IB TOPICAL PAST PAPERS

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IB DIPLOMA Topical Past Papers

PHYSICS

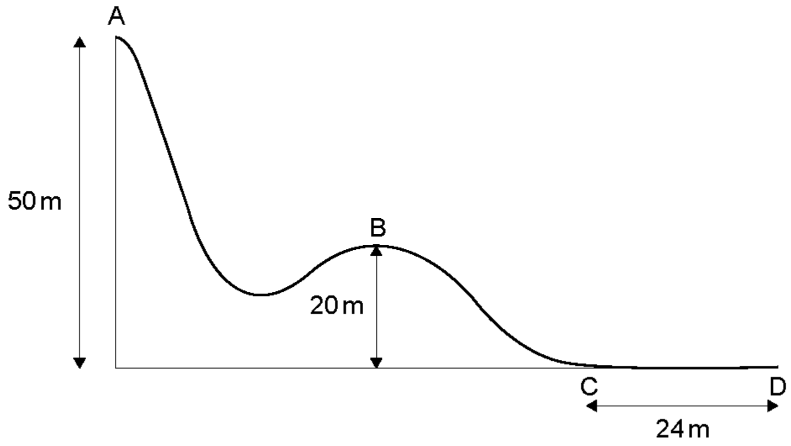
SL

PAPER 2

2017 — 2022

1 – (PHYSI/21_SL_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.

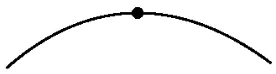


(a) A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

(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]

(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]

(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]

(c) The skier reaches point C with a speed of $8.2\,\text{m s}^{-1}$. 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]

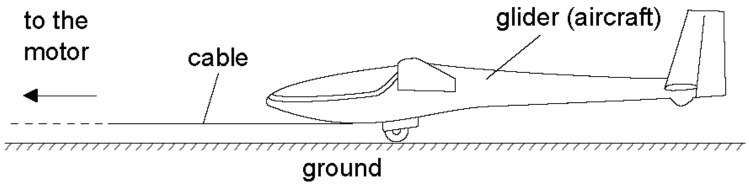
(d) At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed $9.6\,m\,s^{-1}$.

(i) Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. [2]

(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]

2 – (PHYSI/22_SL_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.



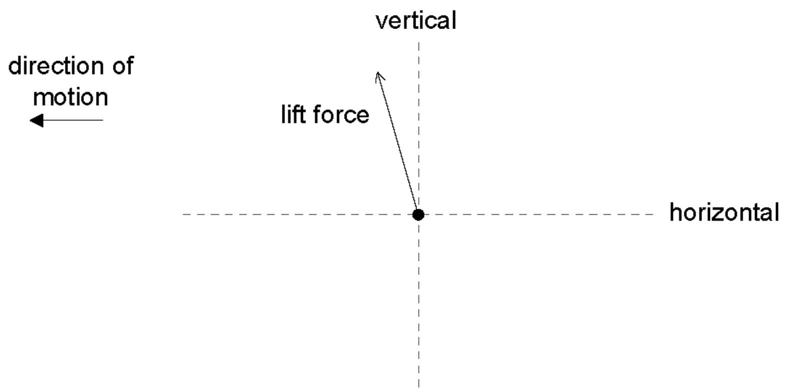
(a) The glider reaches its launch speed of $27.0\,\mathrm{m\,s^{-1}}$ after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. [2]

(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]

(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]

(d) The cable is wound onto a cylinder of diameter 1.2 m. Calculate the angular velocity of the cylinder at the instant when the glider has a speed of $27\,m\,s^{-1}$. Include an appropriate unit for your answer. [2]

(e) 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.



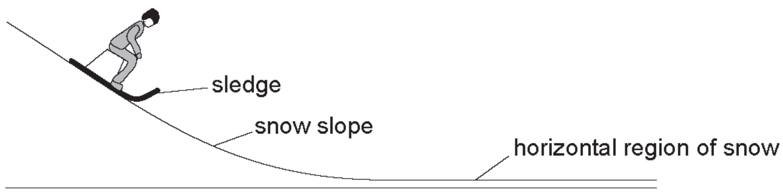
Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions. [2]

(f) Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. [2]

(g) At a particular instant in the flight the glider is losing 1.00 m of vertical height for every 6.00 m that it goes forward horizontally. At this instant, the horizontal speed of the glider is $12.5\,\mathrm{m\,s^{-1}}$. Calculate the **velocity** of the glider. Give your answer to an appropriate number of significant figures. [3]

3 - (PHYSI/20_SL_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]

(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]

(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]

(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.

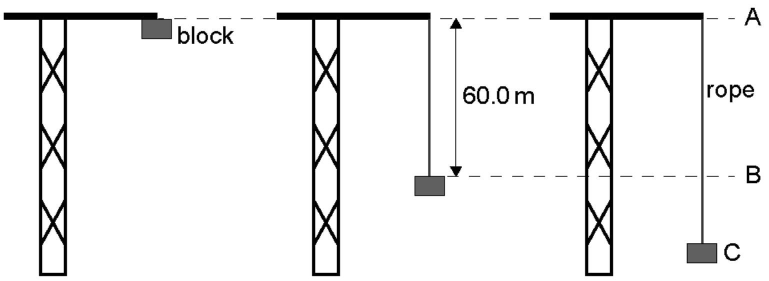
(i) Show that the acceleration of the sledge is about –2 m s^{-2}. [3]

(ii) Calculate the distance along the slope at which the sledge stops moving. Assume that the coefficient of dynamic friction is constant. [2]

(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]

4 – (PHYSI/21_SL_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.



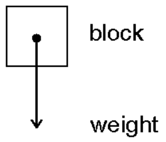
The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

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

(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]

(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

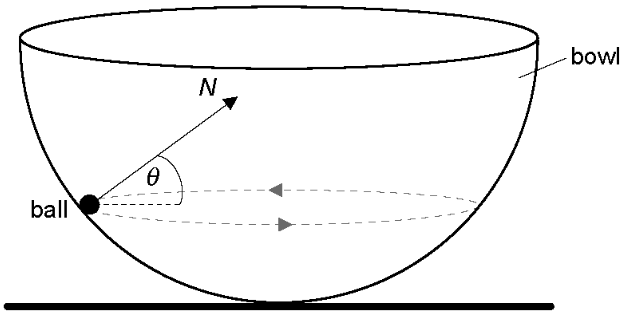
(i) between A and B. [1]

(ii) between B and C. [1]

(d) The length reached by the rope at C is 77.4 m. Suggest how energy considerations could be used to determine the elastic constant of the rope. [2]

5 – (PHYSI/22_SL_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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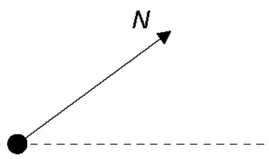
(ii) On the diagram, construct an arrow of the correct length to represent the weight of the ball. [2]



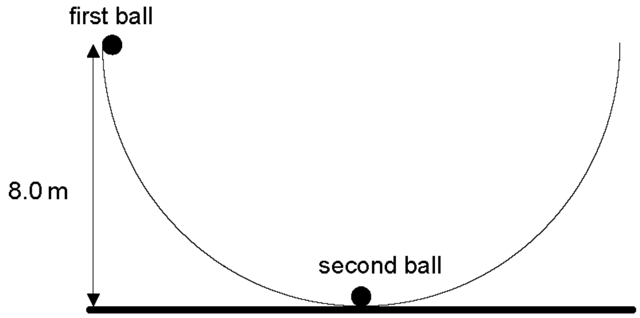
(iii) Show that the magnitude of the net force F on the ball is given by the following equation. [3]

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

(b) The radius of the bowl is 8.0 m and $\theta = 22^{\circ}$. Determine the speed of the ball. [4]

(c) Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl. [2]

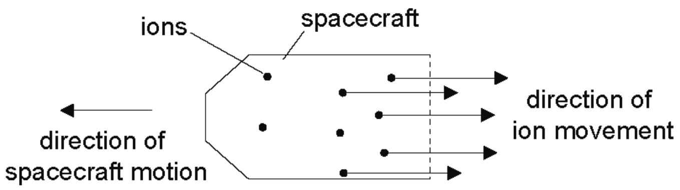
(d) A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m.



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Determine, in m, the maximum height reached by the two balls. [3]

6 – (PHYSI/20_SL_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 6.6×10^{-6} kg and the speed of each ion is 5.2×10^{4} 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.

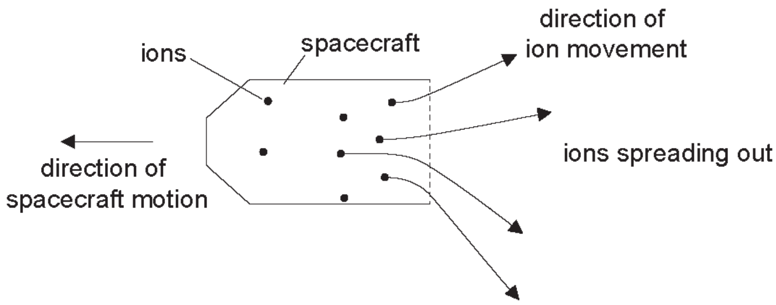
(a) Determine the initial acceleration of the spacecraft. [2]

(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]

(ii) Outline why scientists sometimes use estimates in making calculations. [1]

(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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(d) On arrival at the planet, the spacecraft goes into orbit as it comes into the gravitational field of the planet.

(i) Outline what is meant by the gravitational field strength at a point. [2]

(ii) Newton's law of gravitation applies to point masses. Suggest why the law can be applied to a satellite orbiting a spherical planet of uniform density. [1]

7 - (PHYSI/20_SL_Winter_2018_Q3) - *Mechanics*

A chicken's egg of mass 58 g is dropped onto grass from a height of 1.1 m. The egg comes to rest in a time of 55 ms. Assume that air resistance is negligible and that the egg does not bounce or break.

(a) Determine the magnitude of the average decelerating force that the ground exerts on the egg. [4]

(b) Explain why the egg is likely to break when dropped onto concrete from the same height. [2]

8 – (PHYSI/21_SL_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 $7.0\,\text{m s}^{-1}$ 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 3×10^{3} s. [1]

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

(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]

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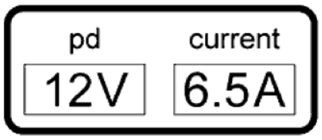
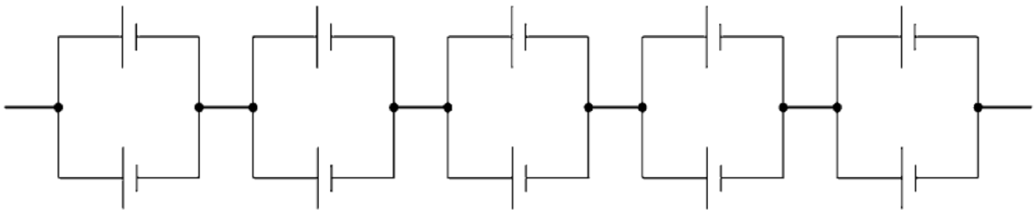
(d) The bicycle has a meter that displays the current and the terminal potential difference (pd) for the battery when the motor is running. The diagram shows the meter readings at one instant. The emf of the cell is 16 V.



Determine the internal resistance of the battery. [2]

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



Calculate

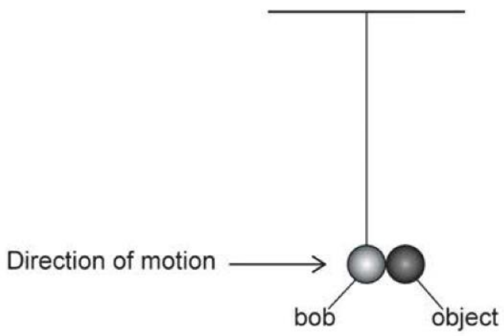
(i) the emf of **one** cell. [1]

(ii) the internal resistance of **one** cell. [2]

9 - (PHYSI/21_SL_Summer_2019_Q5) - *Mechanics, Oscillations & Waves*

A small metal pendulum bob of mass 75 g is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible. The bob is then displaced to the left.

At time $t = 0$ the bob is moving horizontally to the right at $0.8\,\text{m}\,\text{s}^{-1}$. It collides with a small stationary object also of mass 75 g. Both objects then move together with motion that is simple harmonic.



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

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

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(c) Describe the changes in gravitational potential energy of the oscillating system from $t = 0$ as it oscillates through one cycle of its motion. [1]

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10 – (PHYSI/22_SL_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.

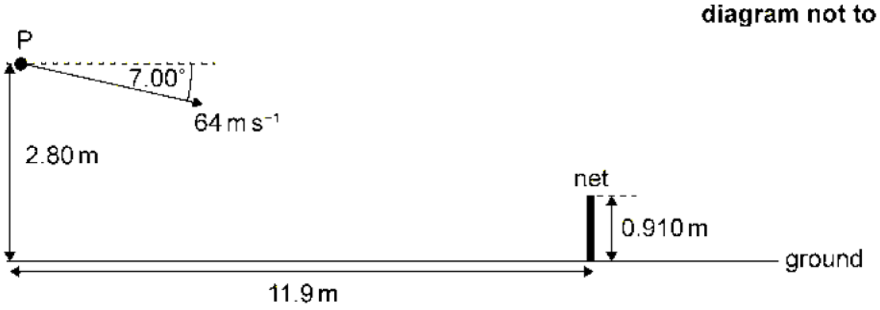
(a) Calculate the

(i) average force exerted by the racquet on the ball. [2]

(ii) average power delivered to the ball during the impact. [2]

(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.

diagram not to scale



The following data are available.

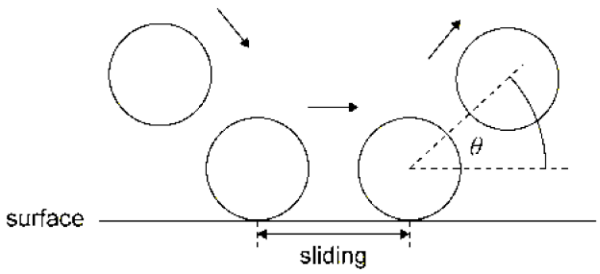
Height of P	= 2.80 m
Distance of student from net	= 11.9 m
Height of net	= 0.910 m
Initial speed of tennis ball	= $64\,m\,s^{-1}$

(i) Calculate the time it takes the tennis ball to reach the net. [2]

(ii) Show that the tennis ball passes over the net. [3]

(iii) Determine the speed of the tennis ball as it strikes the ground. [2]

(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

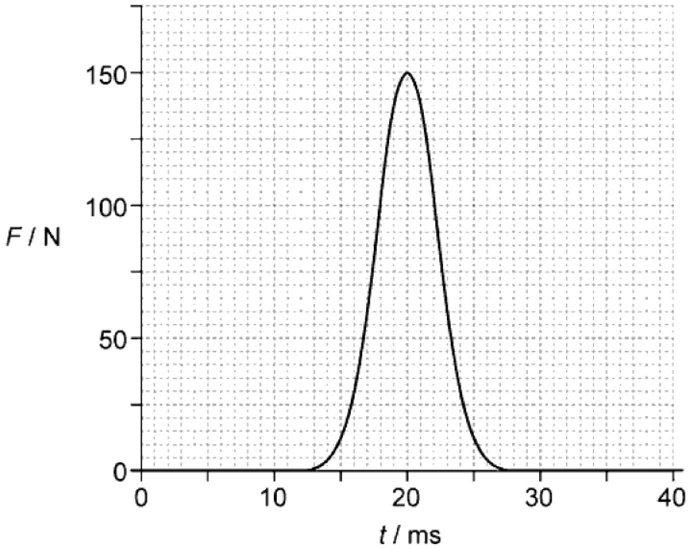
- during contact with the surface the ball slides.
- the sliding time is the same for both surfaces.
- the sliding frictional force is greater for clay than grass.
- the normal reaction force is the same for both surfaces.

Predict for the student's model, without calculation, whether θ is greater for a clay surface **or** for a grass surface. [3]

11 - (PHYSI/20_SL_Winter_2019_Q1) - *Mechanics*

Answer **all** questions. Answers must be written within the answer boxes provided.

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 5.8×10^{-2} 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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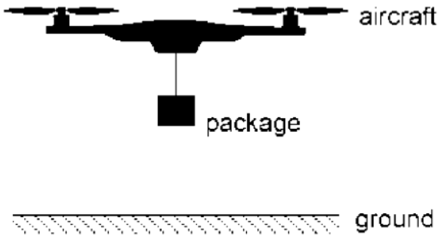
(c) Determine, with reference to the work done by the average force, the horizontal distance travelled by the ball while it was in contact with the racket. [3]

(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_SL_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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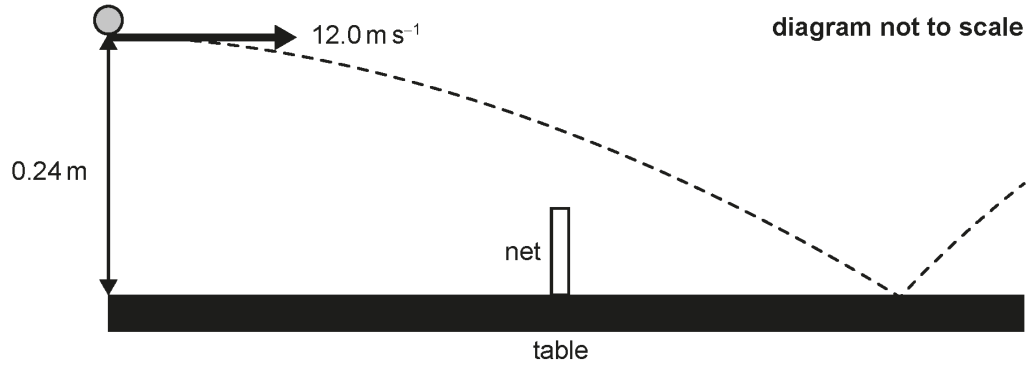
(b) The package and string are now released and fall to the ground. The lift force on the aircraft remains unchanged. Calculate the initial acceleration of the aircraft. [2]

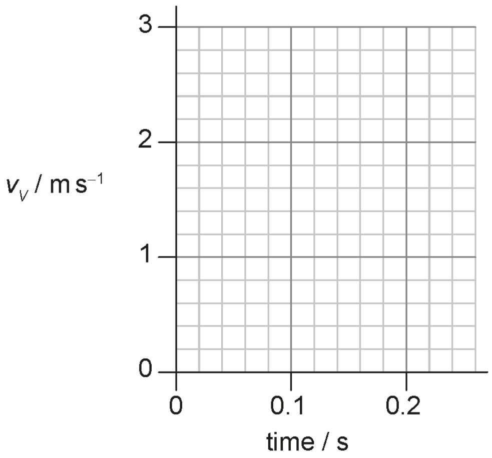
13 – (PHYSI/21_SL_Summer_2021_Q1) – *Mechanics*

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 $12.0\,\text{m s}^{-1}$ 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]

(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]



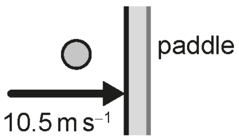
(c) The net is stretched across the middle of the table. The table has a length of 2.74 m and the net has a height of 15.0 cm.

