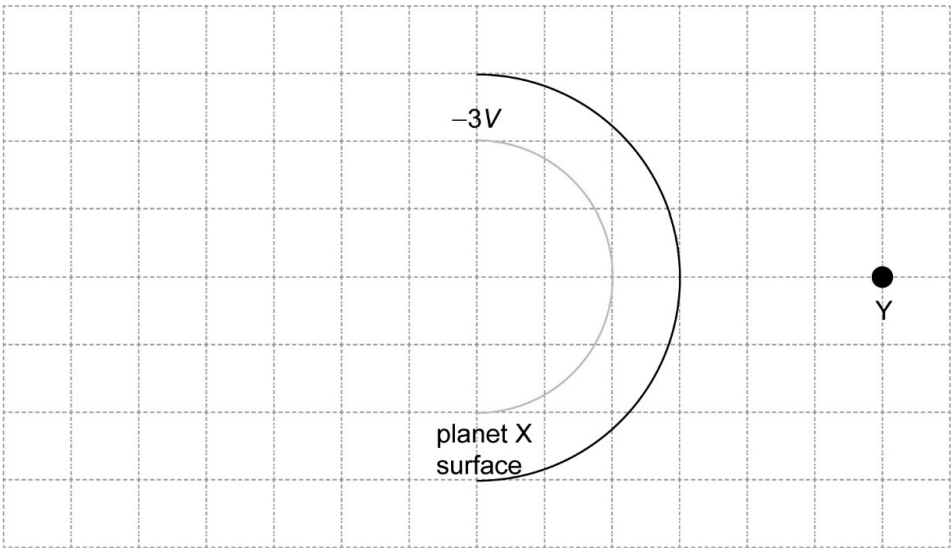
16 – (PHYSI/20_HL_Winter_2022_Q7) – Wave Phenomena (ahl)



a	i	smooth curve decreasing from I_0 to 0 between 0 and x ✓ secondary maximum correctly placed AND of intensity less than $0.3 I_0$ ✓  <i>E.g.</i>		2
a	ii	observed pattern goes beyond the rectangular shape/geometrical shadow OR observed pattern shows maxima/minima ✓ «this is explained by» interference/superposition of waves ✓	Accept any correct description of the diffraction pattern for MP1 .	2
a	iii	angle of the first minimum = $\frac{590 \times 10^{-9}}{0.10 \times 10^{-3}} = \ll 0.0059 \text{ rad} \gg$ ✓ width = $2 \times 0.0059 \times 2.4 = 2.8 \times 10^{-2} \text{ «m»}$ ✓	$1.4 \times 10^{-2} \text{ m}$ scores [1] mark. Do not penalize the use of $\sin$ or $\tan$ in MP2	2
b		intensity at O increases ✓ fringes / a series of maxima and minima ✓ with intensity decreasing away from O OR intensity modulated by diffraction ✓	Accept answers as sketches. For MP1 expect the scale on the y-axis. <i>E.g.</i> 	2 max
c		ALTERNATIVE 1 number of illuminated slits = $2.0 \times 750 = 1500$ ✓ smallest resolvable difference $\ll \frac{\lambda}{mN} = \frac{590}{1 \times 1500} \gg = 0.39 \text{ «nm»}$ ✓ $0.39 < 0.60$ hence the lines can be resolved ✓ ALTERNATIVE 2 number of illuminated slits = $2.0 \times 750 = 1500$ ✓ $\frac{\lambda}{\Delta\lambda} = 983$ ✓ 1500 greater than 983 hence lines can be resolved ✓	Allow ECF from MP2	3

1 - (PHYSI/21_HL_Summer_2017_Q6) - Fields (ahl), Thermal Physics

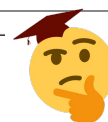


a	the field lines/arrows are further apart at greater distances from the surface ✓
b	circle centred on Planet X ✓ three units from Planet X centre ✓ 
c	loss in gravitational potential = $\frac{6.67 \times 10^{-11} \times 3.1 \times 10^{21}}{1.2 \times 10^6}$ ✓ «= $1.72 \times 10^5 \text{ J kg}^{-1}$» equate to $\frac{1}{2}v^2$ ✓ $v = 590 \text{ «ms}^{-1}\text{»}$ ✓
d	available energy to melt one kg $1.72 \times 10^5 \text{ «J»}$ ✓ fraction that melts is $\frac{1.72 \times 10^5}{3.3 \times 10^5} = 0.52$ OR 52 % ✓

2 - (PHYSI/20_HL_Winter_2017_Q2) - Circular Motion & Gravitation, Oscillations & Waves, Fields (ahl)

a	$v = \sqrt{\frac{Gm_E}{r}} = \sqrt{\frac{6.67 \cdot 10^{-11} \cdot 6.0 \cdot 10^{24}}{6600 \cdot 10^3}} \checkmark$ 7800 «ms⁻¹» ✓	Full substitution required Must see 2 : significant figures.
b	i	Y has smaller orbit/orbital speed is greater so time period is less ✓ Allow answer from appropriate equation Allow converse argument for X

b	ii	to stop Y from getting ahead ✓ to remain stationary with respect to X ✓ otherwise will add tension to cable/damage satellite/pull X out of its orbit ✓	
c		cable is a conductor and contains electrons ✓ electrons/charges experience a force when moving in a magnetic field ✓ use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive» ✓ Alternative 2 cable is a conductor ✓ so current will flow by induction flow when it moves through a B field ✓ use of a suitable hand rule to show current to right so «X becomes positive» ✓	Marks should be awarded from either one alternative or the other. Do not allow discussion of positive charges moving towards X
d		electrons would build up at satellite Y/positive charge at X ✓ preventing further charge flow ✓ by electrostatic repulsion ✓ unless a complete circuit exists ✓	
e		«$\epsilon \cdot B \cdot v$» $31 \cdot 10^{-6} \cdot 7790 \cdot 15000$ ✓ 3600 «V» ✓	Allow 3700 «V» from $v = 8000 \text{ ms}^{-1}$.

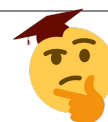


f	i	use of $k = \frac{4\pi^2 m}{T^2}$ » $4 \cdot \frac{\pi^2}{5.2^2} \cdot 350$ ✓ 510 ✓ N m^{-1} or kg s^{-2} ✓	Allow MP1 and MP2 for a bald correct answer Allow 500 Allow N/m etc
f	ii	E_p in the cable/system transfers to E_k of Y ✓ and back again twice in each cycle ✓	Exclusive use of gravitational potential energy negates MP1

3 - (PHYSI/20_HL_Winter_2017_Q8) - Fields (ahl)

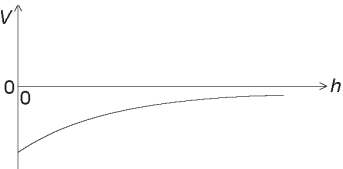
a		force per unit charge ✓ acting on a small/test positive charge ✓	
b		horizontally to the left ✓	Arrow does not need to touch X
c		proton moves to the right/they move in opposite directions ✓ force on each is initially the same ✓ proton accelerates less than electron initially «because mass is greater» ✓ field is stronger on right than left «as lines closer» ✓ proton acceleration increases «as it is moving into stronger field» OR electron acceleration decreases «as it is moving into weaker field» ✓	Allow ECF from (b) Accept converse argument for electron

4 – (PHYSI/21_HL_Summer_2018_Q7) – Electromagnetic Induction (ahl), Fields (ahl)



a		$d = \frac{8.85 \times 10^{-12} \times 0.025^2}{4.3 \times 10^{-12}} = 1.3 \times 10^{-3} \text{ m} \checkmark$		1
b		$6.9 \times 10^{-11} \text{ C} \checkmark$ negative charge/sign $\checkmark$		2
c		charge increases $\checkmark$ because capacitance increases AND pd remains the same. $\checkmark$		2
d		ALTERNATIVE 1 $\frac{1200}{100} = 12 \checkmark$ $2640 \text{ V} \checkmark$ $V_{rms} = \frac{2640}{\sqrt{2}} = 1870 \text{ V} \checkmark$ ALTERNATIVE 2 (Primary) $V_{rms} = \frac{220}{\sqrt{2}} = 156 \text{ V} \checkmark$ (Secondary) $V_{rms} = \frac{156}{100} = 1.56 \text{ V} \checkmark$ $V_{rms} = 1870 \text{ V} \checkmark$	Allow ECF from MP1 and MP2. Award [2] max for 12.96 V (reversing N_p and N_s).	3
e		step-up transformers increase voltage/step-down transformers decrease voltage $\checkmark$ (step-up transformers increase voltage) from plants to transmission lines / (step-down transformers decrease voltage) from transmission lines to final utilizers $\checkmark$ this decreases current (in transmission lines) $\checkmark$ to minimize energy/power losses in transmission $\checkmark$		3 max