Show that the ball will go over the net. [3]

(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]

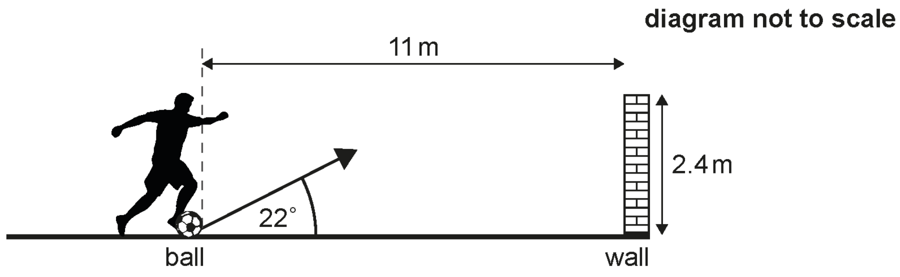
(ii) Player B intercepts the ball when it is at its peak height. Player B holds a paddle (racket) stationary and vertical. The ball is in contact with the paddle for 0.010 s. Assume the collision is elastic.



Calculate the average force exerted by the ball on the paddle. State your answer to an appropriate number of significant figures. [3]

14 - (PHYSI/22_SL_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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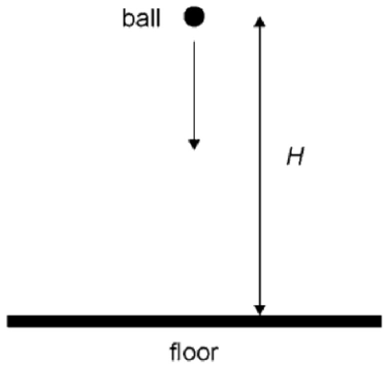
(ii) The top of the wall is 2.4 m above the ground. Deduce whether the ball will hit the wall. [3]

(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]

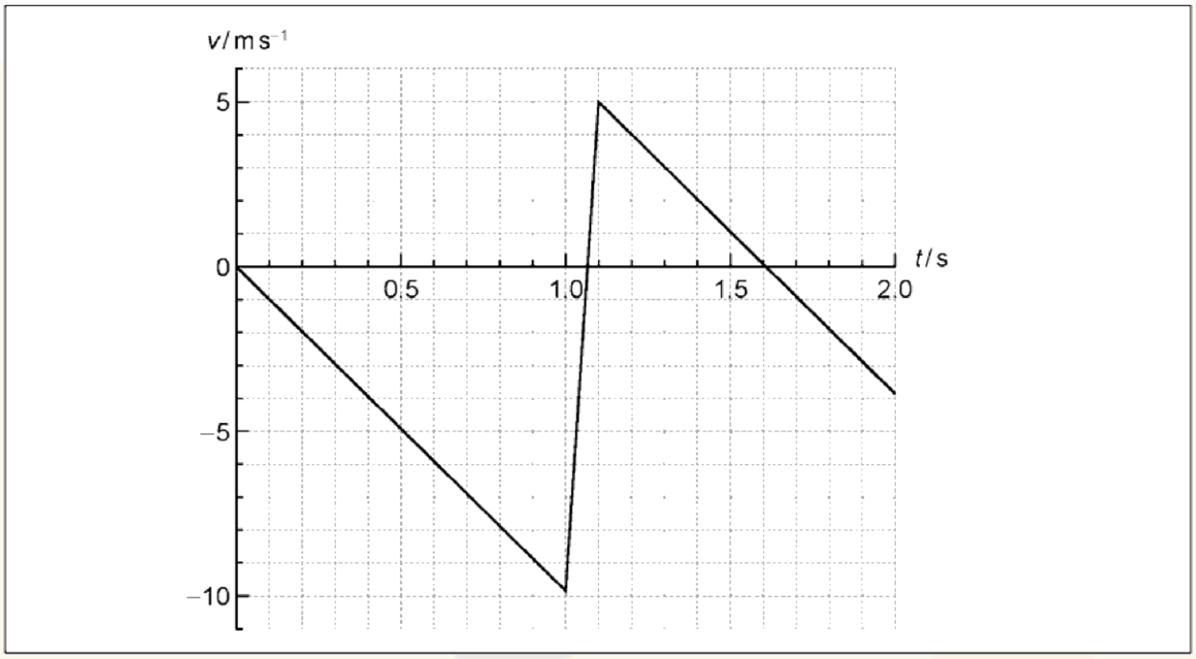
(d) The player kicks the ball again. It rolls along the ground without sliding with a horizontal velocity of $1.40\ \text{m s}^{-1}$. The radius of the ball is 0.11 m. Calculate the angular velocity of the ball. State an appropriate SI unit for your answer. [1]

15 - (PHYSI/20_SL_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.

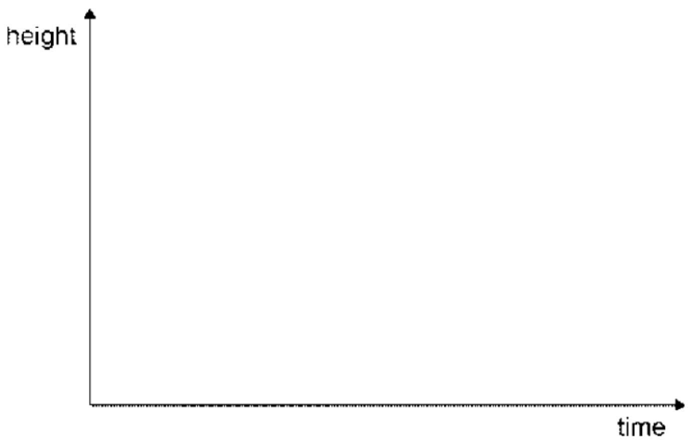


(a) Determine *H*. [1]

(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]

(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]



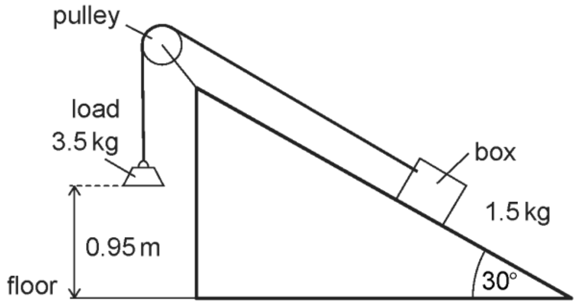
(c) Estimate the loss in the mechanical energy of the ball as a result of the collision with the floor. [1]

(d) (i) Determine the average force exerted on the floor by the ball. [3]

(ii) Suggest why the momentum of the ball was not conserved during the collision with the floor. [1]

16 - (PHYSI/21_SL_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 $2.4\ \text{m s}^{-2}$.

Calculate the tension in the string. [2]

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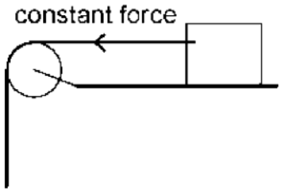
(c) (i) Show that the speed of the load when it hits the floor is about $2.1\ \mathrm{m\,s^{-1}}$. [2]

(ii) The radius of the pulley is 2.5 cm. Calculate the angular speed of rotation of the pulley as the load hits the floor. State your answer to an appropriate number of significant figures. [2]

(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]

(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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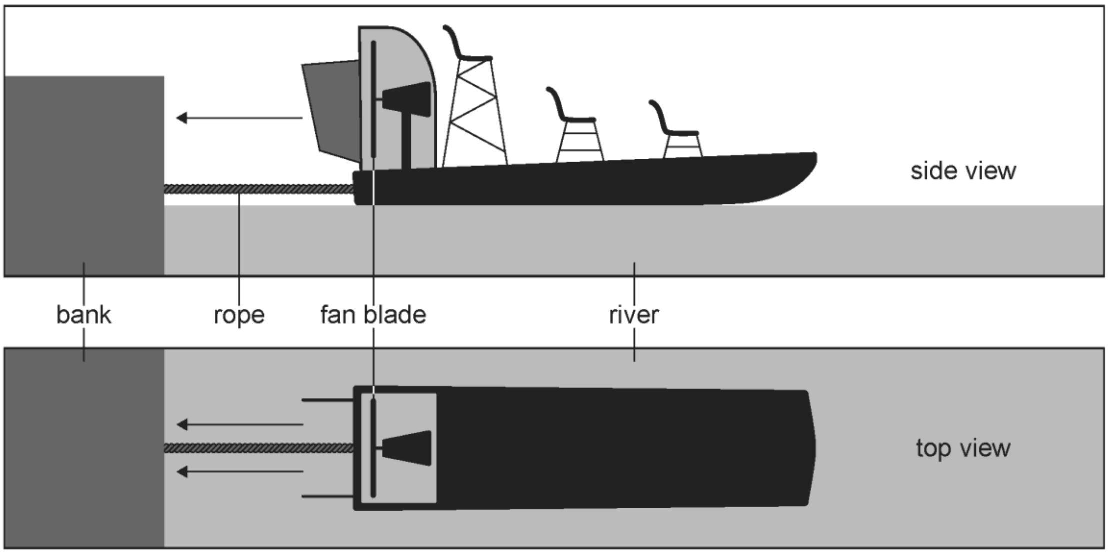
17 - (PHYSI/22_SL_Summer_2022_Q1) - *Mechanics*

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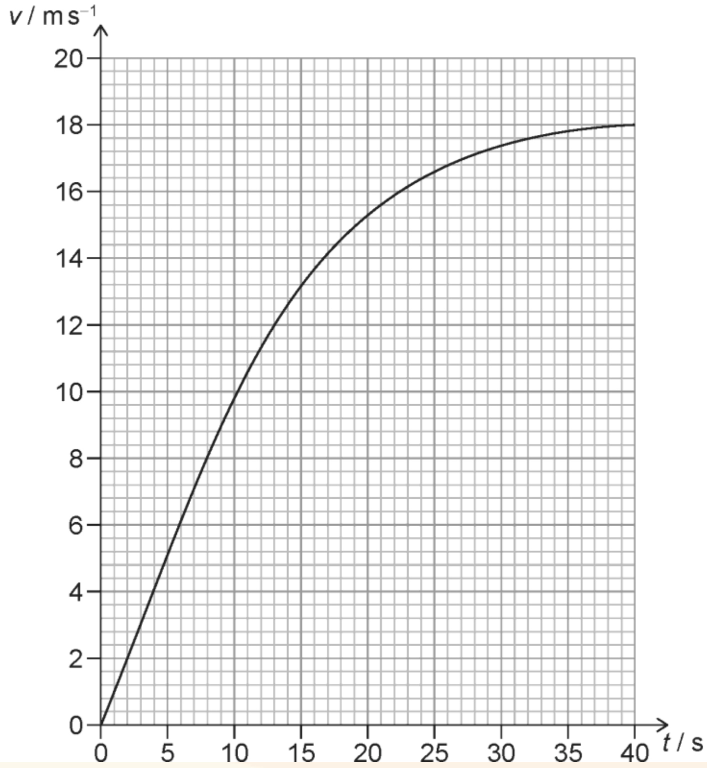
(b) In a test the airboat is tied to the river bank with a rope normal to the bank. The fan propels the air at its maximum speed. There is no wind.

(i) Show that a mass of about 240 kg of air moves through the fan every second. [2]

(ii) Show that the tension in the rope is about 5 kN. [1]

(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) Estimate the distance the airboat travels to reach its maximum speed. [2]

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(ii) Deduce the mass of the airboat. [3]

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(d) The fan is rotating at 120 revolutions every minute. Calculate the centripetal acceleration of the tip of a fan blade. [2]

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18 - (PHYSI/20_SL_Winter_2022_Q1) - *Mechanics*

A raindrop falls vertically from rest.

(a) State the initial acceleration of the raindrop. [1]

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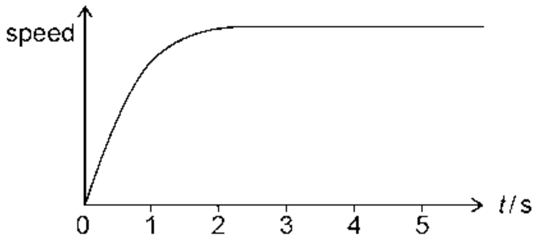
The graph shows how the speed of the raindrop varies with time *t*.



(b) Explain, by reference to the vertical forces, how the raindrop reaches a constant speed. [3]

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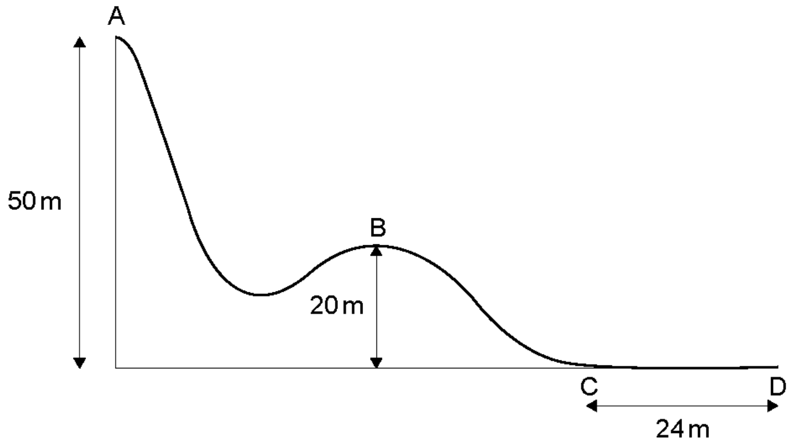
(c) During the first 3.0 s of motion, the raindrop falls a distance of 21 m and reaches a speed of $9.0\,\mathrm{m\,s^{-1}}$. The mass of the raindrop is 34 mg. The temperature of the raindrop does not change.

(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]

(ii) Describe the energy change that takes place for $t > 3.0\,\mathrm{s}$. [1]

1 - (PHYSI/21_SL_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 $12\,\text{m}\,\text{s}^{-1}$. [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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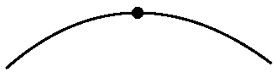
(b) (i) The dot on the following diagram represents the skier as she passes point B. Draw and label the vertical forces acting on the skier. [2]



(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]

(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]

(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 $9.6\,m\,s^{-1}$.

(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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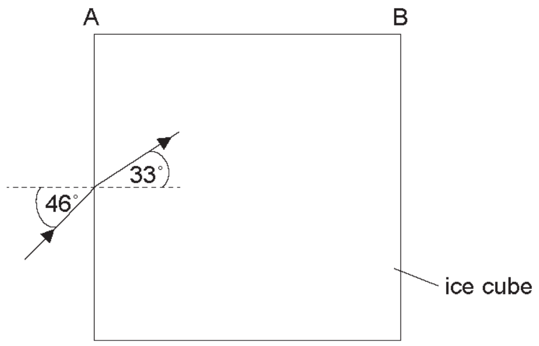
2 – (PHYSI/20_SL_Winter_2017_Q4) – *Oscillations & Waves, Thermal Physics*

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

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(ii) Outline the difference between the molecular structure of a solid and a liquid. [1]

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3 – (PHYSI/21_SL_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]

(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 $3.1\,kJ\,kg^{-1}\,K^{-1}$.

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

(ii) Calculate the average kinetic energy of the particles of the gas. [1]

(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]

4 – (PHYSI/22_SL_Summer_2018_Q2) – *Thermal Physics*

(a) An ideal monatomic gas is kept in a container of volume 2.1×10^{-4} m^3, temperature 310 K and pressure 5.3×10^5 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 6.8×10^{-4} 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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5 - (PHYSI/20_SL_Winter_2018_Q7) - *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	$= 32\ \text{g}$
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]

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

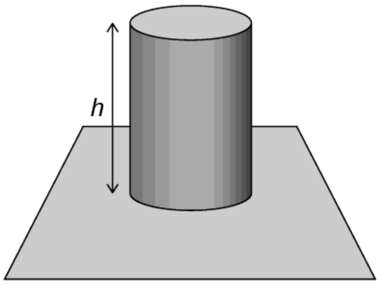
(i) Calculate, in kW, the heater power required. [2]

(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 260 K. [1]

(c) State **one** assumption of the kinetic model of an ideal gas that does not apply to oxygen. [1]

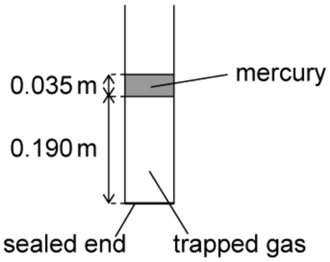
6 - (PHYSI/21_SL_Summer_2019_Q4) - *Thermal Physics*

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]

(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 $1.36 \times 10^4\,\text{kg m}^{-3}$.



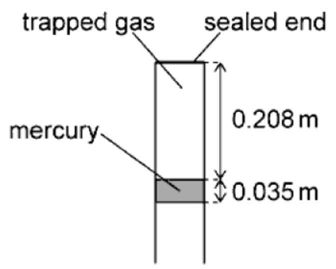
When the mercury is above the gas column the length of the gas column is 0.190 m.

(i) Show that $(p_o + p_m) \times 0.190 = \dfrac{nRT}{A}$ 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]

(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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7 – (PHYSI/22_SL_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 molar mass of helium is $4.0\,\text{g mol}^{-1}$. Show that the mass of a helium atom is $6.6 \times 10^{-27}\,\text{kg}$. [1]

(b) Estimate the average speed of the helium atoms in the container. [2]

(c) Show that the number of helium atoms in the container is about 4×10^{20}. [2]

(d) A helium atom has a volume of $4.9 \times 10^{-31}\,\text{m}^3$.

(i) Calculate the ratio $\dfrac{\text{total volume of helium atoms}}{\text{volume of helium gas}}$. [1]

(ii) Explain, using your answer to (d)(i) and with reference to the kinetic model, why this sample of helium can be assumed to be an ideal gas. [2]

8 - (PHYSI/20_SL_Winter_2019_Q2) - *Thermal Physics*

The air in a kitchen has pressure 1.0×10^5 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]

(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.