5 – (PHYSI/22_HL_Summer_2018_Q6) – Circular Motion & Gravitation, Fields (ahl)

a	i	the «gravitational» force per unit mass exerted on a point/small/test mass $\checkmark$		1
a	ii	at height h potential is $V = -\frac{GM}{(R+h)} \checkmark$ field is $g = \frac{GM}{(R+h)^2} \checkmark$ «dividing gives answer»	Do not allow an answer that starts with $g = -\frac{\Delta V}{\Delta r}$ and then cancels the deltas and substitutes $R+h$	2
a	iii	correct shape and sign $\checkmark$ non-zero negative vertical intercept $\checkmark$	eg: 	2
b		$V = -2.2 \times (3.1 \times 10^6 + 2.4 \times 10^7) = -6.0 \times 10^7 \text{ J kg}^{-1} \checkmark$	Unit is essential Allow eg MJ kg^{-1} if power of 10 is correct Allow other correct SI units eg $\text{m}^2 \text{s}^{-2}$, Nm kg^{-1}	1

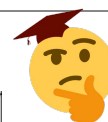
c	total energy at P 0 / KE gained = GPE lost ✓ $\frac{1}{2}mv^2 = mV \Rightarrow v = \sqrt{2V}$ ✓ $v = \sqrt{2 \cdot 6.0 \cdot 10^7} \approx 1.1 \cdot 10^4 \text{ ms}^{-1}$ ✓	Award [3] for a bald correct answer ignore negative sign errors in the workings Allow ECF from 6(b)	3
d	ALTERNATIVE 1 force on asteroid is $6.2 \cdot 10^{12} \cdot 2.2 \approx 1.4 \cdot 10^{13} \text{ N}$ ✓ «by Newton's third law» this is also the force on the planet ✓ ALTERNATIVE 2 mass of planet = $2.4 \times 10^{26} \text{ kg}$ «from $V = \frac{GM}{(R+h)}$ » ✓ force on planet « $\frac{GMm}{(R+h)^2}$ » $1.4 \cdot 10^{13} \text{ N}$ ✓	MP2 must be explicit	2



6 - (PHYSI/22_HL_Summer_2018_Q8) - Fields (ahl), Electromagnetic Induction (ahl)

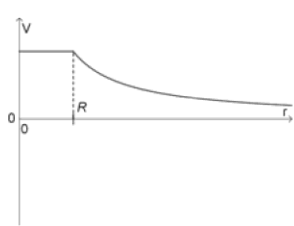
a	$C \approx \frac{A}{d} \approx 8.8 \cdot 10^{12} \frac{1.2 \cdot 10^8}{1600}$ ✓ $C = 6.60 \cdot 10^7 \text{ F}$		1
b	i $V = \frac{Q}{C} \approx \frac{25}{6.6 \cdot 10^7}$ ✓ $V = 3.8 \cdot 10^7 \text{ V}$ ✓	Award [2] for a bald correct answer	2
b	ii ALTERNATIVE 1 $E = \frac{1}{2}QV = \frac{1}{2} \cdot 25 \cdot 3.8 \cdot 10^7$ ✓ $E = 4.7 \cdot 10^8 \text{ J}$ ✓ ALTERNATIVE 2 $E = \frac{1}{2}CV^2 = \frac{1}{2} \cdot 6.60 \cdot 10^7 \cdot (3.8 \cdot 10^7)^2$ ✓ $E = 4.7 \cdot 10^8 \text{ J} / 4.8 \cdot 10^8 \text{ J}$ if rounded value of V used ✓	Award [2] for a bald correct answer Allow ECF from (b)(i) Award [2] for a bald correct answer Allow ECF from (b)(i)	2
c	i $Q = Q_0 e^{-t/\tau} \approx 25 e^{-18/32}$ ✓ $Q = 14.2 \text{ C}$ ✓ charge delivered = $Q = 25 - 14.2 = 10.8 \text{ C}$ ✓ $\approx -11 \text{ C}$	Final answer must be given to at least 3 significant figures	3
c	ii $I = \frac{\Delta Q}{\Delta t} = \frac{11}{18 \cdot 10^{-3}} \approx 611 \text{ A}$ ✓	Accept an answer in the range 597 – 611 A	1
d	the base of the thundercloud must be parallel to the Earth surface OR the base of the thundercloud must be flat OR the base of the cloud must be very long «compared with the distance from the surface» ✓		1

7 - (PHYSI/22_HL_Summer_2019_Q9) - Fields (ahl)



a	i	$E = \frac{1}{2} m \frac{GM}{r} - \frac{GMm}{r} = -\frac{1}{2} \frac{GMm}{r} \checkmark$ comparison with $V = -\frac{GM}{r} \checkmark$ «to give answer»		2
a	ii	ALTERNATIVE 1 «at the position of the planet» the potential depends only on the mass of the star /does not depend on the radius of the star $\checkmark$ the potential will not change and so the energy will not change $\checkmark$ ALTERNATIVE 2 r / distance between the centres of the objects / orbital radius remains unchanged $\checkmark$ since $E_{\text{Total}} = -\frac{1}{2} \frac{GMm}{r}$, energy will not change $\checkmark$		2
b		$\frac{kQ}{(0.600 + 0.820)^2} = \frac{kq}{0.820^2} \checkmark$ $\frac{Q}{q} = \frac{(0.600 + 0.820)^2}{0.820^2} = 2.9988 \approx 3 \checkmark$		2

8 - (PHYSI/20_HL_Winter_2020_Q8) - Fields (ahl)

a		ALTERNATIVE 1 work done on moving a positive test charge in any outward direction is negative $\checkmark$ potential difference is proportional to this work «so V decreases from A to B» $\checkmark$ ALTERNATIVE 2 potential gradient is directed opposite to the field so inwards $\checkmark$ the gradient indicates the direction of increase of V «hence V increases towards the centre/decreases from A to B» $\checkmark$ ALTERNATIVE 3 $V = \frac{kQ}{R}$ so as r increases V decreases $\checkmark$ V is positive as Q is positive $\checkmark$ ALTERNATIVE 4 the work done per unit charge in bringing a positive charge from infinity $\checkmark$ to point B is less than point A $\checkmark$		2
b		curve decreasing asymptotically for $r > R$ $\checkmark$ non – zero constant between 0 and R $\checkmark$ 		2
c	i	$\frac{W}{q} = \frac{1.7 \times 10^{-16}}{1.60 \times 10^{-19}} = 1.1 \times 10^3 \text{ «V»} \checkmark$		1
c	ii	$8.99 \times 10^9 \times Q \times \left(\frac{1}{5.0 \times 10^{-2}} - \frac{1}{1.0 \times 10^{-1}} \right) = 1.1 \times 10^3 \checkmark$ $Q = 1.2 \times 10^{-8} \text{ «C»} \checkmark$		2
d		to highlight similarities between «different» fields $\checkmark$		1

9 – (PHYSI/21_HL_Summer_2021_Q2) – Circular Motion & Gravitation, Fields (ahl)



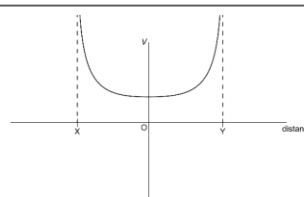
a		«circular motion» involves a changing velocity ✓ «Tangential velocity» is «always» perpendicular to centripetal force/acceleration ✓ there must be a force/acceleration towards centre/star ✓ without a centripetal force the planet will move in a straight line ✓	2 max
b		$F = \frac{(6.67 \times 10^{-11})(8 \times 10^{24})(3.2 \times 10^{30})}{(4.4 \times 10^{10})^2} \approx 8.8 \times 10^{23} \text{ «N»} \checkmark$	1
c	i	$V_{\text{planet}} = \text{«-»} \frac{(6.67 \times 10^{-11})(8 \times 10^{24})}{9.1 \times 10^6} = \text{«-»} 5.9 \times 10^7 \text{ «J kg}^{-1}\text{»} \checkmark$ $V_{\text{star}} = \text{«-»} \frac{(6.67 \times 10^{-11})(3.2 \times 10^{30})}{4.4 \times 10^{10}} = \text{«-»} 4.9 \times 10^7 \text{ «J kg}^{-1}\text{»} \checkmark$ $V_{\text{planet}} - V_{\text{star}} = \text{«-»} 4.9 \times 10^9 \text{ «J kg}^{-1}\text{»} \checkmark$	3
c	ii	use of $v_{\text{esc}} = \sqrt{2V} \checkmark$ $v = 9.91 \times 10^4 \text{ «m s}^{-1}\text{»} \checkmark$	2

10 – (PHYSI/22_HL_Summer_2021_Q10) – Fields (ahl)

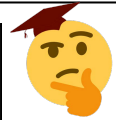
a		$\frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \cdot 8.9 \times 10^{22}}{(1.8 \times 10^8)^2} \Rightarrow 1.8 \checkmark$ N kg⁻¹ OR m s⁻² ✓	2
b	i	$\frac{1.9 \times 10^{27}}{4.9 \times 10^8} \text{ AND } \frac{8.9 \times 10^{22}}{1.8 \times 10^8} \text{ seen} \checkmark$ $\frac{1.9 \times 10^{27} \cdot 1.8 \times 10^8}{4.9 \times 10^8 \cdot 8.9 \times 10^{22}} \approx 78 \checkmark$	2
b	ii	«this is the escape speed for Io alone but» gravitational potential / field of Jupiter must be taken into account ✓	1
c		$-GM_{\text{Jupiter}} \left(\frac{1}{1.88 \times 10^8} - \frac{1}{1.06 \times 10^{11}} \right) = 5.21 \times 10^7 \text{ J kg}^{-1} \checkmark$ « multiplies by 3600 kg to get » $1.9 \times 10^{11} \text{ «J»} \checkmark$	2