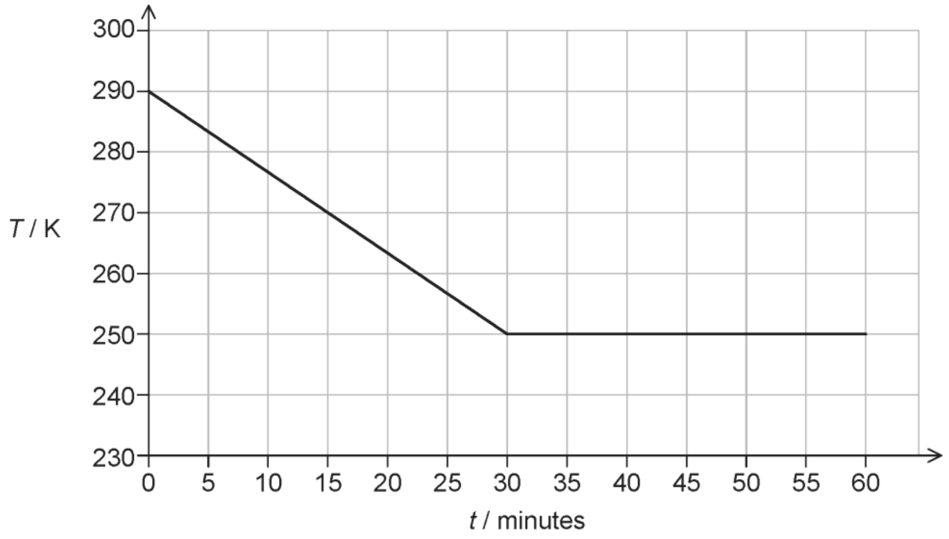
(i) Determine the pressure of the air inside the refrigerator. [2]

(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]

(iii) Comment on the magnitude of the force in (b)(ii). [2]

9 – (PHYSI/20_SL_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 $= 0.32\,\text{kg}$
Specific latent heat of fusion of the oil $= 130\,\text{kJ}\,\text{kg}^{-1}$
Rate of thermal energy transfer $= 15\,\text{W}$

(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]

(c) Calculate the mass of the oil that remains unfrozen after 60 minutes. [2]

10 – (PHYSI/21_SL_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]

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

(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]

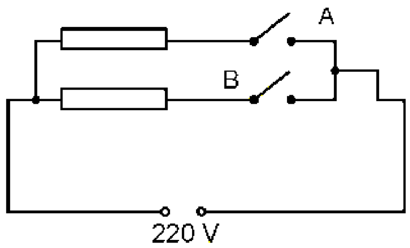
(ii) Explain why the temperature of water remains at 100 °C during this time. [1]

(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]

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



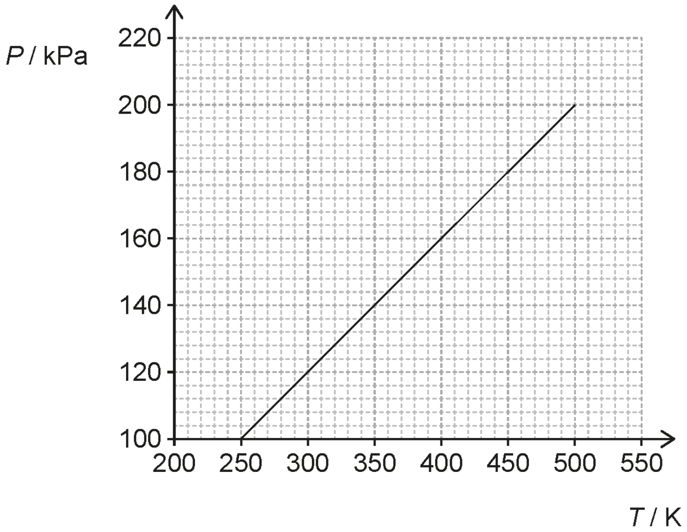
The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

(i) Show that each resistor has a resistance of about 30 Ω. [1]

(ii) Calculate the power transferred by the heater when both switches are closed. [2]

11 – (PHYSI/22_SL_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 $1.0 \times 10^{-3}\,\mathrm{m}^3$.



(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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12 – (PHYSI/20_SL_Winter_2021_Q2) – *Thermal Physics*

(a) State what is meant by the internal energy of an ideal gas. [1]

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(b) A quantity of 0.24 mol of an ideal gas of constant volume 0.20 m^3 is kept at a temperature of 300 K.

(i) Calculate the pressure of the gas. [1]

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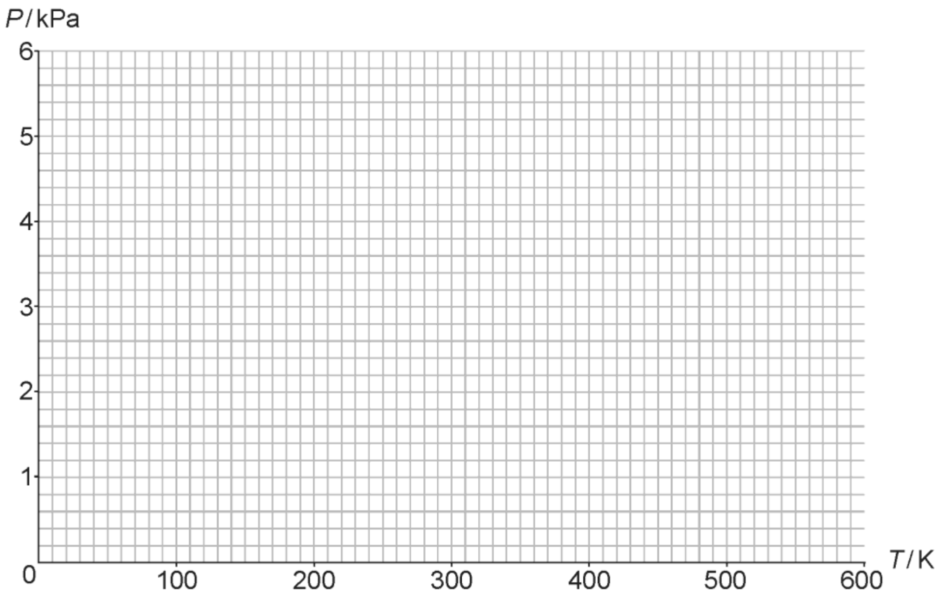
(ii) The temperature of the gas is increased to 500 K. Sketch, on the axes, a graph to show the variation with temperature T of the pressure P of the gas during this change. [2]



(c) A container is filled with 1 mole of helium (molar mass $4\,g\,mol^{-1}$) and 1 mole of neon (molar mass $20\,g\,mol^{-1}$). Compare the average kinetic energy of helium atoms to that of neon atoms. [2]

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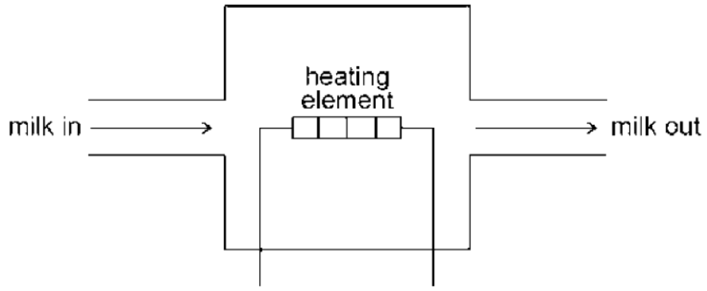
13 – (PHYSI/21_SL_Summer_2022_Q2) – *Thermal Physics*

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 = $3.9\ kJ\ kg^{-1}\ K^{-1}$

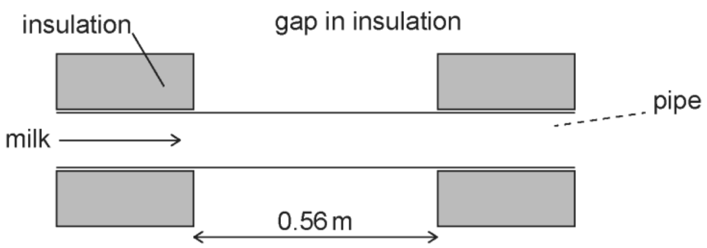
(a) Estimate the power input to the heating element. State an appropriate unit for your answer. [2]

(b) Outline whether your answer to (a) is likely to overestimate or underestimate the power input. [2]

(c) Discuss, with reference to the molecules in the liquid, the difference between milk at 11 °C and milk at 84 °C. [2]

(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]

(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]

(iii) Describe **one** other method by which significant amounts of energy can be transferred from the pipe to the surroundings. [2]

14 – (PHYSI/22_SL_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 $2.5 \times 10^{3}\ m^3$ when the temperature of the gas is 37 °C and the pressure of the gas is 4.0×10^5 Pa.

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

(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]

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

15 - (PHYSI/20_SL_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 $680\,\mathrm{W\,m^{-2}}$.

The following data are available.

Mass of the water in the tank = $250\,\mathrm{kg}$

Initial temperature of the water in the tank = $15\,°\mathrm{C}$

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

Overall efficiency of the heating system = 0.30

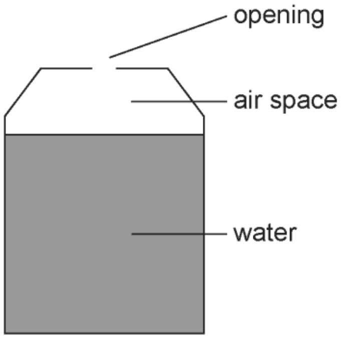
Albedo of the roof tiles = 0.20

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 $30\,°\mathrm{C}$ during a time of 1.0 hour. [3]

(ii) Estimate, in °C, the temperature of the roof tiles. [3]

(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.

Distinguish between photovoltaic cells and solar heating panels. [1]

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1 - (PHYSI/21_SL_Summer_2017_Q2) - *Oscillations & Waves*

(a) Outline what is meant by the principle of superposition of waves. [2]

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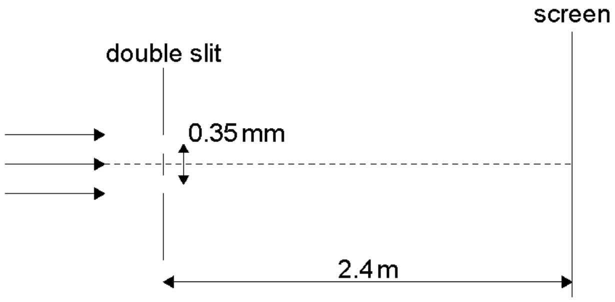
(b) Red laser light is incident on a double slit with a slit separation of 0.35 mm.
A double-slit interference pattern is observed on a screen 2.4 m from the slits.
The distance between successive maxima on the screen is 4.7 mm.



(not to scale)

Calculate the wavelength of the light. Give your answer to an appropriate number of significant figures. [3]

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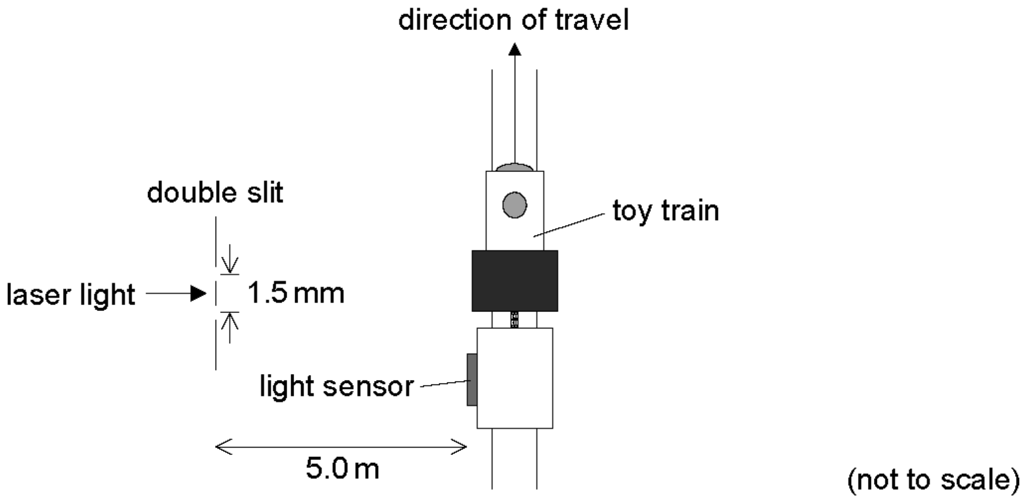
(c) Explain the change to the appearance of the interference pattern when the red-light laser is replaced by one that emits green light. [2]

(d) One of the slits is now covered.

Describe the appearance of the pattern on the screen. [2]

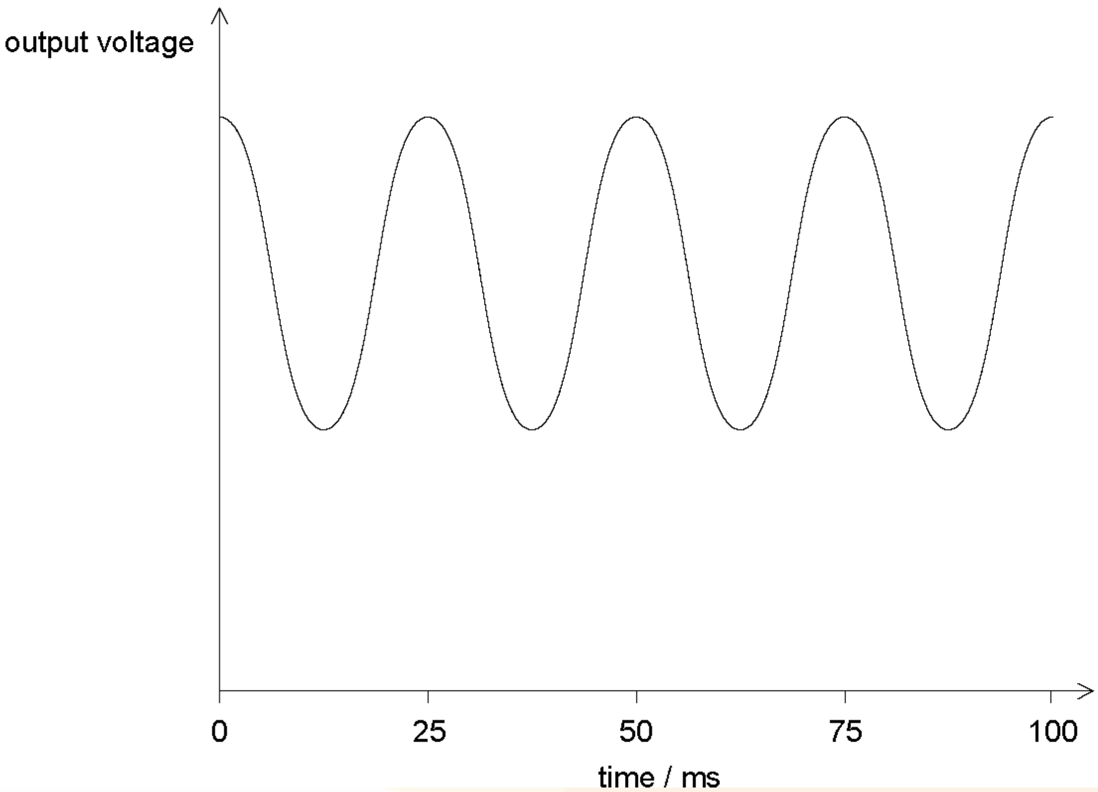
2 - (PHYSI/22_SL_Summer_2017_Q3) - *Oscillations & Waves*

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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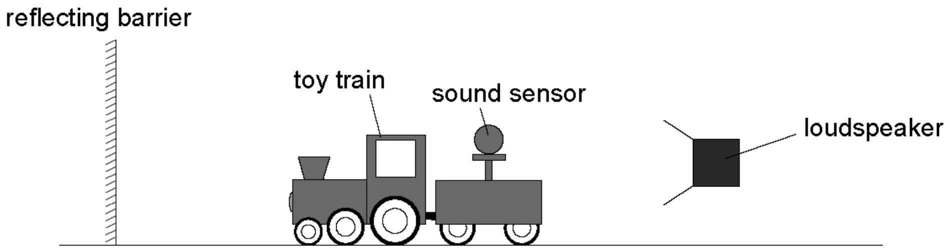
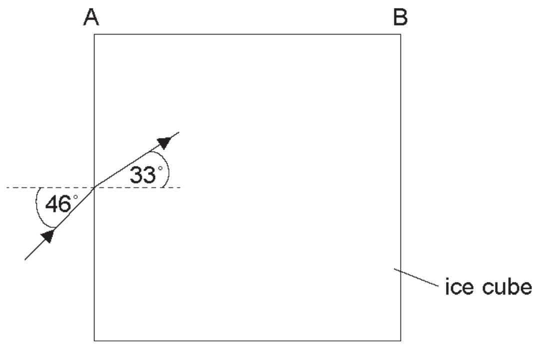
(c) In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier.



The sound sensor gives a graph of the variation of output voltage with time along the track that is similar in shape to the graph on page 8. Explain how this effect arises. [2]

3 – (PHYSI/20_SL_Winter_2017_Q4) – *Oscillations & Waves, Thermal Physics*

(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]

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

(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]

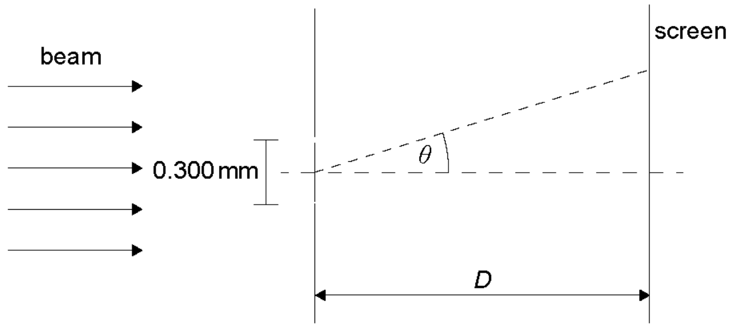
Specific latent heat of fusion of ice	$= 330\ \text{kJ kg}^{-1}$
Specific heat capacity of ice	$= 2.1\ \text{kJ kg}^{-1}\ \text{K}^{-1}$
Density of ice	$= 920\ \text{kg m}^{-3}$

(ii) Outline the difference between the molecular structure of a solid and a liquid. [1]

4 - (PHYSI/21_SL_Summer_2018_Q3) - *Oscillations & Waves*

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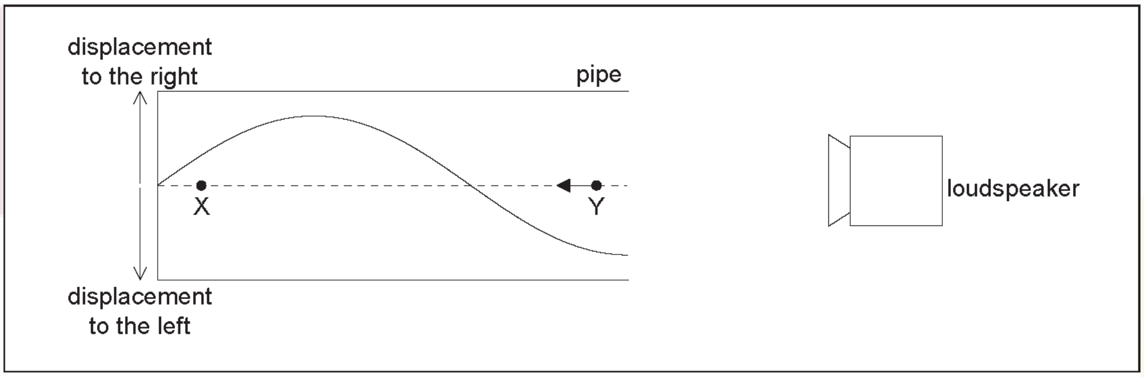
(b) The air between the slits and the screen is replaced with water. The refractive index of water is 1.33.