11 – (PHYSI/21_HL_Summer_2022_Q7) – Fields (ahl)

a		use of $\frac{kQ}{r} \checkmark$ $\frac{(8.99 \times 10^9)(4 \times 10^{-6})}{0.15} \text{ OR } 240 \text{ «kV» for one charge calculated} \checkmark$ 480 «kV» for both ✓	3
b		symmetric curve around 0 with potential always positive, «bowl shape up» and curve not touching the horizontal axis. ✓ clear asymptotes at X and Y ✓	2



c	i	force is towards O ✓ always ✓		2
c	ii	ALTERNATIVE 1 motion is not SHM ✓ «because SHM requires force proportional to r and» this force depends on $\frac{1}{r^2}$ ✓ ALTERNATIVE 2 motion is not SHM ✓ energy-distance «graph must be parabolic for SHM and this» graph is not parabolic ✓		2

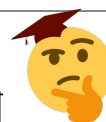


12 – (PHYSI/22_HL_Summer_2022_Q7) – Fields (ahl)

a		the work done per unit charge ✓ In bringing a small/point/positive/test «charge» from infinity to the point ✓	Allow use of energy per unit charge for MP1	2
b		use of $V/r = \text{constant}$ ✓ 0.40 m ✓	Allow [1] max if $r + 2.8$ used to get 0.47 m. Allow [2] marks if they calculate Q at one potential and use it to get the distance at the other potential.	2
c	i	90° / perpendicular ✓		1
c	ii	$\frac{1}{2} \times 0.14 \times 10^{-3} \times 3.1^2$ OR 0.67 «mJ» seen ✓		1
c	iii	«p.d. between point and sphere surface = » {53.9 kV – 7.71} «kV» OR 46.2 «kV» seen ✓ «energy required =» $VQ = 46\,200 \times 2.4 \times 10^{-6} = 1.11 \text{ mJ}$ ✓ this is greater than kinetic energy so will not reach sphere ✓	MP3 is for a conclusion consistent with the calculations shown. Allow ECF from MP1	3

13 – (PHYSI/20_HL_Winter_2022_Q8) – Fields (ahl)

a		potential greater at Y ✓ «from $E = -\frac{\Delta V_e}{\Delta r}$ » the potential increases in the direction opposite to field strength «so from X to Y» OR opposite to the direction of the field lines, «so from X to Y» OR «from $W = q\Delta V_e$ » work done to move a positive charge from X to Y is positive «so the potential increases from X to Y» ✓		2
b	i	orbital radius $6.4 \cdot 10^6 \sim 5.0 \cdot 10^5 \ll 6.9 \cdot 10^6 \text{ m}$ ✓ $KE = \frac{1}{2} \times 8.0 \cdot 10^2 \times \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{6.9 \cdot 10^6}$ OR $2.3 \cdot 10^{12} \text{ «J»}$ ✓	Award [1] max for answers ignoring orbital height ($KE = 2.5 \times 10^{10} \text{ J}$)	2
b	ii	change in PE $= 6.67 \times 10^{-11} \times 8.0 \times 10^{24} \times 8.0 \times 10^2 \left(\frac{1}{6.4 \cdot 10^6} - \frac{1}{6.9 \cdot 10^6} \right) = 3.6 \times 10^9 \text{ «J»}$ ✓ energy needed = $KE + \Delta PE = 2.7 \cdot 10^{10} \text{ «J»}$ ✓	Allow ECF from 8(b)(i).	2

1 - (PHYSI/21_HL_Summer_2017_Q8) - *Electromagnetic Induction (ahl)*

a		the size of the <u>induced</u> emf ✓ is proportional/equal to the rate of change of flux linkage ✓
b	i	varying voltage/current in primary coil produces a varying magnetic field ✓ this produces a change in flux linkage / change in magnetic field in the secondary coil ✓ a «varying» emf is induced/produced/generated in the secondary coil ✓ voltage is stepped down as there are more turns on the primary than the secondary ✓
b	ii	output voltage = $\frac{90 \times 240}{1800}$ ✓ = 12 «V» ✓
c		laminated core reduces eddy currents ✓ less thermal energy is transferred to the surroundings ✓
d		for a certain power to be transmitted, large V means low I ✓ less thermal energy loss as $P = I^2 R$ / joule heating ✓

2 - (PHYSI/22_HL_Summer_2017_Q3) - Electromagnetic Induction (ahl), Electricity & Magnetism



a		$\left\langle \frac{1}{2} CV^2 = \frac{1}{2} \times 0.022 \times 24^2 \right\rangle = 6.3 \text{ «J»} \checkmark$
b		$\frac{1}{100} = e^{-\frac{t}{8.0 \times 0.022}} \checkmark$ $\ln 0.01 = -\frac{t}{8.0 \times 0.022} \checkmark$ $0.81 \text{ «s»} \checkmark$
c	i	$c = \frac{Q}{m \times \Delta T}$ OR $\frac{6.3}{0.00061 \times 28} \checkmark$ $370 \text{ J kg}^{-1} \text{ K}^{-1} \checkmark$

c	ii	ALTERNATIVE 1 some thermal energy will be transferred to surroundings/along connecting wires/to thermometer ✓ estimate «of specific heat capacity by student» will be larger «than accepted value» ✓ ALTERNATIVE 2 not all energy transferred as capacitor did not fully discharge ✓ so estimate «of specific heat capacity by student» will be larger «than accepted value» ✓
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3 - (PHYSI/22_HL_Summer_2017_Q6) - Electromagnetic Induction (ahl)



a		when an electric field is applied to any material «using a cell etc» it acts to accelerate any free electrons ✓ electrons are the charge carriers «in copper» ✓ metals/copper have many free electrons whereas insulators have few/no free electrons/charge carriers ✓
b	i	area = $\frac{1.7 \times 10^{-8} \times 35 \times 10^3}{64}$ «= $9.3 \times 10^{-6} \text{ m}^2$» ✓ radius = «$\sqrt{\frac{9.3 \times 10^{-6}}{\pi}}$ =» 0.00172 m ✓
b	ii	I_{peak} «= $\frac{P_{\text{peak}}}{V_{\text{peak}}}$» = 730 «A» ✓
b	iii	resistance of cable identified as «$\frac{64}{32}$ =» 2 Ω ✓ a power 35000 seen in solution ✓ plausible answer calculated using $\frac{2I^2}{35000}$ «plausible if in range 10 W m⁻¹ to 150 W m⁻¹ when quoted answers in (b)(ii) used» 31 «W m⁻¹» ✓
c		«$\frac{\text{response to (b)(ii)}}{2\sqrt{2}}$» = 260 «A» ✓



d		wires/cable attract whenever current is in same direction ✓ charge flow/current direction in both wires is always same «but reverses every half cycle» ✓ force varies from 0 to maximum ✓ force is a maximum twice in each cycle ✓
e	i	higher voltage gives lower current ✓ «energy losses depend on current» hence thermal/heating/power losses reduced ✓
e	ii	laminated core ✓

4 - (PHYSI/21_HL_Summer_2018_Q7) - Electromagnetic Induction (ahl), Fields (ahl)

a		$d = \frac{8.85 \times 10^{-12} \times 0.025^2}{4.3 \times 10^{-12}} = 1.3 \times 10^{-3} \text{ «m»} \checkmark$		1
b		$6.9 \times 10^{-11} \text{ «C»} \checkmark$ negative charge/sign $\checkmark$		2
c		charge increases $\checkmark$ because capacitance increases AND pd remains the same. $\checkmark$		2
d		ALTERNATIVE 1 $\frac{1200}{100} = 220 \checkmark$ $2640 \text{ «V»} \checkmark$ $V_{rms} = \frac{2640}{\sqrt{2}} = 1870 \text{ «V»} \checkmark$ ALTERNATIVE 2 (Primary) $V_{rms} = \frac{220}{\sqrt{2}} = 156 \text{ «V»} \checkmark$ (Secondary) $V_{rms} = \frac{156}{100} = 1.56 \text{ «V»} \checkmark$ $V_{rms} = 1870 \text{ «V»} \checkmark$	Allow ECF from MP1 and MP2. Award [2] max for 12.96 V (reversing N_p and N_s).	3
e		step-up transformers increase voltage/step-down transformers decrease voltage $\checkmark$ (step-up transformers increase voltage) from plants to transmission lines / (step-down transformers decrease voltage) from transmission lines to final utilizers $\checkmark$ this decreases current (in transmission lines) $\checkmark$ to minimize energy/power losses in transmission $\checkmark$		3 max

5 - (PHYSI/22_HL_Summer_2018_Q8) - Fields (ahl), Electromagnetic Induction (ahl)