(i) Calculate the wavelength of the light in water. [1]

(ii) State **two** ways in which the intensity pattern on the screen changes. [2]

5 – (PHYSI/22_SL_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]

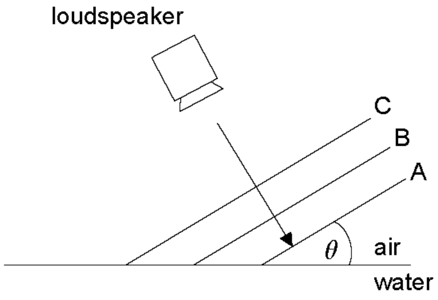
X and Y represent the equilibrium positions of two air molecules in the pipe. The arrow represents the velocity of the molecule at Y.

(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]

(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.

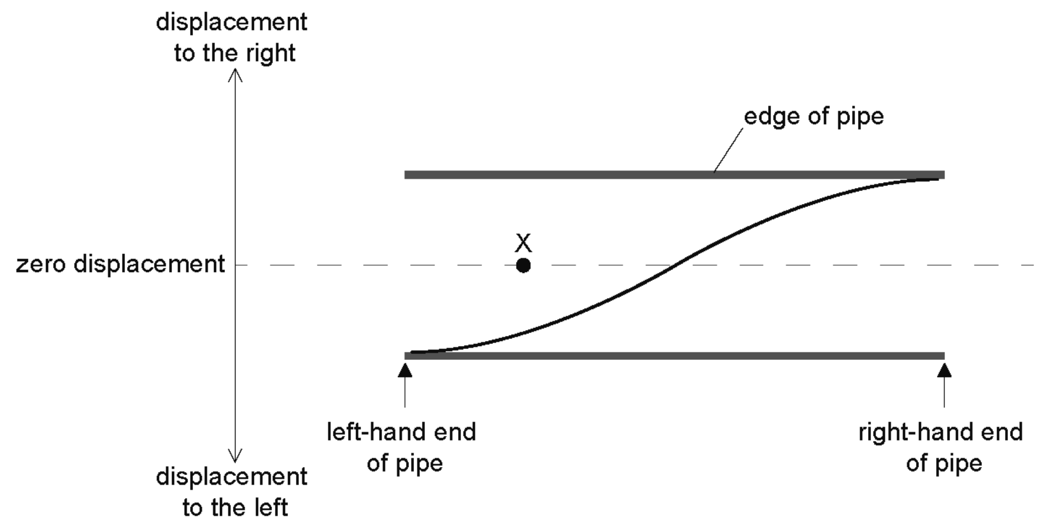


(i) The speed of sound in air is 340 m s^{-1} and in water it is 1500 m s^{-1}. The wavefronts make an angle θ with the surface of the water. Determine the maximum angle, θ_{max}, at which the sound can enter water. Give your answer to the correct number of significant figures. [2]

(ii) Draw lines on the diagram to complete wavefronts A and B in water for $\theta < \theta_{max}$. [2]

6 - (PHYSI/20_SL_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) 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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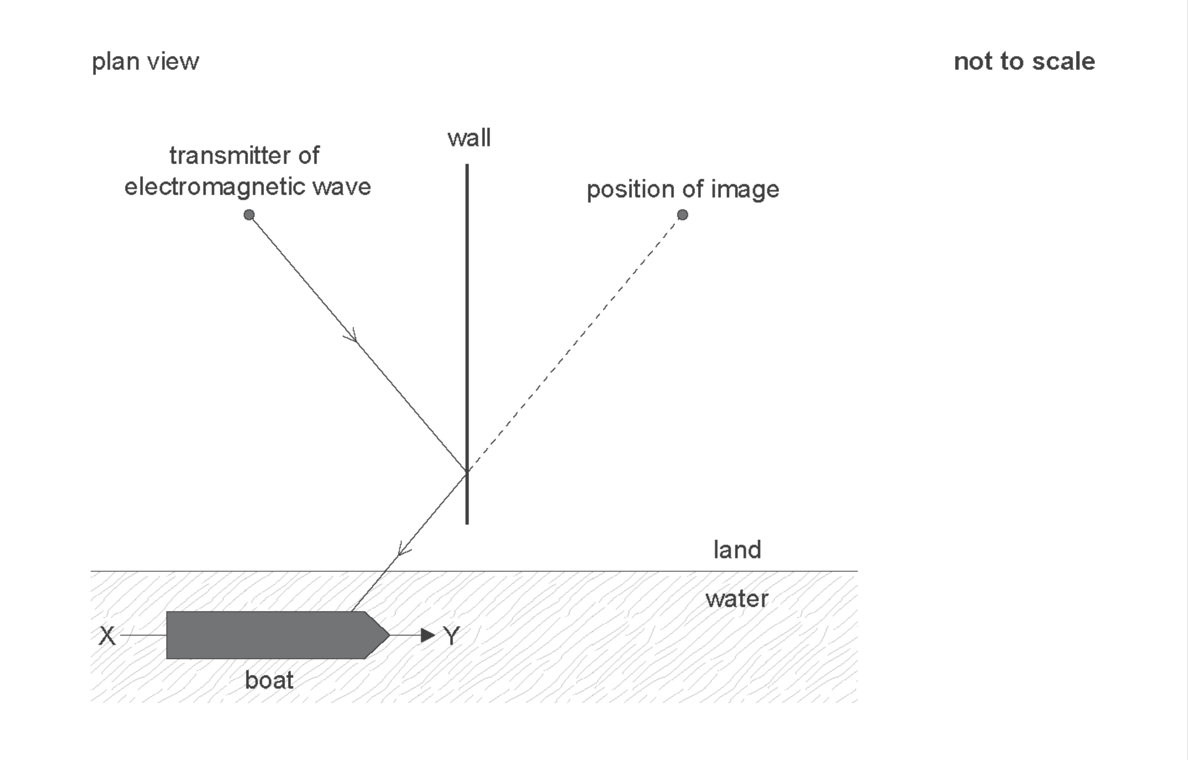
(b) The speed of sound c for longitudinal waves in air is given by

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

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, in kg m^{-1} s^{-2}, the value of K for air. [3]

(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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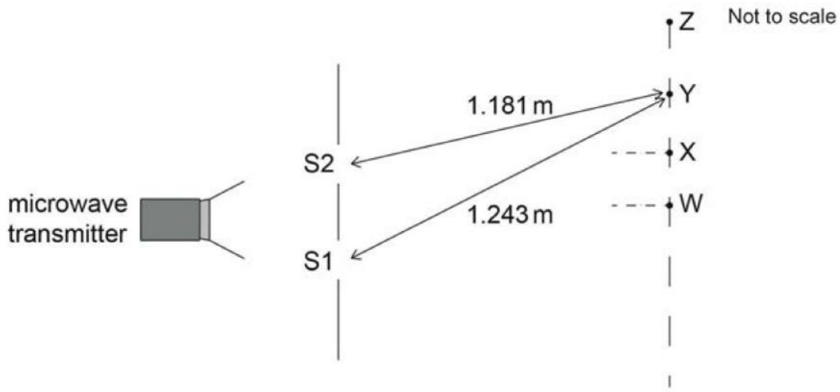
7 – (PHYSI/21_SL_Summer_2019_Q3) – *Oscillations & Waves*

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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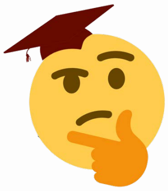
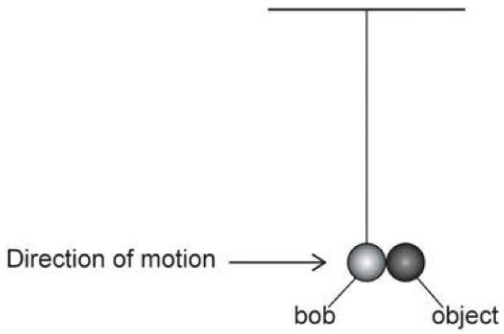


8 – (PHYSI/21_SL_Summer_2019_Q5) – *Mechanics, Oscillations & Waves*

A small metal pendulum bob of mass 75 g is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible. The bob is then displaced to the left.

At time $t = 0$ the bob is moving horizontally to the right at $0.8\,\text{m s}^{-1}$. It collides with a small stationary object also of mass 75 g. Both objects then move together with motion that is simple harmonic.



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

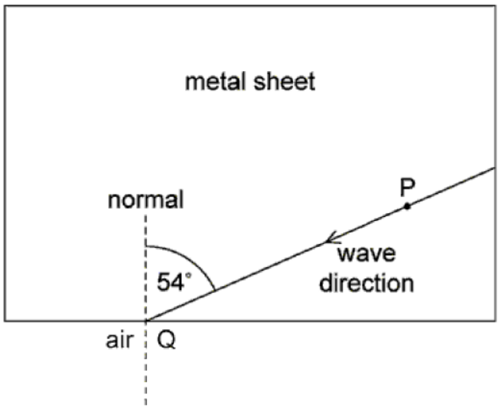
(b) Show that the collision is inelastic. [3]

(c) Describe the changes in gravitational potential energy of the oscillating system from $t = 0$ as it oscillates through one cycle of its motion. [1]

9 – (PHYSI/22_SL_Summer_2019_Q3) – *Oscillations & Waves*

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

diagram not to scale



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

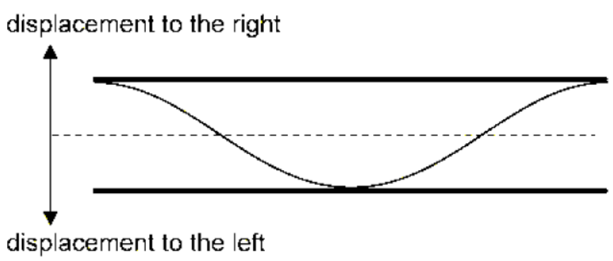
(b) The wave is incident at point Q on the metal–air boundary. The wave makes an angle of 54° with the normal at Q. The speed of sound in the metal is 6010 m s^{-1} and the speed of sound in air is 340 m s^{-1}. Calculate the angle between the normal at Q and the direction of the wave in air. [2]

(c) The frequency of the sound wave in the metal is 250 Hz.

(i) State the frequency of the wave in air. [1]

(ii) Determine the wavelength of the wave in air. [1]

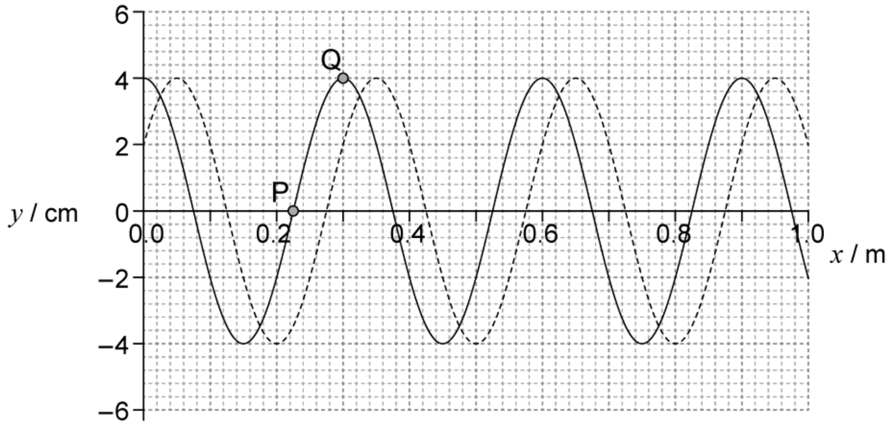
(d) The sound wave in air in (c) enters a pipe that is open at both ends. The diagram shows the displacement, at a particular time *T*, of the standing wave that is set up in the pipe.



On the diagram, at time *T*, label with the letter C a point in the pipe that is at the centre of a compression. [1]

10 - (PHYSI/20_SL_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 $m\,s^{-1}$, 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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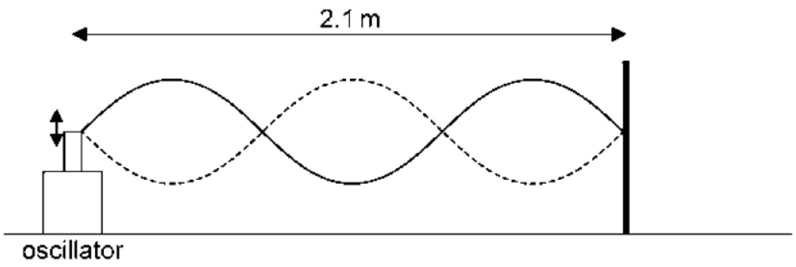
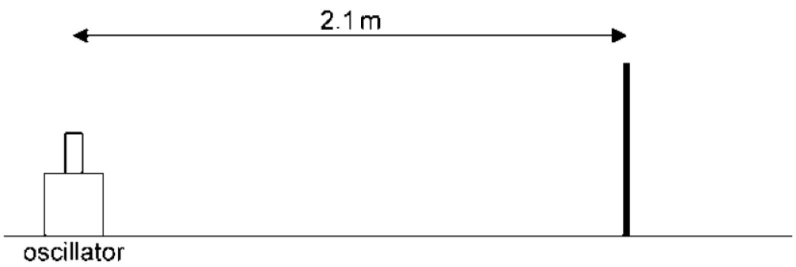
(c) One end of a string is attached to an oscillator and the other is fixed to a wall. When the frequency of the oscillator is 360 Hz the standing wave shown is formed on the string.



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

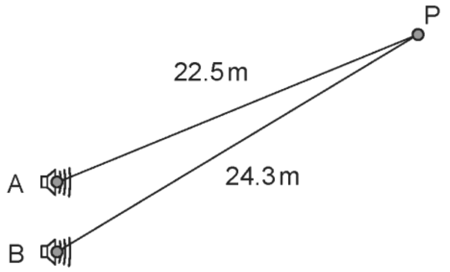
(i) State the number of all other points on the string that have the same amplitude and phase as X. [1]

(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]



11 – (PHYSI/20_SL_Winter_2020_Q4) – *Oscillations & Waves*

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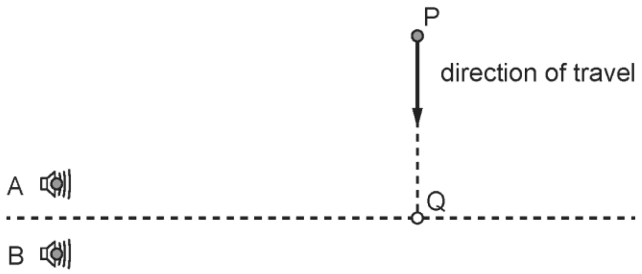
(b) A microphone moves along the line from P to Q. PQ is normal to the line midway between the loudspeakers.

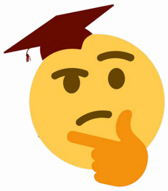


The intensity of sound is detected by the microphone. Predict the variation of detected intensity as the microphone moves from P to Q. [2]

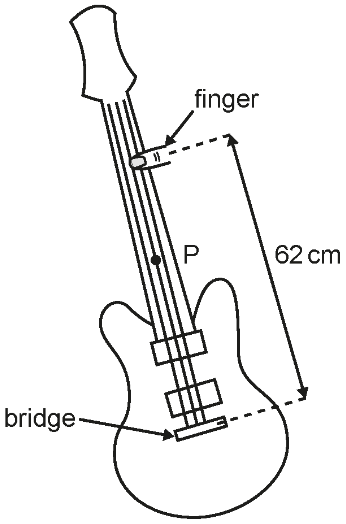
(c) When both loudspeakers are operating, the intensity of sound recorded at Q is I_0. Loudspeaker B is now disconnected. Loudspeaker A continues to emit sound with unchanged amplitude and frequency. The intensity of sound recorded at Q changes to I_A.

Estimate $\frac{I_A}{I_0}$. [2]

12 – (PHYSI/21_SL_Summer_2021_Q6) – *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 $240\,\text{m}\,\text{s}^{-1}$. [2]

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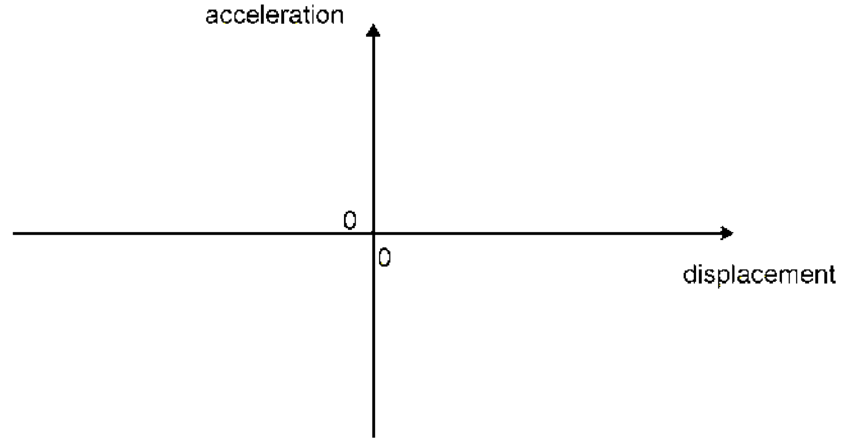
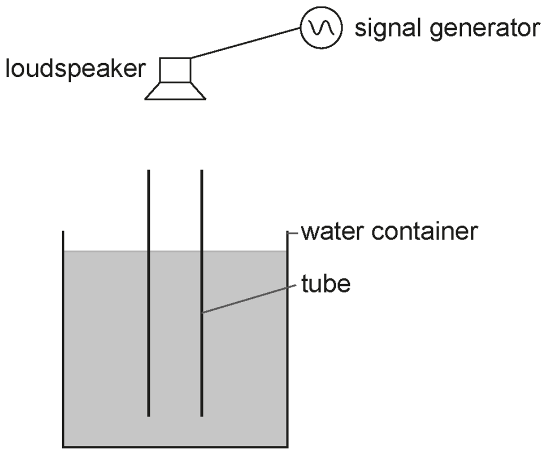
(ii) Sketch a graph to show how the acceleration of point P varies with its displacement from the rest position. [1]



13 – (PHYSI/22_SL_Summer_2021_Q5) – *Oscillations & Waves*

(a) Describe **two** ways in which standing waves differ from travelling waves. [2]

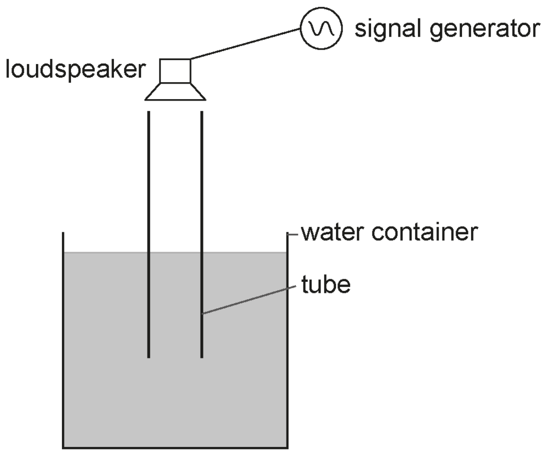
(b) A vertical tube, open at both ends, is completely immersed in a container of water. A loudspeaker above the container connected to a signal generator emits sound. As the tube is raised the loudness of the sound heard reaches a maximum because a standing wave has formed in the tube.



(i) Outline how a standing wave forms in the tube. [2]

(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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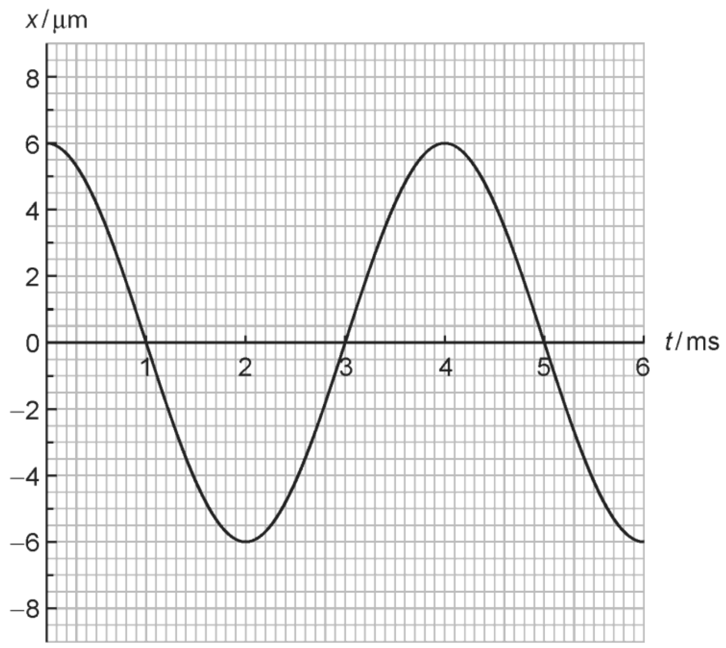
14 - (PHYSI/20_SL_Winter_2021_Q3) - *Oscillations & Waves*

A longitudinal wave travels in a medium with speed $340\,\text{m s}^{-1}$. 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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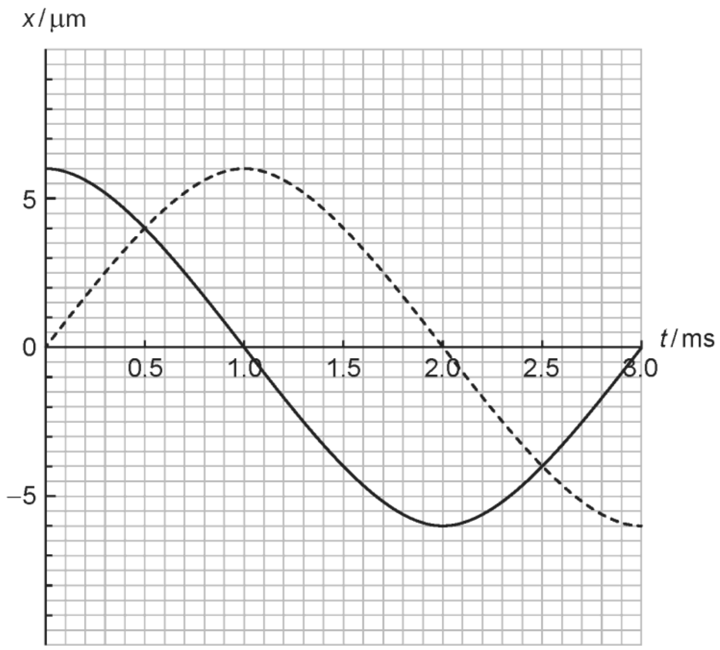
(b) Another wave travels in the medium. The graph shows the variation with time t of the displacement of each wave at the position of P.



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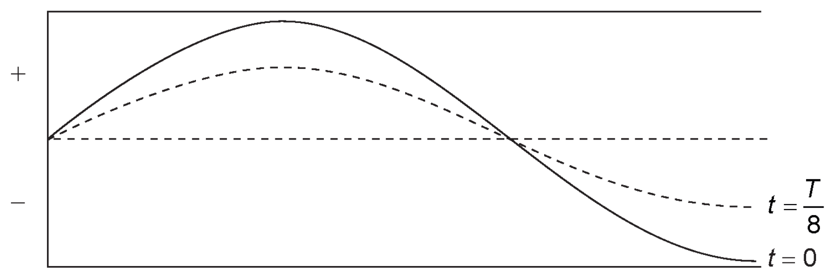
(c) A standing sound wave is established in a tube that is closed at one end and open at the other end. The period of the wave is T. The diagram represents the standing wave at $t = 0$ and at $t = \frac{T}{8}$. The wavelength of the wave is 1.20 m. Positive displacements mean displacements to the right.



(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 $t = \frac{T}{8}$. [2]

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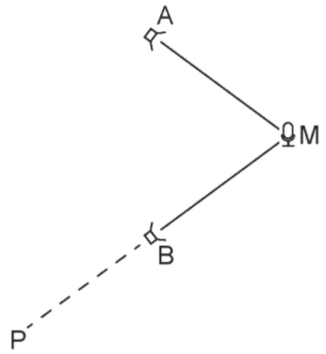
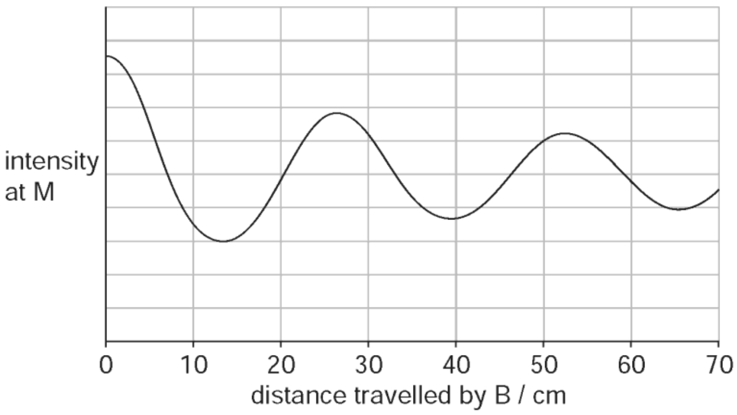
(iii) Draw on the diagram the standing wave at time $t = \frac{T}{4}$. [1]

15 - (PHYSI/21_SL_Summer_2022_Q3) - *Oscillations & Waves*

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]

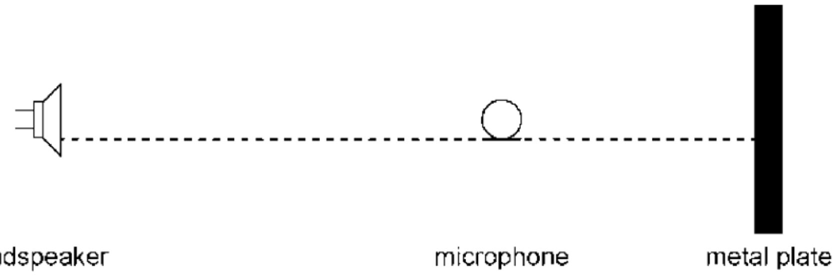
(c) B is placed at the first minimum. The frequency is then changed until the received intensity is again at a maximum.

Show that the lowest frequency at which the intensity maximum can occur is about 3 kHz.

Speed of sound = $340\ \text{m s}^{-1}$ [2]

16 – (PHYSI/22_SL_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 $340\,\text{m}\,\text{s}^{-1}$.

(a) (i) Explain the variation in intensity. [3]

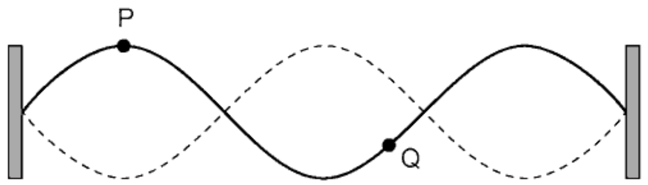
(ii) Adjacent minima are separated by a distance of 0.12 m. Calculate f. [2]

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

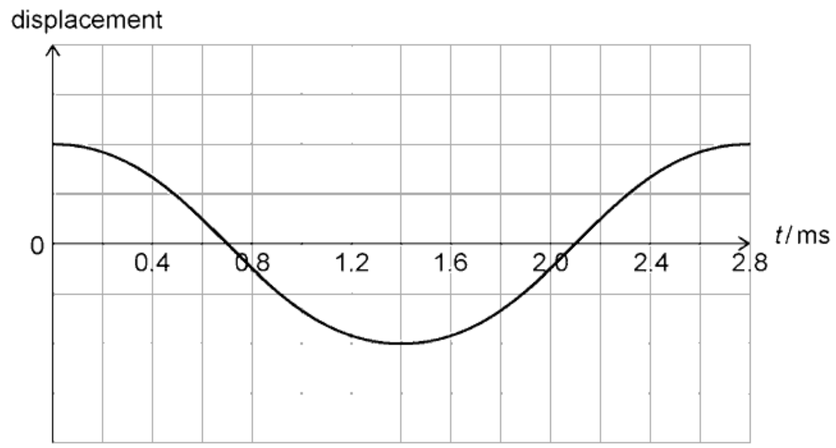
State and explain the differences between the sound intensities detected by the same microphone with the metal plate and the wooden plate. [3]

17 – (PHYSI/20_SL_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]

(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]

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

Outline **two** differences between a standing wave and a travelling wave. [2]

1 - (PHYSI/21_SL_Summer_2017_Q4) - *Electricity & Magnetism*

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	= $1.7 \times 10^{-8}\,\Omega\,m$

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

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

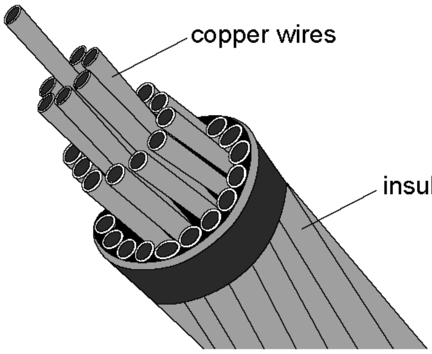
(b) Explain, in terms of electrons, what happens to the resistance of the cable as the temperature of the cable increases. [3]

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

Determine the rate at which water flows through the shower. State an appropriate unit for your answer. [4]

2 - (PHYSI/22_SL_Summer_2017_Q5) - *Electricity & Magnetism*

A cable consisting of many copper wires is used to transfer electrical energy from a 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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(b) The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of 64 Ω. The resistivity of copper is $1.7 \times 10^{-8}\ \Omega\,m$.

(i) Calculate the radius of each wire. [2]

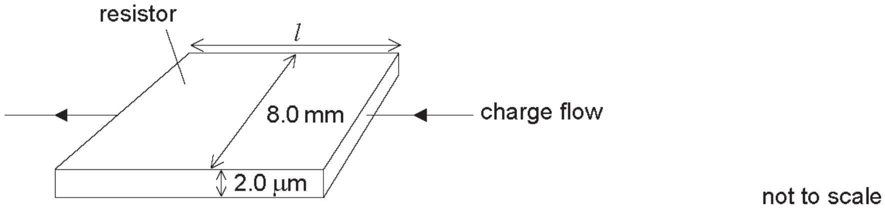
(ii) There is a current of 730 A in the cable. Show that the power loss in 1 m of the cable is about 30 W. [2]

(iii) When the current is switched on in the cable the initial rate of rise of temperature of the cable is $35\ mK\,s^{-1}$. The specific heat capacity of copper is $390\ J\,kg^{-1}\,K^{-1}$. Determine the mass of a length of one metre of the cable. [2]

3 - (PHYSI/20_SL_Winter_2017_Q3) - *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 μm. The diagram shows the direction of charge flow through the resistor.



(i) The resistance of the carbon film is 82 Ω. The resistivity of carbon is 4.1×10^{-5} Ω 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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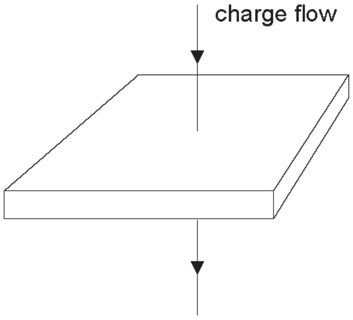
(b) The current direction is now changed so that charge flows vertically through the film.



not to scale

Deduce, without calculation, the change in the resistance. [2]

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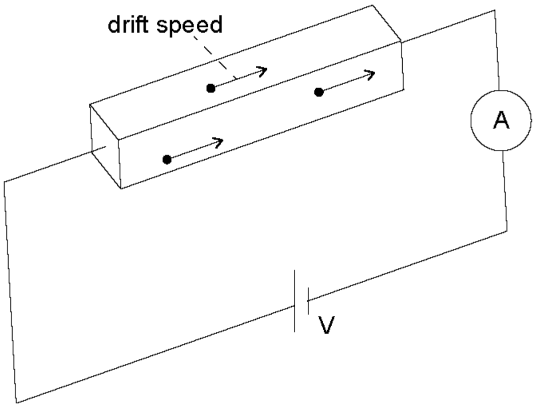
(c) Draw a circuit diagram to show how you could measure the resistance of the carbon-film resistor using a potential divider arrangement to limit the potential difference across the resistor. [2]

4 – (PHYSI/21_SL_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 2.0A.

(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 $\text{cm}\,\text{s}^{-1}$.
State your answer to an appropriate number of significant figures. [3]

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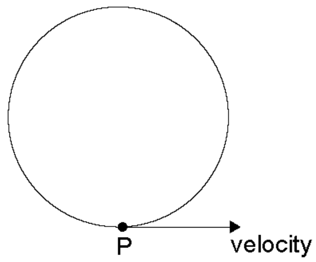
5 – (PHYSI/21_SL_Summer_2018_Q5) – *Electricity & Magnetism, Circular Motion & Gravitation*

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



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

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

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

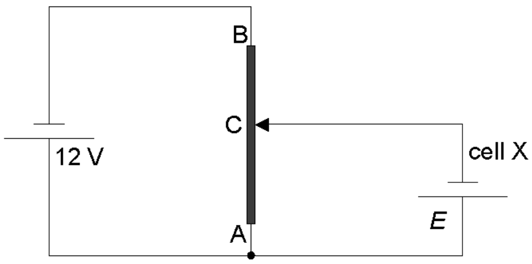
(c) Explain why the electron moves

(i) at constant speed. [1]

(ii) on a circular path. [2]

6 – (PHYSI/22_SL_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]

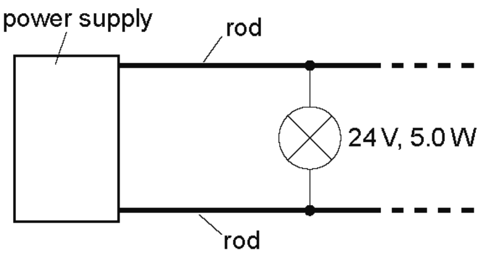
(b) AB is a wire of uniform cross-section and length 1.0 m. The resistance of wire AB is 80 Ω. When the length of AC is 0.35 m the current in cell X is zero.

(i) Show that the resistance of the wire AC is 28 Ω. [2]

(ii) Determine E. [2]

7 – (PHYSI/20_SL_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 emf	24 V
Power supply maximum 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 0.10 Ω. Calculate, in m, the minimum radius of each rod. Give your answer to an appropriate number of significant figures. [3]

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

(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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8 – (PHYSI/21_SL_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 $7.0\,\text{m s}^{-1}$ 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 3×10^3 s. [1]

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

(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]

(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.

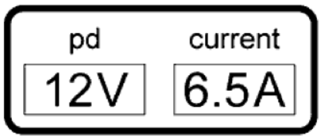
(i) Calculate the component of weight for the bicycle and girl acting down the slope. [1]

(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]

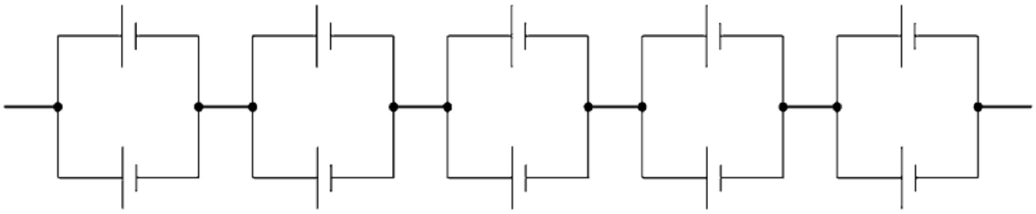
(c) On another journey up the slope, the girl carries an additional mass. Explain whether carrying this mass will change the maximum distance that the bicycle can travel along the slope. [2]

(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]

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



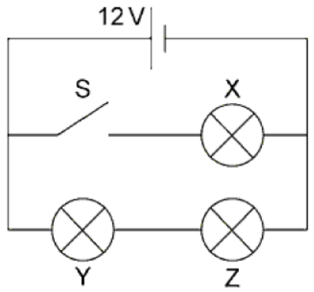
Calculate

(i) the emf of **one** cell. [1]

(ii) the internal resistance of **one** cell. [2]

9 – (PHYSI/22_SL_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 V. The cell has negligible internal resistance.



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

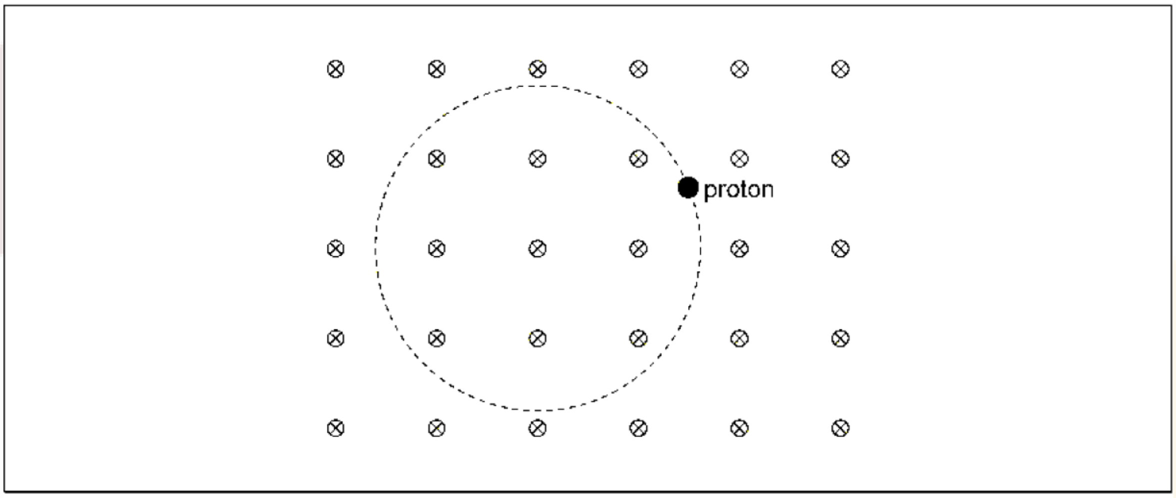
(b) The switch is now closed.