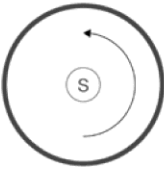
a		$C \ll \frac{Q}{V} \approx 8.8 \cdot 10^{-12} \frac{1.2 \cdot 10^8}{1500} \checkmark$ $\ll C \approx 6.60 \cdot 10^{-7} \text{ F} \checkmark$		1
b	i	$V \ll \frac{Q}{C} \approx \frac{25}{6.6 \cdot 10^{-7}} \checkmark$ $V \approx 3.8 \cdot 10^7 \text{ V} \checkmark$	Award [2] for a bald correct answer	2
b	ii	ALTERNATIVE 1 $E \ll \frac{1}{2} QV \approx \frac{1}{2} \cdot 25 \cdot 3.8 \cdot 10^7 \checkmark$ $E \approx 4.7 \cdot 10^8 \text{ J} \checkmark$ ALTERNATIVE 2 $E \ll \frac{1}{2} CV^2 \approx \frac{1}{2} \cdot 6.60 \cdot 10^{-7} \cdot (3.8 \cdot 10^7)^2 \checkmark$ $E \approx 4.7 \cdot 10^8 \text{ J} / 4.8 \cdot 10^8 \text{ J} \approx 1 \text{ if rounded value of } V \text{ used} \checkmark$	Award [2] for a bald correct answer Allow ECF from (b)(i) Award [2] for a bald correct answer Allow ECF from (b)(i)	2
c	i	$Q \ll Q_0 e^{-t/\tau} \approx 25 \cdot e^{-18/32} \checkmark$ $Q \approx 14.2 \text{ C} \checkmark$ charge delivered = $Q = 25 - 14.2 = 10.8 \text{ C} \checkmark$ $\approx -11 \text{ C} \checkmark$	Final answer must be given to at least 3 significant figures	3
c	ii	$I \ll \frac{\Delta Q}{\Delta t} \approx \frac{11}{18 \cdot 10^{-3}} \approx 610 \text{ A} \checkmark$	Accept an answer in the range 597 – 611 A	1
d		the base of the thundercloud must be parallel to the Earth surface OR the base of the thundercloud must be flat OR the base of the cloud must be very long «compared with the distance from the surface» $\checkmark$		1

6 - (PHYSI/21_HL_Summer_2019_Q8) - Electromagnetic Induction (ahl), Electricity & Magnetism

a	i	length $\cdot \frac{d \times C}{\text{width} \times \mu_0} \checkmark$ $\approx 0.33 \text{ m} \checkmark$ so 0.66/0.67 m «as two lengths required» $\checkmark$		3
a	ii	$1.5 \times 10^6 \times 55 \times 10^{-6} = 83 \text{ V} \checkmark$ $q \ll CV \approx 5.6 \times 10^{-6} \text{ C} \checkmark$		2
b	i	$0.5 = e^{-\frac{t}{RC}} = e^{-\frac{t}{1200 \cdot 6.8 \cdot 10^{-6}}} \checkmark$ $t \approx 1200 \times 6.8 \cdot 10^{-6} \times \ln 0.5 \checkmark$ $5.7 \times 10^{-5} \text{ s} \checkmark$ OR use of $t_1 = RC \times \ln 2 \checkmark$ $1200 \times 6.8 \times 10^{-6} \times 0.693 \checkmark$ $5.7 \times 10^{-5} \text{ s} \checkmark$		3
b	ii	mention of Faraday's law $\checkmark$ indicating that changing current in discharge circuit leads to change in flux in coil/change in magnetic field «and induced emf» $\checkmark$		2
b	iii	decrease/reduce $\checkmark$ resistance (R) OR capacitance (C) $\checkmark$		2

7 - (PHYSI/22_HL_Summer_2019_Q10) - Electromagnetic Induction (ahl)



a	the magnetic field at the position of the ring is increasing «because the magnet gets closer to the ring» ✓		1
b	the current must be counterclockwise «in diagram 2» ✓ eg:  Diagram 2: view from above		1
c	since the induced magnetic field is upwards OR by Lenz law the change «of magnetic field/flux» must be opposed OR by conservation of energy the movement of the magnet must be opposed ✓ therefore the force is repulsive/upwards ✓		2

8 - (PHYSI/20_HL_Winter_2019_Q9) - Electromagnetic Induction (ahl)

a	$E = \frac{1}{2} \frac{Q^2}{C} \text{ OR } V = \frac{Q}{C} \checkmark$ $E = \frac{1}{2} \frac{(48 \times 10^{-6})^2}{18 \times 10^{-6}} = 6.4 \times 10^{-5} \text{ «J» } \checkmark$		2
b	i ALTERNATIVE 1 $Q_X + Q_Y = 48 \checkmark$ $\frac{Q_X}{18} = \frac{Q_Y}{12} \checkmark$ solving to get $Q_X = 29 \text{ «}\mu\text{C»}$ $Q_Y = 19 \text{ «}\mu\text{C»}$ ✓ ALTERNATIVE 2 $48 - 18 \text{ V} = 12 \text{ V} \Rightarrow V = 1.6 \text{ «V» } \checkmark$ $Q_X = 1.6 \times 18 = 29 \text{ «}\mu\text{C»}$ $Q_Y = 1.6 \times 12 = 19 \text{ «}\mu\text{C»} \checkmark$	Award [3] for bald correct answer	3
b	ii ALTERNATIVE 1 $E_T = \frac{1}{2} \frac{(29 \times 10^{-6})^2}{18 \times 10^{-6}} + \frac{1}{2} \frac{(19 \times 10^{-6})^2}{12 \times 10^{-6}} \checkmark$ $= 3.8 \times 10^{-5} \text{ «J» } \checkmark$ ALTERNATIVE 2 $E_T = \frac{1}{2} \times 18 \times 10^{-6} \times 1.6^2 + \frac{1}{2} \times 12 \times 10^{-6} \times 1.6^2 \checkmark$ $= 3.8 \times 10^{-5} \text{ «J» } \checkmark$	Allow ECF from (b)(i) Award [2] for bald correct answer Award [1] max as ECF to a calculation using only one charge	2
c	charge moves/current flows «in the circuit» ✓ thermal losses «in the resistor and connecting wires» ✓	Accept heat losses for MP2	2

9 - (PHYSI/20_HL_Winter_2020_Q9) - Electromagnetic Induction (ahl)

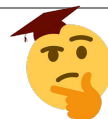


a		there is a magnetic flux «linkage» in the coil / coil cuts magnetic field ✓ this flux «linkage» changes as the angle varies/coil rotates ✓ «Faraday's law» connects induced emf with rate of change of flux «linkage» with time ✓	Do not award MP2 or 3 for answers that don't discuss flux.	3
b	i	$V_{\text{rms}} = \frac{25 \cdot 10^{-3}}{\sqrt{2}} \approx 17.7 \cdot 10^{-3} \text{ V}$ ✓ $I_{\text{rms}} = \frac{8.5 \cdot 10^{-3}}{17.7 \cdot 10^{-3}} \approx 48 \text{ A}$ ✓		2
b	ii	«power loss proportional to I^2 hence the step-up factor is $\sqrt{2.5 \cdot 10^{-2}} \approx 16$ ✓		1
b	iii	peak emf doubles ✓ T halves ✓	Must show at least 1 cycle.	2

10 - (PHYSI/21_HL_Summer_2021_Q5) - Electromagnetic Induction (ahl)

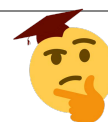
a		to charge a capacitor current must be direct ✓ diode will only allow current to flow in one direction OR the diode provides half wave rectification ✓		2
b	i	$V_s = 15 \cdot 220 = 3300 \text{ V}$ ✓ $E = \frac{1}{2} C V^2 = \frac{1}{2} \cdot 30 \cdot 10^{-6} \cdot 3300^2$ OR 163 J ✓	Allow use of 220 V as an RMS value to calculate $V_s = 467 \text{ V}$ and $E = 327 \text{ J}$ for full marks if appropriate work is provided. Answer must be to 3 or more sf or working shown for MP2	2
b	ii	$Q_0 = 0.0989 \approx 0.1 \text{ C}$ ✓	Allow ECF from (b)(i) ($Q = 30 \mu\text{F} \times V$)	1
b	iii	labels - on the lower side of the capacitor ✓		1
c	i	the energy stored in the capacitor is delivered to the resistor/heart ✓		1
c	ii	use of $Q = Q_0 e^{-\frac{t}{\tau}}$ to show that $0.37 \frac{1}{e}$ ✓		1
c	iii	ALTERNATIVE 1 reads from the graph $\tau = 1.6 \text{ ms}$ ✓ so $R = \frac{0.0016}{30 \cdot 10^{-6}} = 53 \Omega$ ✓ ALTERNATIVE 2 reads a correct value from the graph for $\frac{Q}{Q_0}$ and t ✓ so $R = \frac{t}{\ln\left(\frac{Q}{Q_0}\right) (3 \cdot 10^{-6})}$ ✓		2
d		«the capacitors are in parallel hence» capacitances are added / more charge is stored OR C_{eq} is larger OR electrode capacitor charges and discharges ✓ «therefore» discharge takes longer/increases ✓		2