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

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

10 - (PHYSI/22_SL_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

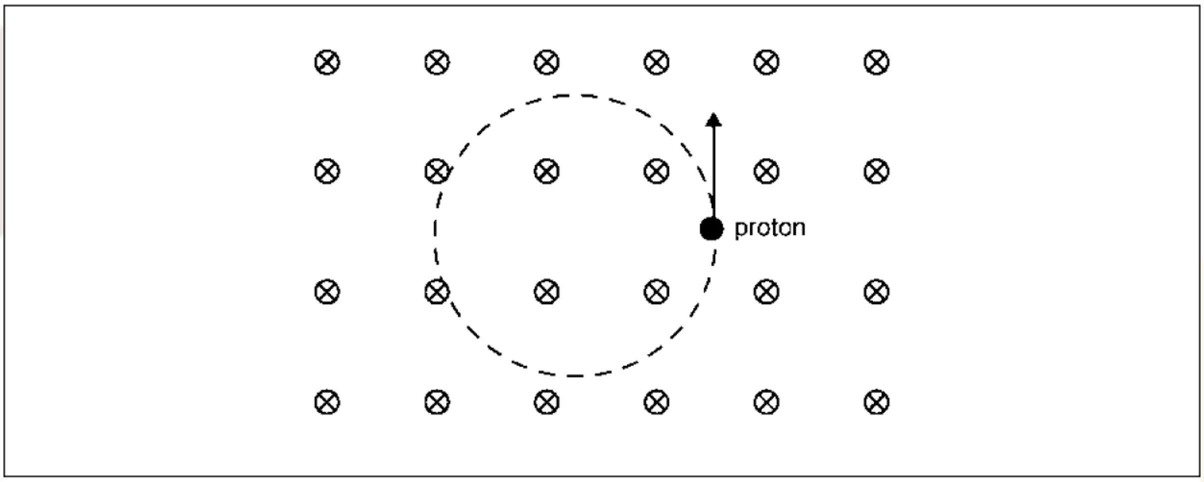
(i) magnetic force F on the proton. [1]

(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, determine, in m, the radius of the circular path. Give your answer to an appropriate number of significant figures. [3]

11 – (PHYSI/20_SL_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]

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

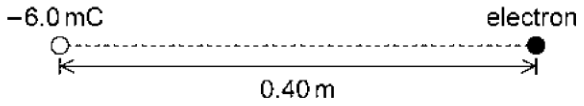
(i) Show that the radius of the path is about 6 cm. [2]

(ii) Calculate the time for **one** complete revolution. [2]

(c) Explain why the kinetic energy of the proton is constant. [2]

12 - (PHYSI/20_SL_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.



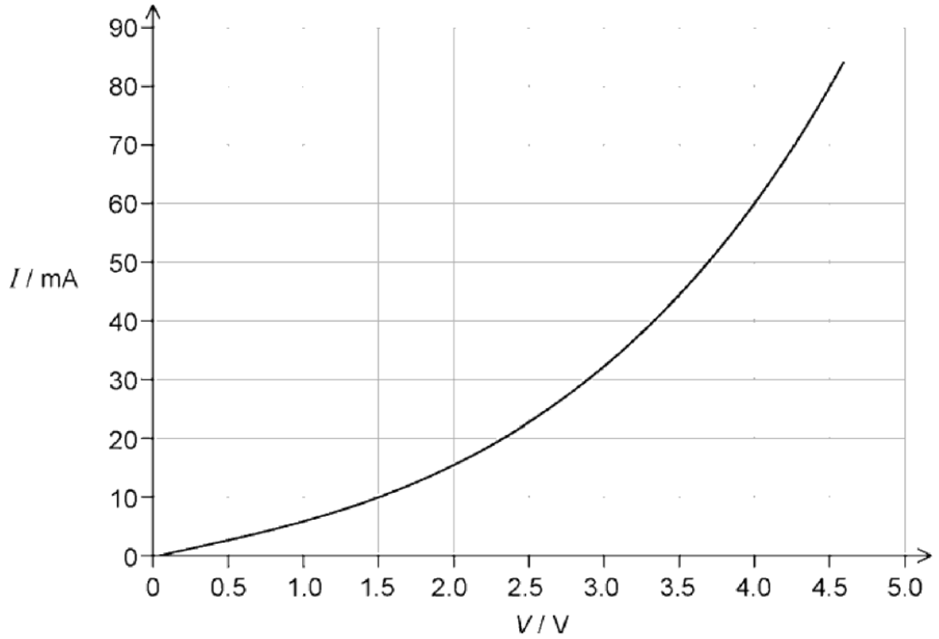
(a) Show that the electric field strength due to the point charge at the position of the electron is $3.4 \times 10^{8}\ \mathrm{N\,C^{-1}}$. [2]

(b) (i) Calculate the magnitude of the initial acceleration of the electron. [2]

(ii) Describe the subsequent motion of the electron. [3]

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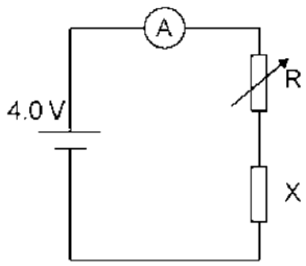
(b) Component X and a cell of negligible internal resistance are placed in a circuit. A variable resistor R is connected in series with component X. The ammeter reads 20 mA.



(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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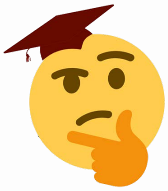
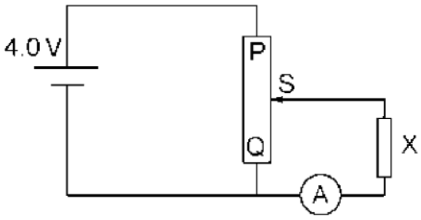


(c) Component X and the cell are now placed in a potential divider circuit.



(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) Describe, by reference to your answer for (c)(i), the advantage of the potential divider arrangement over the arrangement in (b). [2]

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14 – (PHYSI/21_SL_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 $18\,\text{g mol}^{-1}$. Estimate the average speed of the water molecules in the vapor produced. Assume the vapor behaves as an ideal gas. [2]

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

(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]

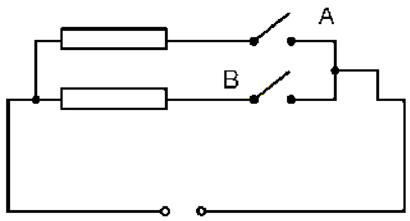
(ii) Explain why the temperature of water remains at 100 °C during this time. [1]

(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]

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



220 V

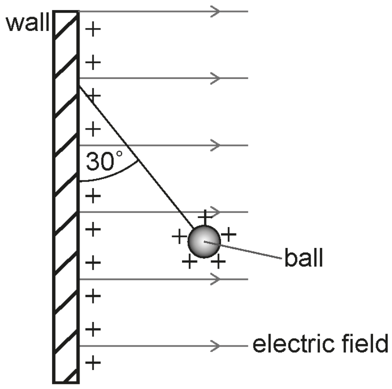
The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

(i) Show that each resistor has a resistance of about 30 Ω. [1]

(ii) Calculate the power transferred by the heater when both switches are closed. [2]

15 – (PHYSI/22_SL_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

$$E = \frac{\sigma}{2\varepsilon_0}.$$

Demonstrate that the units of the quantities in this equation are consistent. [2]

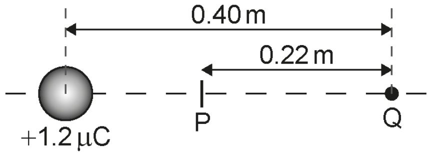
(b) (i) The thread makes an angle of 30° with the vertical wall. The ball has a mass of 0.025 kg.

Determine the horizontal force that acts on the ball. [3]

(ii) The charge on the ball is 1.2×10^{-6} C. Determine σ. [2]

(c) The centre of the ball, still carrying a charge of 1.2×10^{-6} 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.



Calculate the charge on Q. State your answer to an appropriate number of significant figures. [3]

16 – (PHYSI/22_SL_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]

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

(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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17 – (PHYSI/20_SL_Winter_2021_Q4) – *Electricity & Magnetism*

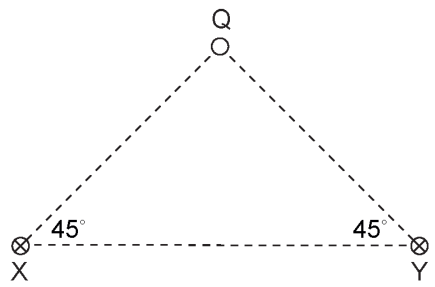
(a) The work done to move a particle of charge $0.25\,\mu C$ from one point in an electric field to another is $4.5\,\mu J$. Calculate the magnitude of the potential difference between the two points. [1]

(b) A charged particle, P, of charge $+68\,\mu C$ is fixed in space. A second particle, Q, of charge $+0.25\,\mu C$ is held at a distance of 48 cm from P and is then released.

(i) Determine the force on Q at the instant it is released. [2]

(ii) Describe the motion of Q after release. [2]

(c) The diagram shows two parallel wires X and Y that carry equal currents into the page.



Point Q is equidistant from the two wires. The magnetic field at Q due to wire X **alone** is 15 mT.

(i) On the diagram draw an arrow to show the direction of the magnetic field at Q due to wire X **alone**. [1]

(ii) Determine the magnitude and direction of the resultant magnetic field at Q. [2]

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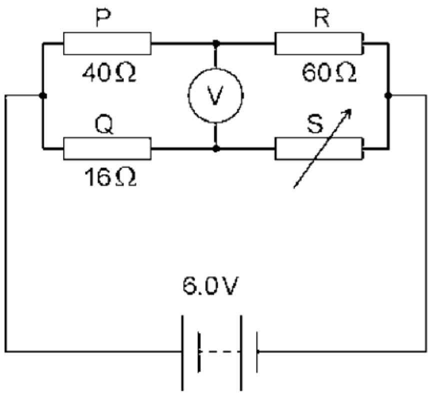
18 - (PHYSI/21_SL_Summer_2022_Q4) - *Electricity & Magnetism*

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

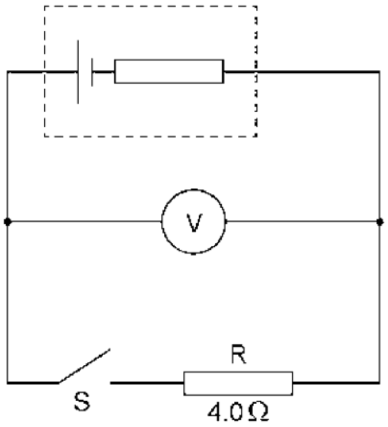
(i) Deduce the resistance of this new cylinder when it has been reshaped. [3]

(ii) Outline, without calculation, the change in the total power dissipated in Q and the new cylinder after it has been reshaped. [2]

19 – (PHYSI/22_SL_Summer_2022_Q4) – *Electricity & Magnetism*

(a) Identify the laws of conservation that are represented by Kirchhoff's circuit laws. [2]

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

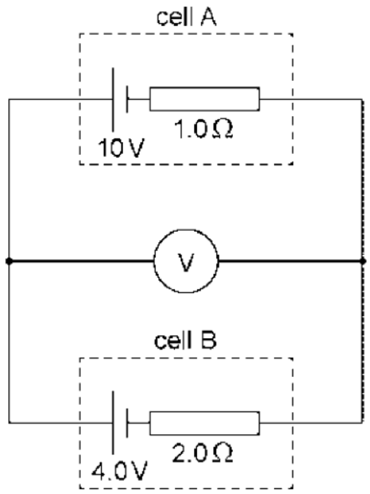


When S is open the reading on the voltmeter is 12 V. When S is closed the voltmeter reads 8.0 V.

(i) State the emf of the cell. [1]

(ii) Deduce the internal resistance of the cell. [2]

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



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

Calculate the reading on the voltmeter. [3]

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(d) Electricity can be generated using renewable resources.

(i) Outline why electricity is a secondary energy source. [1]

(ii) Some fuel sources are renewable. Outline what is meant by renewable. [1]

(e) (i) A fully charged cell of emf 6.0 V delivers a constant current of 5.0 A 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 $0.40\,m \times 0.15\,m$ at a place where the maximum intensity of sunlight is $380\,W\,m^{-2}$.

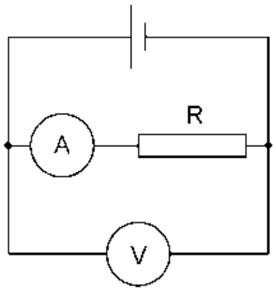
The overall efficiency of the re-charging process is 18%.

Calculate the minimum time required to re-charge the cell fully. [3]

(ii) Outline why research into solar cell technology is important to society. [1]

20 - (PHYSI/20_SL_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 cell has an emf of 1.49 V. The resistance of R is 50.0 Ω. The voltmeter reads 1.47 V.

(i) Show that the internal resistance of the cell is about 0.7 Ω. [2]

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(ii) Determine the total power dissipated in the circuit. [2]

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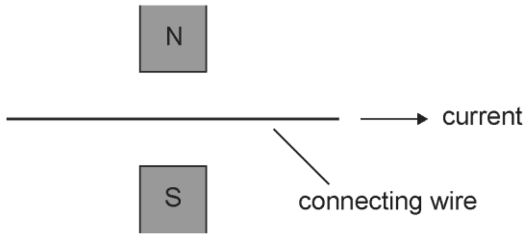
One of the connecting wires is placed in a magnetic field. The direction of the current in the wire is shown.



(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) Every current-carrying wire produces a magnetic field.

Describe **one** piece of evidence that supports this statement. [1]

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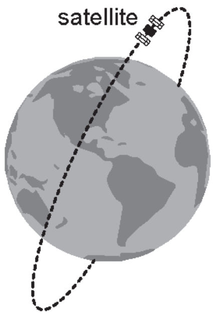
1 – (PHYSI/20_SL_Winter_2017_Q5) – *Circular Motion & Gravitation, Energy Production*

A satellite powered by solar cells directed towards the Sun is in a polar orbit about the Earth.



The satellite is orbiting the Earth at a distance of 6600 km from the centre of the Earth.

(a) Determine the orbital period for the satellite. [3]

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

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(b) 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.

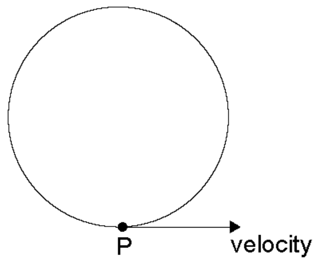
(i) Determine the mean temperature of the Earth. [2]

(ii) Suggest how the difference between λ_S and λ_E helps to account for the greenhouse effect. [3]

(c) 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]

2 – (PHYSI/21_SL_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 $6.8 \times 10^5\,\text{m s}^{-1}$ 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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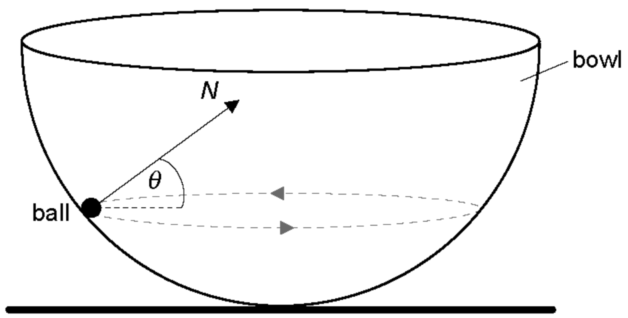
3 – (PHYSI/22_SL_Summer_2018_Q1) – *Mechanics, Circular Motion & Gravitation*

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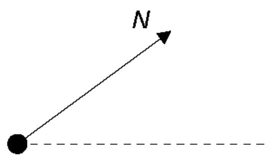
(ii) On the diagram, construct an arrow of the correct length to represent the weight of the ball. [2]



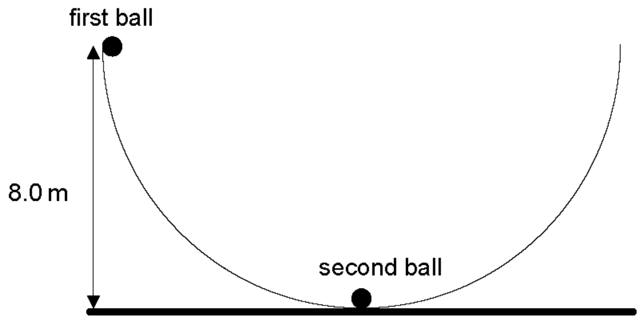
(iii) Show that the magnitude of the net force F on the ball is given by the following equation. [3]

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

(b) The radius of the bowl is 8.0 m and $\theta = 22^{\circ}$. Determine the speed of the ball. [4]

(c) Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl. [2]

(d) 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. Determine, in m, the maximum height reached by the two balls. [3]

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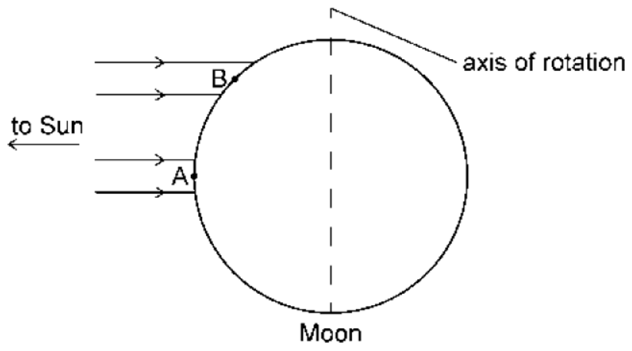
4 - (PHYSI/21_SL_Summer_2019_Q6) - *Circular Motion & Gravitation, Energy Production*

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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(c) The Moon orbits the Earth in a circular path.

Outline why

(i) a force acts on the Moon. [1]

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(ii) this force does no work on the Moon. [1]

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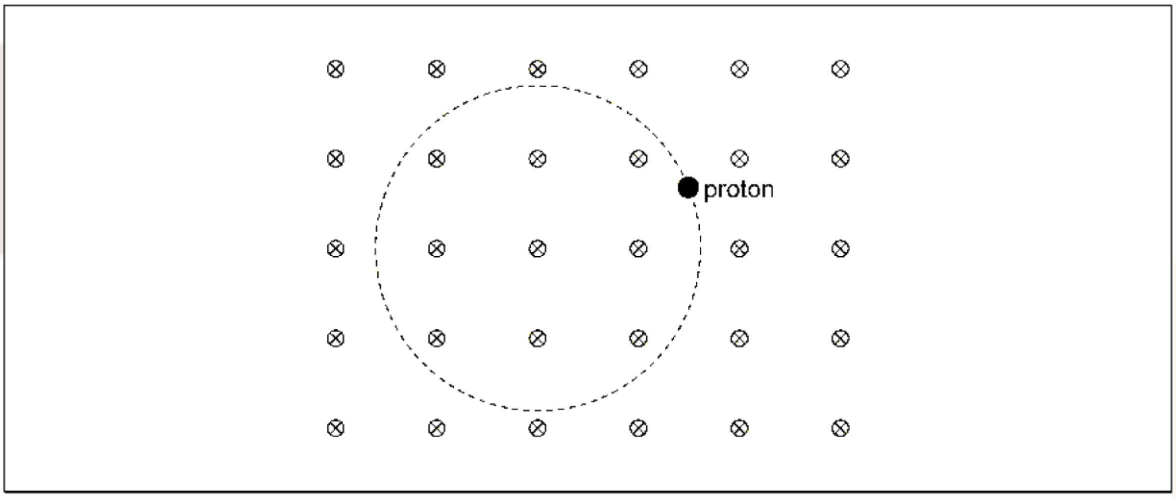
5 - (PHYSI/22_SL_Summer_2019_Q5) - *Electricity & Magnetism, Circular Motion & Gravitation*

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

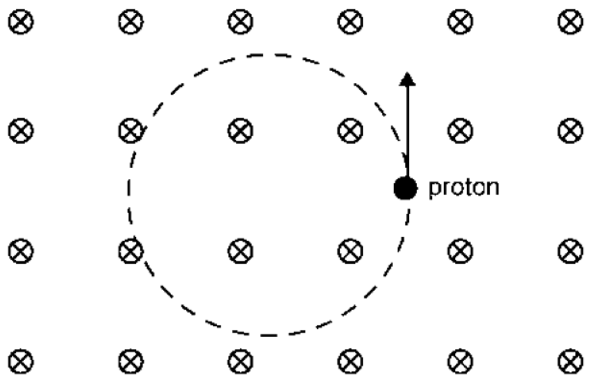
(i) magnetic force F on the proton. [1]

(ii) velocity vector v of the proton. [1]

(b) The speed of the proton is $2.16 \times 10^6\,\mathrm{m\,s^{-1}}$ and the magnetic field strength is 0.042 T. For this proton, determine, in m, the radius of the circular path. Give your answer to an appropriate number of significant figures. [3]

6 – (PHYSI/20_SL_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 $2.0 \times 10^6\,\mathrm{m\,s^{-1}}$ 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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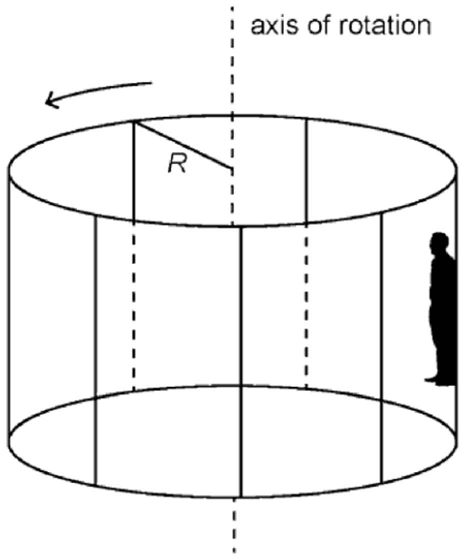
7 – (PHYSI/20_SL_Winter_2020_Q2) – *Circular Motion & Gravitation*

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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8 – (PHYSI/21_SL_Summer_2021_Q2) – *Circular Motion & Gravitation*

A planet is in a circular orbit around a star. The speed of the planet is constant.

(a) (i) Explain why a centripetal force is needed for the planet to be in a circular orbit. [2]

(ii) State the nature of this centripetal force. [1]

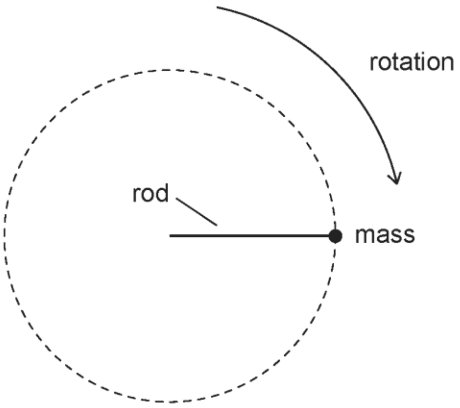
(b) Determine the gravitational field of the planet.

The following data are given:

Mass of planet = 8.0×10^{24} kg
Radius of the planet = 9.1×10^{6} m. [2]

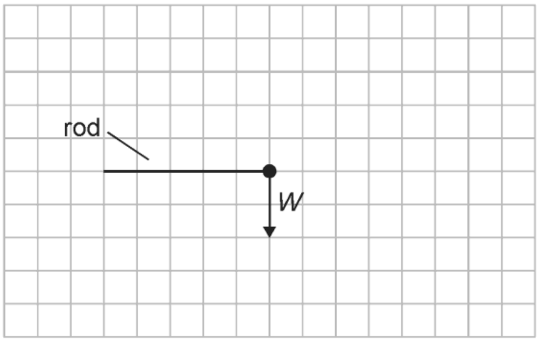
9 - (PHYSI/20_SL_Winter_2022_Q4) - *Circular Motion & Gravitation*

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_SL_Summer_2017_Q5) – *Atomic,nuclear & Particle Physics*

(a) State the quark structures of a meson and a baryon. [2]

Meson: ....

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Baryon: ....

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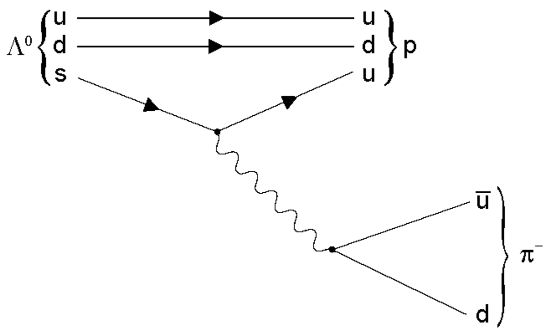
(b) A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.



(i) Explain which interaction is responsible for this decay. [2]

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(ii) Draw arrow heads on the lines representing $\overline{u}$ 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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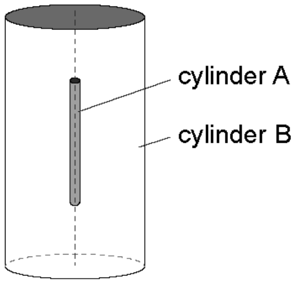
2 – (PHYSI/22_SL_Summer_2017_Q4) – *Atomic,nuclear & Particle Physics*

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{88}Ra$) decays by alpha emission to form a nuclide known as radon (Rn).

(a) Write down the missing values in the nuclear equation for this decay. [1]

$$^{226}_{88}Ra \rightarrow {}^{\cdots\cdots}_{86}Rn + {}^{\cdots\cdots}_{2}\alpha$$

(b) Rutherford and Royds put some pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B.



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.

The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin. [1]

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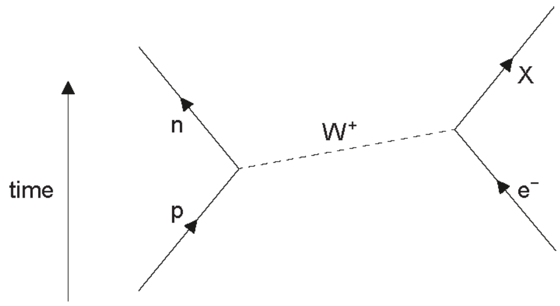
(c) Rutherford and Royds expected 2.7×10^{15} alpha particles to be emitted during the experiment. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3×10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B. [3]

(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]

(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]

3 – (PHYSI/20_SL_Winter_2017_Q2) – *Atomic,nuclear & Particle Physics*

The Feynman diagram shows electron capture.



(a) Deduce that X must be an electron neutrino. [2]

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(b) Distinguish between hadrons and leptons. [2]

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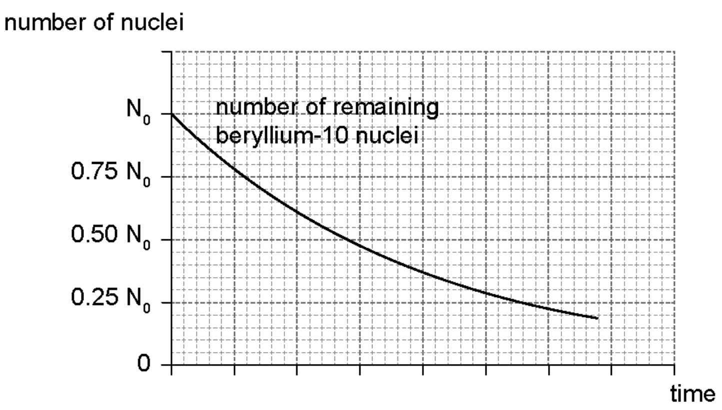
4 - (PHYSI/21_SL_Summer_2018_Q6) - *Atomic,nuclear & Particle Physics, Energy Production*

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. [1]

$$^{10}_{\square}\text{Be} \rightarrow {}^{\square}_{5}\text{B} + \beta + \bar{\nu}$$

(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.



(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. State the number of remaining beryllium-10 nuclei in the sample after 2.8×10^{6} years. [1]

(c) An ice sample is moved to a laboratory for analysis. The temperature of the sample is $-20\,^{\circ}\mathrm{C}$.

(i) State what is meant by thermal radiation. [1]

(ii) Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. [2]

(iii) Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. [2]

(iv) Derive the units of intensity in terms of fundamental SI units. [2]

5 – (PHYSI/22_SL_Summer_2018_Q6) – *Atomic,nuclear & Particle Physics*

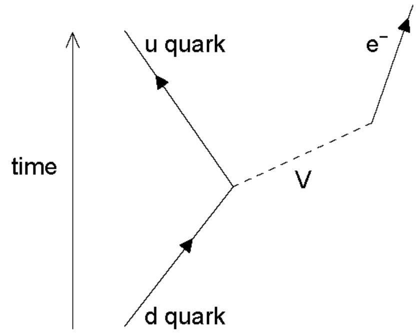
(a) Rutherford constructed a model of the atom based on the results of the alpha particle scattering experiment. Describe this model. [2]

(b) Rhodium-106 $\left({}^{106}_{45}\text{Rh}\right)$ decays into palladium-106 $\left({}^{106}_{46}\text{Pd}\right)$ by beta minus (β^{-}) decay. The binding energy per nucleon of rhodium is 8.521 MeV and that of palladium is 8.550 MeV.

(i) State what is meant by the binding energy of a nucleus. [1]

(ii) Show that the energy released in the β^{-} decay of rhodium is about 3 MeV. [1]

(c) 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]

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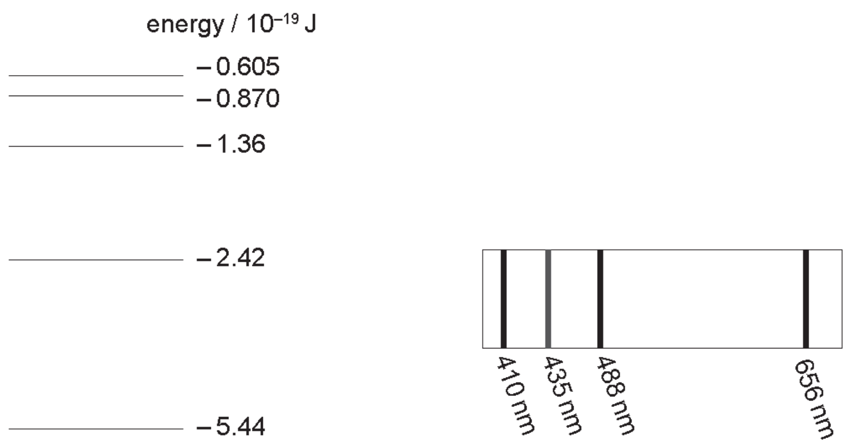
6 – (PHYSI/20_SL_Winter_2018_Q5) – *Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)*

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.



(a) Determine the energy of a photon of blue light (435nm) emitted in the hydrogen spectrum. [3]

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(b) 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). [1]

(c) Explain your answer to (b). [2]

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7 – (PHYSI/21_SL_Summer_2019_Q2) – *Atomic,nuclear & Particle Physics*

(a) Silicon-30 ($^{30}_{14}Si$) can be formed from phosphorus-30 ($^{30}_{15}P$) by a process of beta-plus decay.

(i) Write down the nuclear equation that represents this reaction. [2]

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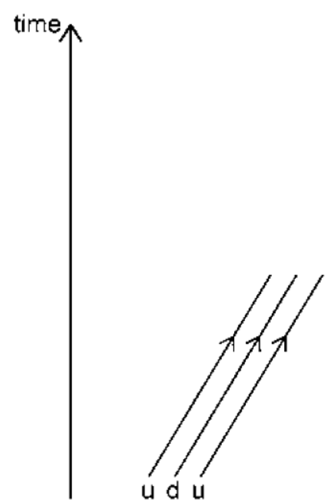
(ii) Sketch the Feynman diagram that represents this reaction. The diagram has been started for you. [3]



(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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(b) 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]

8 - (PHYSI/22_SL_Summer_2019_Q6) - *Atomic,nuclear & Particle Physics*

Deuterium, ${}^{2}_{1}H$, undergoes fusion according to the following reaction.

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + X$$

(a) Identify particle X. [1]

(b) The following data are available for binding energies per nucleon.

$${}^{2}_{1}H = 1.12\,MeV$$

$${}^{3}_{1}H = 2.78\,MeV$$

(i) Determine, in MeV, the energy released. [2]

(ii) Suggest why, for the fusion reaction above to take place, the temperature of deuterium must be very high. [2]

(c) Particle Y is produced in the collision of a proton with a K^- in the following reaction.

$$K^- + p^+ \rightarrow K^0 + K^+ + Y$$

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]

(ii) strangeness. [1]

9 – (PHYSI/20_SL_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]

(ii) Calculate the ratio $\dfrac{\text{kinetic energy of alpha particle}}{\text{kinetic energy of thorium nucleus}}$. [2]

10 – (PHYSI/20_SL_Winter_2020_Q6) – *Atomic,nuclear & Particle Physics, Energy Production*

(a) One possible fission reaction of uranium-235 (U-235) is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{140}_{54}\text{Xe} + ^{94}_{38}\text{Sr} + 2^{1}_{0}\text{n}$$

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]

(ii) Outline why quantities such as atomic mass and nuclear binding energy are often expressed in non-SI units. [1]

(iii) Show that the energy released in the reaction is about 180 MeV. [1]

(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]

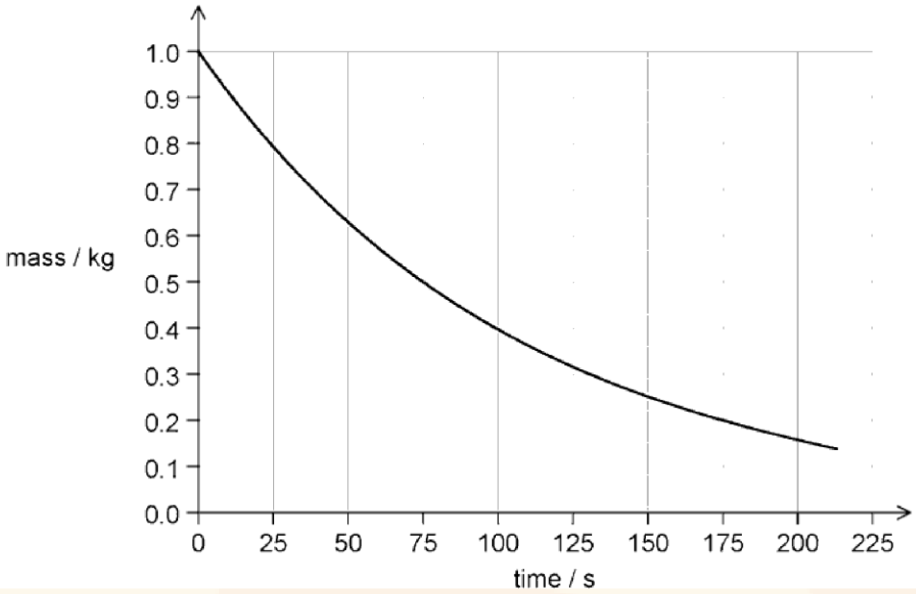
(ii) The power station has a useful power output of 1.2 GW and an efficiency of 36 %. Determine the mass of U-235 that undergoes fission in one day. [2]

(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

$$^{94}_{38}\mathrm{Sr} \rightarrow \mathrm{X} + \bar{\nu}_e + e.$$

(i) Write down the proton number of nuclide X. [1]

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/21_SL_Summer_2021_Q5) – *Atomic,nuclear & Particle Physics*

Radioactive uranium-238 $\left({}^{238}_{92}\text{U}\right)$ 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]

$${}^{238}_{92}\text{U} \rightarrow$$

(b) Thallium-206 $\left({}^{206}_{81}\text{Tl}\right)$ decays into lead-206 $\left({}^{206}_{82}\text{Pb}\right)$.

Identify the quark changes for this decay. [1]

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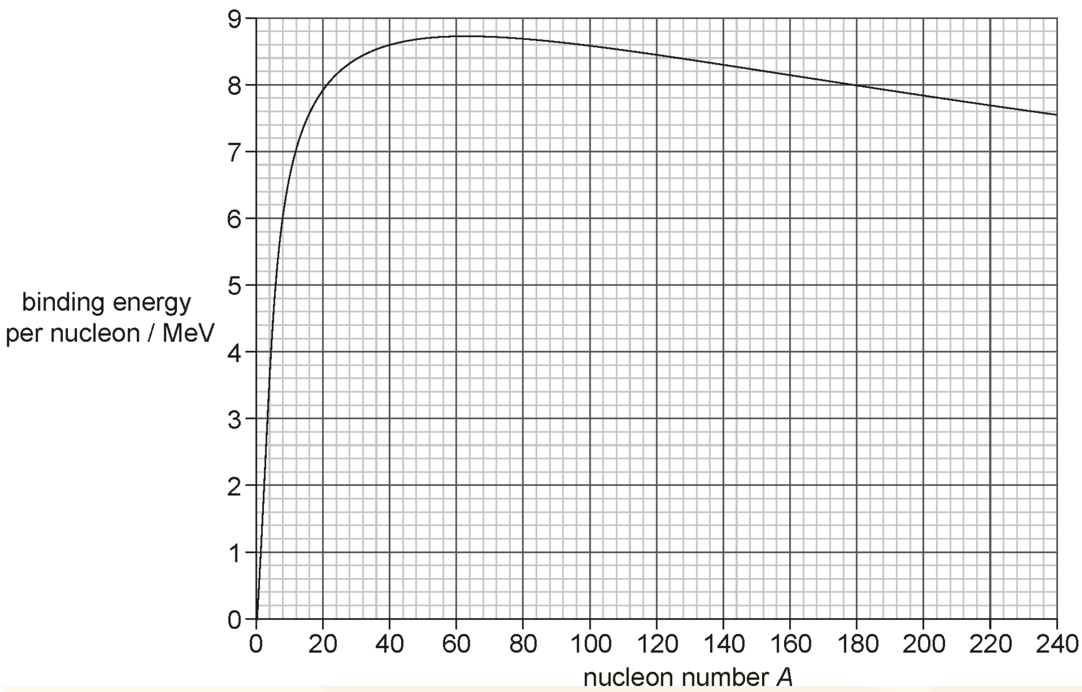
(c) The graph shows the variation with the nucleon number *A* of the binding energy per nucleon.