11 - (PHYSI/22_HL_Summer_2021_Q7) - Oscillations & Waves, Electromagnetic Induction (ahl)



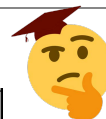
a	i	$\llcorner \frac{15}{110} \times 3300 = \gg 450 \llcorner \text{turns} \gg \checkmark$		1
a	ii	ALTERNATIVE 1 calculates total current = $\frac{35}{15} \times 8 \llcorner = 18.7 \text{ A} \gg \checkmark$ resistance = $\llcorner \frac{15}{18.7} = \gg 0.80 \llcorner \Omega \gg \checkmark$ ALTERNATIVE 2 calculates total power = $35 \times 8 \llcorner = 280 \text{ W} \gg \checkmark$ resistance = $\llcorner \frac{15^2}{280} = \gg 0.80 \llcorner \Omega \gg \checkmark$ ALTERNATIVE 3 calculates individual resistance = $\frac{15^2}{35} \llcorner = 6.43 \llcorner \Omega \gg \checkmark$ resistance = $\llcorner \frac{6.43}{8} = \gg 0.80 \llcorner \Omega \gg \checkmark$		2
a	iii	total power required = $280 \llcorner \text{W} \gg$ OR uses factor $\frac{3300}{450}$ OR total current = $18.7 \llcorner \text{A} \gg \checkmark$ current = $2.5 \text{ OR } 2.6 \llcorner \text{A} \gg \checkmark$	Award [2] marks for a bald correct answer. Allow ECF from (a)(ii).	2
a	iv	the secondary coil does not enclose all flux $\llcorner \text{lines from core} \gg \checkmark$ induced emf in secondary OR power transferred to the secondary OR efficiency is less than expected $\checkmark$	Award [0] for references to eddy currents/heating of the core as the reason. Award MP2 if no reason stated.	2
b		bob cuts mag field lines OR there is a change in flux linkage $\checkmark$ induced emf across bob $\checkmark$ leading to eddy/induced current in bob $\checkmark$ eddy/induced current produces a magnetic field that opposes $\llcorner \text{direction of} \gg$ motion $\checkmark$ force due to the induced magnetic field decelerates bob $\checkmark$ damping of pendulum increases/there is additional $\llcorner \text{magnetic} \gg$ damping $\checkmark$	MP4 and MP5 can be expressed in terms of energy transfer from kinetic energy of bob to electrical/thermal energy in bob	4 max

12 - (PHYSI/20_HL_Winter_2021_Q5) - Electromagnetic Induction (ahl)



a		70 3.5 ✓		1
b	i	shape as above ✓		1
b	ii	shape as above ✓	Vertical lines not necessary to score Allow ECF from (b)(i).	1
c	i	ALTERNATIVE 1 maximum flux at $5.0 \cdot 5.0 \cdot 10^{-4} \cdot 85 = 0.94$ ✓ emf = $\frac{0.20}{0.25} = 0.80$ «V» ✓ ALTERNATIVE 2 emf induced in one turn = $BvL = 0.94 \cdot 0.20 \cdot 0.05 = 0.0094$ «V» ✓ emf = $85 \cdot 0.0094 = 0.80$ «V» ✓	Award [2] marks for a bald correct answer Allow ECF from MP1	2
c	ii	$I = \frac{V}{R} = \frac{0.8}{2.4}$ OR 0.33 «A» ✓ $F = \alpha NBI L = 85 \cdot 0.94 \cdot 0.33 \cdot 0.05 = 1.3$ «N» ✓	Allow ECF from (c)(i) Award [2] marks for a bald correct answer	2
d	i	Energy is being dissipated for 0.50 s ✓ $E = FvL = 1.3 \cdot 0.20 \cdot 0.50 = 0.13$ J ✓ OR $E = VIt = 0.80 \cdot 0.33 \cdot 0.50 = 0.13$ J ✓	Allow ECF from (b) and (c). Watch for candidates who do not justify somehow the use of 0.5 s and just divide by 2 their answer.	2
d	ii	$\Delta T = \frac{0.13}{0.018 \cdot 385}$ ✓ $\Delta T = 1.9 \cdot 10^{-2}$ «K» ✓	Allow [2] marks for a bald correct answer Award [1] for a POT error in MP1	2

13 – (PHYSI/21_HL_Summer_2022_Q8) – Electromagnetic Induction (ahl)



a		$Q = CV = 1.5 \times 28 \times 10^{-6} = 0.042 \text{ «mC»} \checkmark$	Award MP for full replacement or correct answer to at least 2 significant figures.	1
b	i	$E_1 = \frac{1}{2} \times (28 \times 10^{-6}) (1.5)^2 = 3.15 \times 10^{-6} \text{ «J»} \checkmark$ total capacitance = 50 «μF» OR $p.d. = \frac{42 \times 10^{-6}}{50 \times 10^{-6}} = 0.84 \text{ «V»}$ OR charge on C_1 after switch moved to B = 0.0235 «mC» $\checkmark$ $E_1 = \frac{1}{2} \times (28 \times 10^{-6}) (0.84)^2 = 9.9 \times 10^{-6} \text{ «J»} \checkmark$ energy lost = $3.2 \times 10^{-6} - 9.9 \times 10^{-6} = 22 \text{ «μJ»} \checkmark$		4
b	ii	energy transferred to electromagnetic radiation «to environment» OR energy is transferred as thermal energy / heat «to circuit components» $\checkmark$		1
c	i	initial deflection by voltmeter falling to zero reading $\checkmark$ emf is induced «only» while the field / flux is changing		2
c	ii	attempted use of $\epsilon = \frac{\Delta \phi}{\Delta t}$ OR $NA \frac{\Delta B}{\Delta t} \checkmark$ $\epsilon = \frac{5 \times 7.5 \times 10^{-3} \times 6.4 \times 10^{-4}}{3 \times 10^{-3}} \checkmark$ 8.0 «mV» $\checkmark$		3

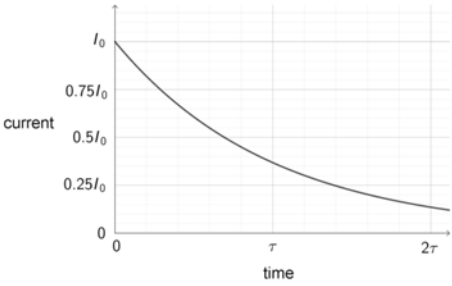
14 – (PHYSI/22_HL_Summer_2022_Q8) – Electromagnetic Induction (ahl)

a	i	«–» 5.0 «mV» OR $5.0 \times 10^{-3} \text{ «V»} \checkmark$	Accept 5.1	1
a	ii	$\text{kg m}^2 \text{A}^{-1} \text{s}^{-3} \checkmark$		1
b	i	ALTERNATIVE 1 Flux linkage is represented by magnetic field lines through the coil $\checkmark$ when magnet has passed through the coil / is moving away $\checkmark$ flux «linkage» is decreasing $\checkmark$ suitable comment that it is the opposite when above $\checkmark$ when the magnet goes through the midpoint the induced emf is zero $\checkmark$ ALTERNATIVE 2 reference to / states Lenz's law $\checkmark$ when magnet has passed through the coil / is moving away $\checkmark$ «coil attracts outgoing S pole so» induced field is downwards $\checkmark$ before «coil repels incoming N pole so» induced field is upwards OR induced field has reversed $\checkmark$ when the magnet goes through the midpoint the induced emf is zero $\checkmark$	OWTTE	3 max

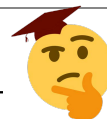
b	ii	area represents the total change in flux «linkage» ✓ the change in flux is the same going in and out ✓ «when magnet is approaching» flux increases to a maximum ✓ «when magnet is receding» flux decreases to zero ✓ «so areas must be the same»		2 max
c		magnet moves slower ✓ overall time «for interaction» will be longer ✓ peaks will be smaller ✓ areas will be the same as before ✓	Allow a graphical interpretation for MP2 as "graph more spread out"	3 max

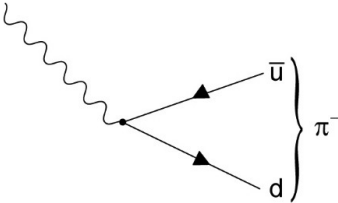


15 - (PHYSI/20_HL_Winter_2022_Q9) - Electromagnetic Induction (ahl)

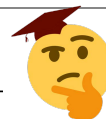
a		$\frac{1}{2} \times 1.5 \times 10^{-10} \times 24^2 \Rightarrow 4.3 \times 10^{-8} \text{ «J»} \checkmark$		1
b	i	«from $C = \epsilon \frac{A}{d}$ » capacitance decreases «by factor 4 / to $3.8 \times 10^{-11} \text{ F}$ » ✓ «from $V = \frac{q}{C}$ » charge unchanged hence p.d. increases by factor 4 / to 96 «V» ✓	Award [1] max for a reasoning without numbers.	2
b	ii	work = (energy in the new arrangement) – (initial energy) ✓ «energy increased by factor 4 hence» work = $3 \times 4.3 \times 10^{-8} = 1.3 \times 10^{-7} \text{ «J»} \checkmark$	Allow ECF from 9(a) Award [2] for a BCA	2
c	i	exponential decrease from current = $I_0 \checkmark$ approximately correct values for time = τ AND $2\tau \checkmark$ 	For MP2, the curve should be between 0.30 and 0.45 when time $t = \tau$ and below 0.20 when time $t = 2\tau$	2
c	ii	«activity vs time in» radioactive decay OR thermal energy transfer ✓	Accept any other appropriate physics phenomenon, as X-ray absorption. Accept terminal velocity as the question can be interpreted as a phenomenon modelled with an exponential function (i.e. including growth). Do not accept dice throwing.	1
d		without a capacitor, output voltage/current drops to zero «twice per cycle of input voltage» ✓ capacitor provides smoothing / smooths out voltage/current variations ✓ voltage/current output becomes constant / similar to direct current output ✓ voltage/current does not drop to zero ✓ by returning some of its energy/charge to the circuit «when input voltage is low» ✓		2 max

1 - (PHYSI/21_HL_Summer_2017_Q5) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



a		<i>Meson</i>: quark-antiquark pair ✓ <i>Baryon</i>: 3 quarks ✓
b	i	Alternative 1 strange quark changes «flavour» to an up quark ✓ changes in quarks/strangeness happen only by the weak interaction ✓ Alternative 2 Strangeness is not conserved in this decay «because the strange quark changes to an up quark» ✓ Strangeness is not conserved during the weak interaction ✓
	ii	arrows drawn in the direction shown ✓ 
	iii	W^- ✓
c		it lowers the cost to individual nations, as the costs are shared ✓ international co-operation leads to international understanding OR historical example of co-operation OR co-operation always allows science to proceed ✓ large quantities of data are produced that are more than one institution/research group can handle ✓ co-operation allows effective analysis\collaboration of able scientists ✓

2 - (PHYSI/21_HL_Summer_2017_Q9) - Quantum & Nuclear Physics (ahl)



a		Observation 1: particle – photon energy is below the work function OR $E = hf$ and energy is too small «to emit electrons» ✓ wave – the energy of an <i>em</i> wave is independent of frequency ✓ Observation 2: particle – a single electron absorbs the energy of a single photon «in an almost instantaneous interaction» ✓ wave – it would take time for the energy to build up to eject the electron ✓
b	i	attempt to calculate gradient of graph = $\frac{4.2 \times 10^{-19}}{6.2 \times 10^{14}}$ ✓ = $6.8 - 6.9 \times 10^{-34}$ «Js» ✓
	ii	ALTERNATIVE 1 minimum energy required to remove an electron «from the metal surface» ✓ ALTERNATIVE 2 energy required to remove the least tightly bound electron «from the metal surface» ✓
	iii	ALTERNATIVE 1 reading of y intercept from graph in range $3.8 - 4.2 \times 10^{-19}$ «J» ✓ conversion to eV = $2.4 - 2.6$ «eV» ✓ ALTERNATIVE 2 reading of x intercept from graph «$5.8 - 6.0 \times 10^{14}$ Hz» and using hf_0 to get $3.8 - 4.2 \times 10^{-19}$ «J» ✓ conversion to eV = $2.4 - 2.6$ «eV» ✓
c		line parallel to existing line ✓ to the right of the existing line ✓

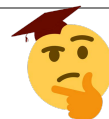
3 - (PHYSI/22_HL_Summer_2017_Q5) - Quantum & Nuclear Physics (ahl)

a		${}^4_2\alpha$ OR ${}^4_2\text{He}$ ✓ ${}^{222}_{86}\text{Rn}$ ✓
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b	i	ALTERNATIVE 1 6 days is 5.18×10^5 s ✓ activity after 6 days is $A_0 e^{-1.4 \times 10^{-11} \times 5.18 \times 10^5} \approx A_0$ OR $A = 0.9999927 A_0$ or $0.9999927 \lambda N_0$ OR states that index of e is so small that $\frac{A}{A_0}$ is ≈ 1 OR $A - A_0 \approx 10^{-15} \text{ «s}^{-1}\text{»}$ ✓ ALTERNATIVE 2 shows half-life of the order of 10^{11} s or 5.0×10^{10} s ✓ converts this to year «1600 y» or days and states half-life much longer than experiment compared to experiment ✓
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b	ii	ALTERNATIVE 1 use of $A = \lambda N_0$ ✓ conversion to number of molecules = $n N_A = 3.7 \times 10^{20}$ OR initial activity = $5.2 \times 10^9 \text{ «s}^{-1}\text{»}$ ✓ number emitted = $(6 \times 24 \times 3600) \times 1.4 \times 10^{-11} \times 3.7 \times 10^{20}$ or 2.7×10^{15} alpha particles ✓ ALTERNATIVE 2 use of $N = N_0 e^{-\lambda t}$ ✓ $N_0 = n \times N_A = 3.7 \times 10^{20}$ ✓ alpha particles emitted « = number of atoms disintegrated = $N - N_0$ » $N_0 (1 - e^{-\lambda \times 6 \times 24 \times 3600})$ or 2.7×10^{15} alpha particles ✓
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	c	i	alpha particles highly ionizing OR alpha particles have a low penetration power OR thin glass increases probability of alpha crossing glass OR decreases probability of alpha striking atom/nucleus/molecule ✓
	c	ii	conversion of temperature to 291 K ✓ $p = 4.5 \times 10^{-9} \times 8.31 \times \left\langle \frac{291}{1.3 \times 10^{-5}} \right\rangle$ OR $p = 2.7 \times 10^{15} \times 1.38 \times 10^{-23} \times \left\langle \frac{291}{1.3 \times 10^{-5}} \right\rangle \quad \checkmark$ 0.83 <i>or</i> 0.84 «Pa» ✓

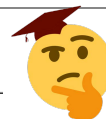
d		electron/atom drops from high energy state/level to low state ✓ energy levels are discrete ✓ wavelength/frequency of photon is related to energy change <i>or</i> quotes $E = hf$ <i>or</i> $E = \frac{hc}{\lambda}$ and is therefore also discrete ✓
e		peer review guarantees the validity of the work OR means that readers have confidence in the validity of work ✓

4 - (PHYSI/22_HL_Summer_2017_Q7) - Quantum & Nuclear Physics (ahl)

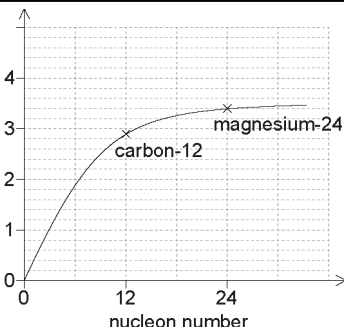


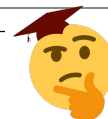
a	i	wavelength = $\ll \frac{hc}{E} = \frac{1.99 \times 10^{-25}}{3.5 \times 10^{-19}} = \gg 5.7 \times 10^{-7} \ll \text{m} \gg \checkmark$
a	ii	«potential» energy is required to leave surface $\checkmark$ all/most energy given to potential «so none left for kinetic energy» $\checkmark$
b		energy surplus = $1.7 \times 10^{-19} \text{ J} \checkmark$ $v_{\text{max}} = \sqrt{\frac{2 \times 1.7 \times 10^{-19}}{9.1 \times 10^{-31}}} = 6.1 \times 10^5 \ll \text{m s}^{-1} \gg \checkmark$
c	i	«same intensity of radiation so same total energy delivered per square metre per second» light has higher photon energy so fewer photons incident per second $\checkmark$
c	ii	1:1 correspondence between photon and electron $\checkmark$ so fewer electrons per second $\checkmark$ current smaller $\checkmark$

5 - (PHYSI/20_HL_Winter_2017_Q3) - Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl), Measurements & Uncertainties

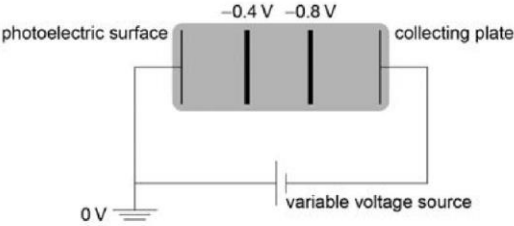


a	i	«electron» neutrino ✓ it has a lepton number of 1 «as lepton number is conserved» ✓ it has a charge of zero/is neutral «as charge is conserved» OR it has a baryon number of 0 «as baryon number is conserved» ✓	<i>Do not allow antineutrino</i> <i>Do not credit answers referring to energy</i>
a	ii	hadrons experience strong force OR leptons do not experience the strong force ✓ hadrons made of quarks/not fundamental OR leptons are not made of quarks/are fundamental ✓ hadrons decay «eventually» into protons OR leptons do not decay into protons ✓	<i>Accept leptons experience the weak force</i> <i>Allow "interaction" for "force"</i>
b	i	«high energy particles incident on» thin sample ✓ detect angle/position of deflected particles ✓ reference to interference/diffraction/minimum/maximum/numbers of particles ✓	<i>Allow "foil" instead of thin</i>
b	ii	$\lambda \propto \frac{1}{\sqrt{E}}$ OR $\lambda \propto \frac{1}{E}$ ✓ so high energy gives small λ ✓ to match the small nuclear size ✓ Alternative 2 $E = hf$ /energy is proportional to frequency ✓ frequency is inversely proportional to wavelength/ $c = f\lambda$ ✓ to match the small nuclear size ✓ Alternative 3 higher energy means closer approach to nucleus ✓ to overcome the repulsive force from the nucleus ✓ so greater precision in measurement of the size of the nucleus ✓	<i>Accept inversely proportional</i> <i>Only allow marks awarded from one alternative</i>
c		two analogous situations stated ✓ one element of the analogy equated to an element of physics ✓	<i>eg: moving away from Earth is like climbing a hill where the contours correspond to the equipotentials</i> <i>Atoms in an ideal gas behave like pool balls</i> <i>The forces between them only act during collisions</i>

d	i	$R = 2.7 \times 10^{-15} \times 2^{\frac{1}{3}} \checkmark$ $3.4 - 3.5 \times 10^{-15} \text{ «m» } \checkmark$	Allow use of the Fermi radius from the data booklet
d	ii	correctly plotted $\checkmark$	Allow ECF from (d)(i)
d	iii	single smooth curve passing through both points with decreasing gradient $\checkmark$ through origin $\checkmark$	



6 - (PHYSI/21_HL_Summer_2018_Q8) - Quantum & Nuclear Physics (ahl)

a		$E_1 = 13.6 \text{ «eV»}$ $E_2 = \frac{13.6}{4} = 3.4 \text{ «eV» } \checkmark$ energy of photon is difference $E_2 - E_1 = 10.2 \text{ «eV» } \checkmark$	Must see at least 10.2 eV.	2
b	i	$10 \times 5.1 = 4.9 \text{ «eV» } \checkmark$ $4.9 \times 1.6 \times 10^{-19} = 7.8 \times 10^{-19} \text{ «J» } \checkmark$	Allow 5.1 if 10.2 is used to give $8.2 \times 10^{-19} \text{ «J»}$.	2
b	ii	EPE produced by battery $\checkmark$ exceeds maximum KE of electrons / electrons don't have enough KE $\checkmark$	For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.	2
b	iii	$4.9 \text{ «V» } \checkmark$	Allow 5.1 if 10.2 is used in (b)(i). Ignore sign on answer.	1
c	i	two equally spaced vertical lines (judge by eye) at approximately 1/3 and 2/3 $\checkmark$ labelled correctly $\checkmark$ 		2
c	ii	kinetic energy at collecting plate = $0.9 \text{ «eV» } \checkmark$ $\text{speed} = \sqrt{\frac{2 \times 0.9 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} = 5.6 \times 10^5 \text{ «ms}^{-1}\text{» } \checkmark$	Allow ECF from MP1	2

7 – (PHYSI/22_HL_Summer_2018_Q9) – Quantum & Nuclear Physics (ahl), Atomic, nuclear & Particle Physics



a	«most of» the mass of the atom is confined within a very small volume/nucleus ✓ «all» the positive charge is confined within a very small volume/nucleus ✓ electrons orbit the nucleus «in circular orbits» ✓	2 max
b	the electrons accelerate and so radiate energy ✓ they would therefore spiral into the nucleus/atoms would be unstable ✓ electrons have discrete/only certain energy levels ✓ the only orbits where electrons do not radiate are those that satisfy the Bohr condition «$mvr = n \frac{h}{2\pi}$» ✓	3 max

c	i	$\frac{m_e v^2}{r} = \frac{ke^2}{r^2}$ OR KE = $\frac{1}{2} m_e v^2$ PE = $\frac{1}{2} \frac{ke^2}{r}$ hence $\frac{1}{2} m_e v^2 = \frac{1}{2} \frac{ke^2}{r}$ ✓ «solving for v to get answer»	Answer given – look for correct working	1
c	ii	combining $v = \sqrt{\frac{ke^2}{m_e r}}$ with $m_e v r = \frac{h}{2\pi}$ using correct substitution ✓ «eg $m_e^2 \frac{ke^2}{r^2} = \frac{h^2}{4\pi^2 r^2}$ » correct algebraic manipulation to gain the answer ✓	Answer given – look for correct working Do not allow a bald statement of the answer for MP2. Some further working eg cancellation of m or r must be shown	2
c	iii	$r = \frac{(6.63 \times 10^{-34})^2}{4\pi^2 \cdot 8.99 \times 10^9 \cdot 9.11 \times 10^{-31} \cdot (1.6 \times 10^{-19})^2}$ $r = 5.3 \times 10^{-11} \text{ «m»}$ ✓		1
d	i	the energy released is $3.54 - 0.48 = 3.06 \text{ «MeV»}$ ✓ this is shared by the electron and the antineutrino ✓ so the electron's energy varies from 0 to 3.06 «MeV» ✓		3
d	ii	the palladium nucleus emits the photon when it decays into the ground state «from the excited state» ✓		1

d	iii	Photon energy $E = 0.48 \times 10^6 \times 1.6 \times 10^{-19} = 7.68 \times 10^{-14} \text{ J}$ ✓ $\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{7.68 \times 10^{-14}} = 2.6 \times 10^{-12} \text{ «m»}$ ✓	Award [2] for a bald correct answer Allow ECF from incorrect energy	2
e	i	line <u>with arrow</u> as shown labelled anti-neutrino/ $\bar{\nu}$ ✓ eg: 	Correct direction of the "arrow" is essential The line drawn must be "upwards" from the vertex in the time direction i.e. above the horizontal	1
e	ii	$V = W^-$ ✓		1

8 – (PHYSI/20_HL_Winter_2018_Q5) – Atomic, nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)



a	i	identifies $\lambda = 435 \text{ nm}$ ✓ $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4.35 \times 10^{-7}} \text{ J}$ ✓ $4.6 \times 10^{-19} \text{ J}$ ✓		3
a	ii	-0.605 OR -0.870 OR -1.36 to -5.44 AND arrow pointing downwards ✓	Arrow MUST match calculation in (a)(i) Allow ECF from (a)(i)	1
a	iii	Difference in energy levels is equal to the energy of the photon ✓ Downward arrow as energy is lost by hydrogen/energy is given out in the photon/the electron falls from a higher energy level to a lower one ✓		2
b	i	$\frac{\lambda}{2 \sin \theta} = \frac{656.20}{0.181 \times 2} = 1813 \text{ nm}$ ✓ so spacing is $\frac{3.5 \times 10^{-3}}{1813} = 1.9 \times 10^{-6} \text{ m}$ ✓	Allow use of either wavelength or the mean value Must see at least 2 SF for a bald correct answer	2
b	ii	$2 \times 4.1 \times 10^{-7} = 1.9 \times 10^{-6} \sin \theta_r$ seen OR $6.6 \times 10^{-7} = 1.9 \times 10^{-6} \sin \theta_r$ seen ✓ $\theta_r = 24 - 26^\circ$ ✓ OR $\theta_r = 19 - 20^\circ$ ✓ $\theta = 5 - 6^\circ$ ✓	For MP3 answer must follow from answers in MP2 For MP3 do not allow ECF from incorrect angles	3
b	iii	centre of pattern is white ✓ coloured fringes are formed ✓ blue/violet edge of order is closer to centre of pattern OR red edge of order is furthest from centre of pattern ✓ the greater the order the wider the pattern ✓ there are gaps between «first and second order» spectra ✓		3 max

9 – (PHYSI/22_HL_Summer_2019_Q11) – Quantum & Nuclear Physics (ahl)

a		«de Broglie's hypothesis states that the» electron is represented by a wave ✓ therefore it cannot be localized/it is spread out/it does not have a definite position ✓	Award MP1 for any mention of wavelike property of an electron.	2
b	i	« $d \sin \theta = \lambda \Rightarrow d = \frac{1.6 \times 10^{-15}}{\sin 17} / 5.47 \times 10^{-15} \text{ m}$ » ✓ $R = \frac{d}{2} = 2.7 / 2.8 \times 10^{-15} \text{ m}$ ✓		2
b	ii	this implies that the nucleons are very tightly packed/that there is very little space in between the nucleons ✓ because the nuclear force is stronger than the electrostatic force ✓		2
c	i	number of nuclei is $\frac{28 \times 10^3}{64} \times 6.02 \times 10^{23} / 2.63 \times 10^{20}$ ✓ $A = \lambda N = 2.63 \times 10^{20} \times \frac{5.5 \times 10^{-2}}{3600} = 4.0 \times 10^{15} \text{ Bq}$ ✓		2
c	ii	$\frac{1}{3} = e^{-\lambda t}$ ✓ $t = 20 \text{ hr}$ ✓		2

10 – (PHYSI/20_HL_Winter_2019_Q8) – Quantum & Nuclear Physics (ahl)



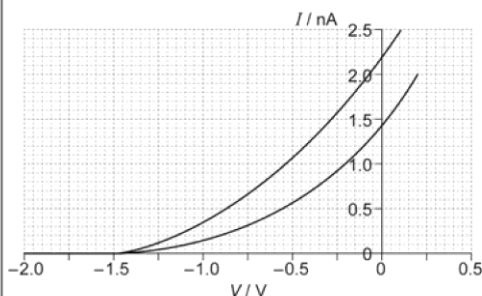
a	i	equating centripetal to electrical force $\frac{2ke^2}{r^2} = \frac{mv^2}{r}$ to get result ✓	1
a	ii	uses (a)(i) to state $E_k \propto \frac{ke^2}{r}$ OR states $E_p \propto -\frac{2ke^2}{r}$ ✓ adds « $E_{TOT} = E_k + E_p = \frac{ke^2}{r} - \frac{2ke^2}{r}$ » to get the result ✓	2
a	iii	the total energy decreases OR by reference to $E_{TOT} = -\frac{ke^2}{r}$ ✓ the radius must also decrease ✓	2

b	i	with $n = 3$, $v = \sqrt{\frac{2 \times 8.99 \times 10^9 \times (1.6 \times 10^{-19})^2}{9.11 \times 10^{-31} \times 9 \times 2.7 \times 10^{-11}}} = 1.44 \times 10^6 \text{ m s}^{-1}$ ✓ $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.44 \times 10^6}$ OR $\lambda = 5.05 \times 10^{-10} \text{ m}$ ✓	2
b	ii	$\frac{2\pi r}{\lambda} = \frac{2\pi \times 9 \times 2.7 \times 10^{-11}}{5.1 \times 10^{-10}} = 2.99 \approx 3$ ✓	1
c		reference to fixed orbits/specific radii OR quantized angular momentum in Bohr model ✓ electron described by a wavefunction/as a wave in Schrödinger model OR as particle in Bohr model ✓ reference to «same» energy levels in both models ✓ reference to «relationship between wavefunction and» probability «of finding an electron in a point» in Schrödinger model ✓	3 max

11 – (PHYSI/20_HL_Winter_2019_Q11) – Quantum & Nuclear Physics (ahl)

a	i	«low intensity light would» transfer energy to the electron at a low rate/slowly ✓ time would be required for the electron «to absorb the required energy» to escape/be emitted ✓	OWTTE	2
a	ii	«in the photon theory of light» the electron interacts with a single photon ✓ and absorbs all the energy OR and can leave the metal immediately ✓	Reference to photon-electron collision scores MP1	2
b	i	$\phi = \frac{hc}{\lambda} - E_k$ ✓ $E_k = 1.5 \text{ eV}$ ✓ $\phi = \frac{1.24 \times 10^{-5}}{480 \times 10^{-9}} - 1.5 = 1.1 \text{ eV}$ ✓	Allow reading from the graph of $E_k = 1.4$ leading to an answer of 1.2 «eV»	3

b	ii	similar curve lower than original ✓ with same horizontal intercept ✓			2
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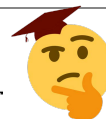
12 – (PHYSI/20_HL_Winter_2020_Q10) – Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)

a		$\lambda = \frac{6.63 \cdot 10^{-34} \cdot 3 \cdot 10^8}{1.60 \cdot 10^{-16} \cdot 4.2 \cdot 10^6}$ OR $2.96 \cdot 10^{-11}$ «m» ✓	Answer to at least 2 s.f. (i.e. 3.0)	1
b	i	«the shape of the graph suggests that» electrons undergo diffraction «with carbon nuclei» ✓ only waves diffract ✓		2
b	ii	$\sin \theta_n = \frac{2.96 \cdot 10^{-11}}{4.94 \cdot 10^{-10}}$ «-0.599» ✓ 37 «degrees» OR 0.64/0.65 «rad» ✓		2
b	iii	the de Broglie wavelength of electrons is «much» longer than the size of a nucleus ✓ hence electrons would not undergo diffraction OR no diffraction pattern would be observed ✓		2
c		volume of a nucleus proportional to $A^{\frac{1}{3}}$ – A AND mass proportional to A ✓ the ratio $\frac{\text{mass}}{\text{volume}}$ independent of A «hence density the same for all nuclei» ✓	Both needed for MP1	2

13 – (PHYSI/21_HL_Summer_2021_Q10) – Quantum & Nuclear Physics (ahl)

a		electrons are ejected from the surface of a metal ✓ after gaining energy from photons/electromagnetic radiation ✓ there is a minimum «threshold» energy/frequency OR maximum «threshold» wavelength ✓		2 max
b		$eV = \frac{1}{2} mv^2$ and manipulation to get v ✓ $v = \sqrt{\frac{2 \cdot 1.6 \cdot 10^{-19} \cdot 1.4}{9.1 \cdot 10^{-31}}}$ OR 702 «km s ⁻¹ » ✓	Must see either complete substitution or calculation to at least 3 s.f. for MP2.	2
c		$E = 2.3 + 1.4$ ✓ $\lambda = \frac{6.63 \cdot 10^{-34} \cdot 3 \cdot 10^8}{3.7 \cdot 1.6 \cdot 10^{-19}}$ ✓ $= 3.4 \cdot 10^{-7}$ m OR 340 nm ✓	Must see an appropriate unit to award MP3.	3

14 – (PHYSI/22_HL_Summer_2021_Q9) – Quantum & Nuclear Physics (ahl)

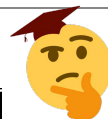


a	i	photon transfers «all» energy to electron ✓		1
a	ii	photon energy is less than both work functions OR photon energy is insufficient «to remove an electron» ✓	Answer must be in terms of photon energy.	1
a	iii	Identifies P work function lower than Q work function ✓		1
b		changing/doubling intensity «changes/doubles number of photons arriving but» does not change energy of photon ✓		1
c		$5.1 \times 10^{-19} = 1.1 \times 10^{-18} - \phi$ ✓ work function = « $\frac{(11.0 - 5.1) \times 10^{-19}}{1.6 \times 10^{-19}}$ » 3.7 «eV» ✓	Award [2] marks for a bald correct answer.	2

15 – (PHYSI/22_HL_Summer_2022_Q9) – Quantum & Nuclear Physics (ahl)

a	i	wave properties ✓	Accept reference to diffraction or interference.	1
a	ii	$440 \times 10^8 \times 1.6 \times 10^{-19}$ OR 7.0×10^{-11} «J» ✓		1
a	iii	$\frac{6.63 \times 10^{-34} \times 3 \times 10^8}{7 \times 10^{-11}}$ OR $\frac{1.24 \times 10^{-11}}{440 \times 10^6}$ OR 2.8×10^{-15} «m» seen ✓ read off graph as 46° ✓ «Use of $D = \frac{\lambda}{\sin \theta}$ » 3.9×10^{-15} m ✓	Accept an angle between 45 and 47 degrees. Allow ECF from MP2	3
b		ALTERNATIVE 1 use of $R \propto A^{\frac{1}{3}}$ OR $V \propto A$ ✓ volume of Sn = $\frac{4}{3} \pi \left(\frac{A_{\text{Sn}}}{A_0} \right)^{\frac{1}{3}} r_0^3$ or equivalent working ✓ 2.3 to 2.5×10^{-43} «m ³ » ✓ answer to 1 or 2sf ✓ ALTERNATIVE 2 use of $R = R_0 \times A^{\frac{1}{3}}$ ✓ volume of Sn = $\frac{4}{3} \pi R^3$ OR 5.9×10^{-15} seen ✓ 8.5×10^{-43} «m ³ » ✓ answer to 1 or 2sf ✓	Although the question expects candidates to work from the oxygen radius found, allow ALT 2 working from the Fermi radius. MP4 is for any answer stated to 1 or 2 significant figures.	4

16 – (PHYSI/20_HL_Winter_2022_Q10) – Quantum & Nuclear Physics (ahl)



a	i	strong «nuclear» force ✓		1
a	ii	ALTERNATIVE 1 attempt to apply conservation law of baryon number to the overall reaction ✓ baryon number of X is zero ✓ this is only possible if constituent quarks of X have an opposite baryon number ✓ «so quark-antiquark pair» ALTERNATIVE 2 attempt to apply conservation law of charge to the overall reaction ✓ charge of X is -1 ✓ this is only possible if constituent quarks of X have charges of $-\frac{2}{3}$ and $-\frac{1}{3}$ ✓ «so quark-antiquark pair» ALTERNATIVE 3 attempt to apply conservation law of baryon number OR charge to each vertex ✓ at first vertex, the unknown particle has charge $-\frac{1}{3}$ OR baryon number $\frac{1}{3}$ hence a quark ✓ at second vertex, the unknown particle has charge $-\frac{2}{3}$ OR baryon number $-\frac{1}{3}$ hence an antiquark ✓		3
b		$10^8 \times 1.6 \times 10^{-19}$ OR 1.6×10^{-11} seen ✓ $\Delta t \sim \frac{6.63 \cdot 10^{-34}}{4\pi \cdot 10^8 \cdot 1.60 \cdot 10^{-19}} = 3 \cdot 10^{-24}$ «s» ✓	Award [2] for a BCA Award [1] for an answer of 5.3×10^{-43} s. Allow ECF from MP1	2