(i) Outline why high temperatures are required for fusion to occur. [2]

(ii) Outline, with reference to the graph, why energy is released both in fusion and in fission. [1]

(iii) Uranium-235 $\left({}^{235}_{92}\mathrm{U}\right)$ 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]

(i) Outline why high temperatures are required for fusion to occur. [2]

(ii) Outline, with reference to the graph, why energy is released both in fusion and in fission. [1]

(iii) Uranium-235 $\left({}^{235}_{92}\text{U}\right)$ 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]

12 – (PHYSI/21_SL_Summer_2021_Q7) – *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]

(b) When a pi meson $\pi-$ ($d\bar{u}$) 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]

13 – (PHYSI/22_SL_Summer_2021_Q4) – *Atomic,nuclear & Particle Physics*

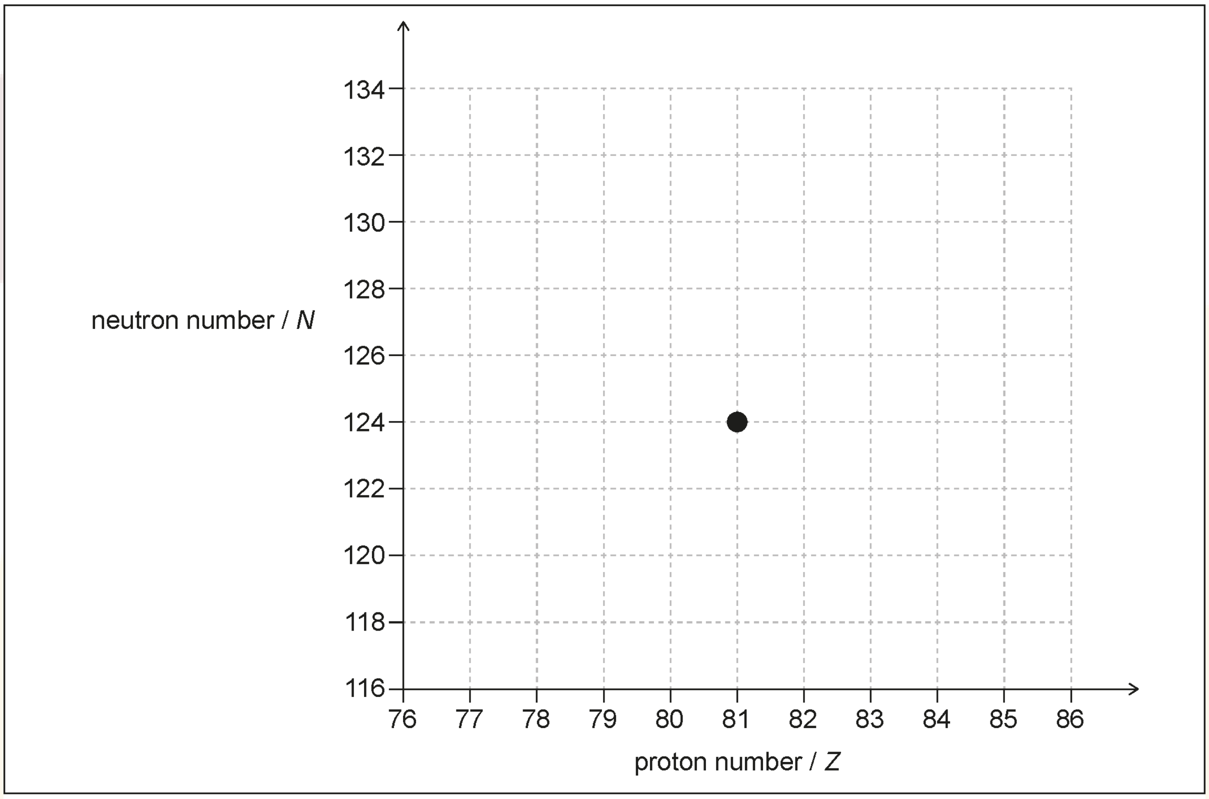
(a) During electron capture, an atomic electron is captured by a proton in the nucleus. The stable nuclide thallium-205 ($^{205}_{81}Tl$) can be formed when an unstable lead (Pb) nuclide captures an electron.

Write down the equation to represent this decay. [2]

$$^{\square}_{\square}Pb + ^{\square}_{\square}e \longrightarrow ^{205}_{81}Tl + ^{\square}_{\square}\nu_e$$

(b) The neutron number N and the proton number Z are not equal for the nuclide $^{205}_{81}Tl$. Explain, with reference to the forces acting within the nucleus, the reason for this. [2]

(c) Thallium-205 ($^{205}_{81}Tl$) 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 $^{205}_{81}Tl$ 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 $^{205}_{81}Tl$ forms from the unstable nuclide. [3]

14 - (PHYSI/20_SL_Winter_2021_Q5) - *Atomic,nuclear & Particle Physics*

(a) (i) State what is meant by the binding energy of a nucleus. [1]

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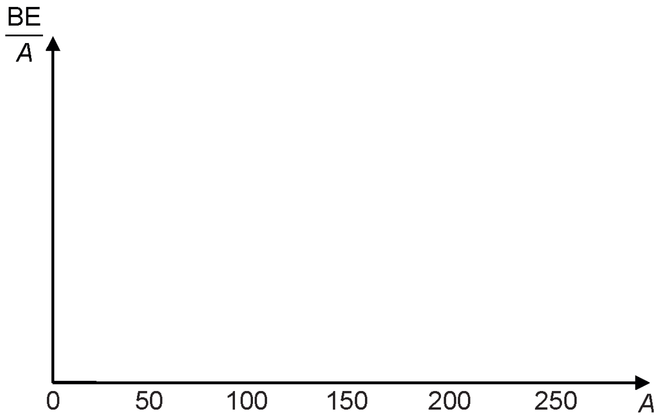
(ii) Draw, on the axes, a graph to show the variation with nucleon number A of the binding energy per nucleon, $\frac{BE}{A}$. Numbers are not required on the vertical axis. [2]



(iii) Identify, with a cross, on the graph in (a)(ii), the region of greatest stability. [1]

(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]

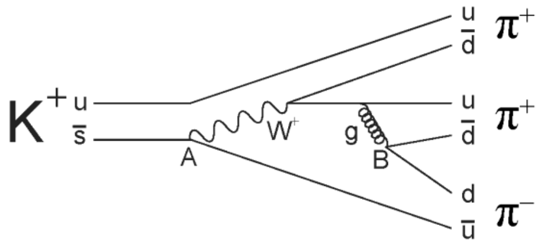
(ii) The plutonium nucleus is at rest when it decays.

Calculate the ratio $\dfrac{\text{kinetic energy of alpha particle}}{\text{kinetic energy of uranium}}$ [2]

15 - (PHYSI/21_SL_Summer_2022_Q5) - *Atomic,nuclear & Particle Physics*

(a) Describe the quark structure of a baryon. [2]

(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]

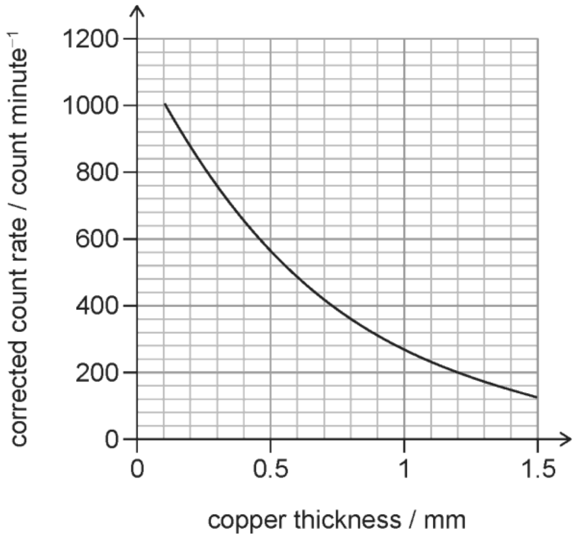
(c) The K^+ meson can decay as

$$K^+ \rightarrow \mu^+ + \nu_\mu.$$

State and explain the interaction that is responsible for this decay. [2]

16 - (PHYSI/22_SL_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 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]

(d) Another radioactive source consists of a nuclide of caesium ($^{137}_{55}Cs$) that decays to barium ($^{137}_{56}Ba$).

Write down the reaction for this decay. [2]

17 – (PHYSI/20_SL_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 emission can be followed by the emission of a gamma photon.

State and explain whether the alpha particle or gamma photon will cause greater ionization in the surrounding material. [2]

1 – (PHYSI/21_SL_Summer_2017_Q3) – *Energy Production*

Two renewable energy sources are solar and wind.

(a) Describe the difference between photovoltaic cells and solar heating panels. [1]

(b) A solar farm is made up of photovoltaic cells of area 25 000 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]

(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]

(ii) Explain **two** reasons why the number of turbines required is likely to be greater than your answer to (c)(i). [2]

2 – (PHYSI/22_SL_Summer_2017_Q2) – *Energy Production*

(a) Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. [2]

(b) The hydroelectric system has four 250 MW generators. The specific energy available from the water is 2.7 kJ kg^{-1}. Determine the maximum time for which the hydroelectric system can maintain full output when a mass of 1.5×10^{10} kg of water passes through the turbines. [2]

(c) Not all the stored energy can be retrieved because of energy losses in the system. Explain **one** such loss. [1]

(d) At the location of the hydroelectric system, an average intensity of 180 $W m^{-2}$ arrives at the Earth's surface from the Sun. Solar photovoltaic (PV) cells convert this solar energy with an efficiency of 22 %. The solar cells are to be arranged in a square array. Determine the length of **one** side of the array that would be required to replace the hydroelectric system. [2]

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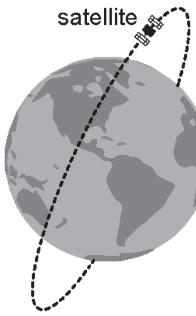
3 - (PHYSI/20_SL_Winter_2017_Q5) - *Circular Motion & Gravitation, Energy Production*

A satellite powered by solar cells directed towards the Sun is in a polar orbit about the Earth.



The satellite is orbiting the Earth at a distance of 6600 km from the centre of the Earth.

(a) Determine the orbital period for the satellite. [3]

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

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(b) 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]

(ii) Suggest how the difference between λ_S and λ_E helps to account for the greenhouse effect. [3]

(c) 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]

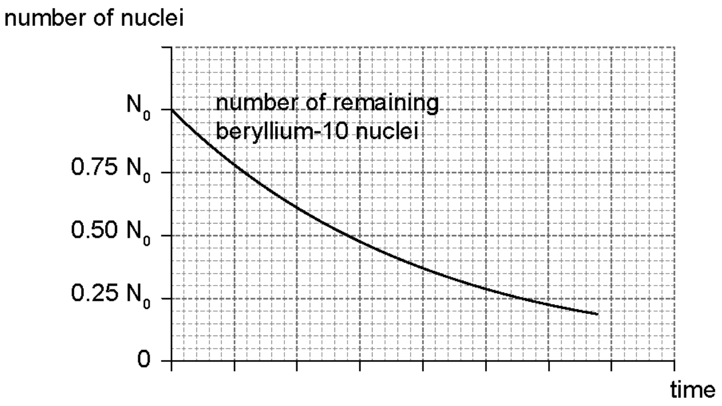
4 – (PHYSI/21_SL_Summer_2018_Q6) – *Atomic,nuclear & Particle Physics, Energy Production*

The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus ($\beta-$) decay to form a stable boron (B) nuclide.

(a) Identify the missing information for this decay. [1]

$$^{10}_{\square}\text{Be} \rightarrow {}^{\square}_{5}\text{B} + \beta + \overline{\upsilon}$$

(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.



(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. State the number of remaining beryllium-10 nuclei in the sample after 2.8×10^{6} years. [1]

(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]

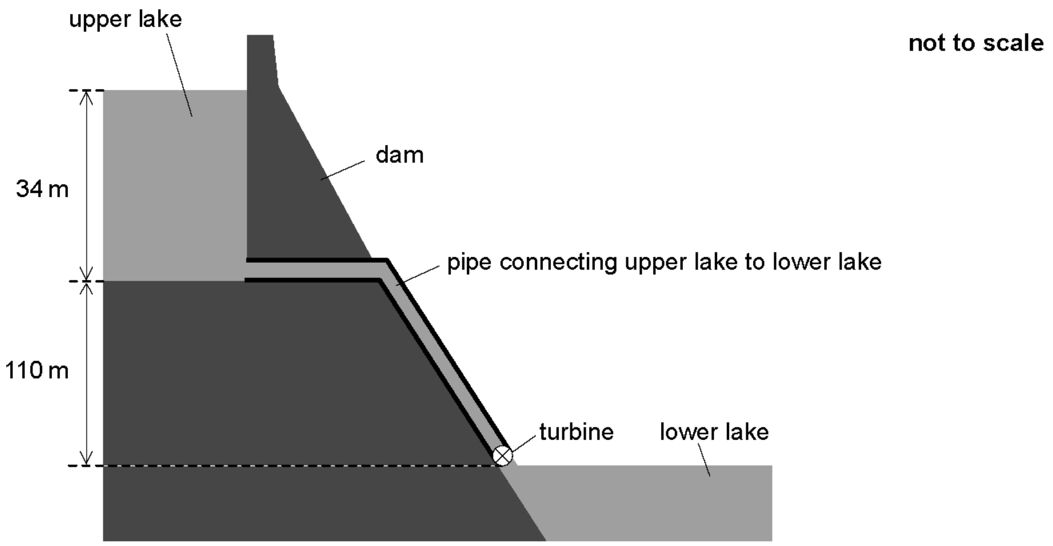
(ii) Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. [2]

(iii) Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. [2]

(iv) Derive the units of intensity in terms of fundamental SI units. [2]

5 – (PHYSI/22_SL_Summer_2018_Q5) – *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 1.2×10^5 m^3 per minute. The density of water is 1.0×10^3 kg m^{-3}.

(i) Estimate the specific energy of water in this storage system, giving an appropriate unit for your answer. [2]

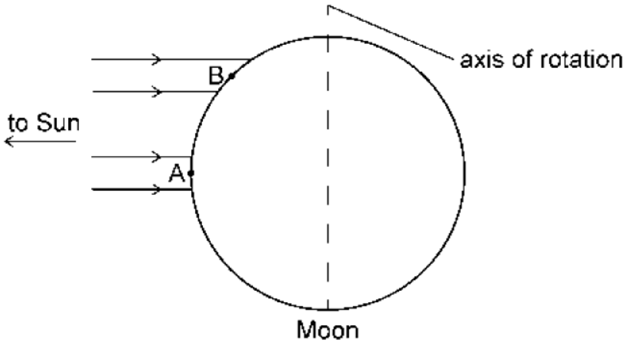
(ii) Show that the average rate at which the gravitational potential energy of the water decreases is 2.5 GW. [3]

(iii) The storage system produces 1.8 GW of electrical power. Determine the overall efficiency of the storage system. [1]

(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. [1]

6 - (PHYSI/21_SL_Summer_2019_Q6) - *Circular Motion & Gravitation, 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]

(c) The Moon orbits the Earth in a circular path.

Outline why

(i) a force acts on the Moon. [1]

(ii) this force does no work on the Moon. [1]

7 - (PHYSI/22_SL_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 $\mathrm{W\,m^{-2}}$. [1]

(b) Explain why some of this radiation is returned to the oceans from the atmosphere. [3]

8 - (PHYSI/20_SL_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	$1.20\,\mathrm{kg\,m^{-3}}$	$1.32\,\mathrm{kg\,m^{-3}}$
Wind speed	$8.0\,\mathrm{m\,s^{-1}}$	$4.0\,\mathrm{m\,s^{-1}}$

(a) Determine the maximum power that can be extracted from the wind by this turbine. [3]

(b) Suggest why the answer in (a) is a maximum. [1]

9 – (PHYSI/20_SL_Winter_2020_Q6) – *Atomic,nuclear & Particle Physics, Energy Production*

(a) One possible fission reaction of uranium-235 (U-235) is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{140}_{54}\text{Xe} + ^{94}_{38}\text{Sr} + 2^{1}_{0}\text{n}$$

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]

(ii) Outline why quantities such as atomic mass and nuclear binding energy are often expressed in non-SI units. [1]

(iii) Show that the energy released in the reaction is about 180 MeV. [1]

(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]

(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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(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

$$^{94}_{38}\text{Sr} \rightarrow \text{X} + \bar{\nu}_e + e.$$

(i) Write down the proton number of nuclide X. [1]

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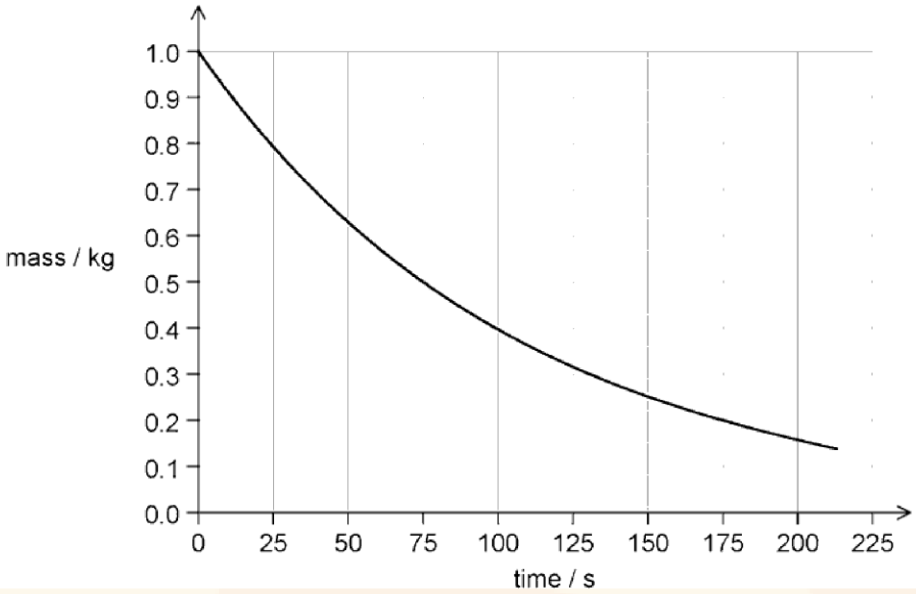
The graph shows the variation with time of the mass of Sr-94 remaining in the sample.



(ii) State the half-life of Sr-94. [1]

(iii) Calculate the mass of Sr-94 remaining in the sample after 10 minutes. [2]

10 – (PHYSI/21_SL_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

$$\frac{P}{4\pi d^2} \times \frac{A}{4}.$$

[2]

(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]

(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 α_M = 0.13. The solar constant is $1.36 \times 10^3\,\mathrm{W\,m^{-2}}$. Calculate the surface temperature of the Moon. [2]

11 – (PHYSI/22_SL_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]

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

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

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]

(d) State **two** reasons why future energy demands will be increasingly reliant on sources such as photovoltaic cells. [2]

Reason 1:

Reason 2:

12 - (PHYSI/20_SL_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 $16\,W\,m^{-2}$ [1]

(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 $3.1\,W\,m^{-2}$ [3]

(iii) Show that the equilibrium surface temperature of Titan is about 90 K. [1]

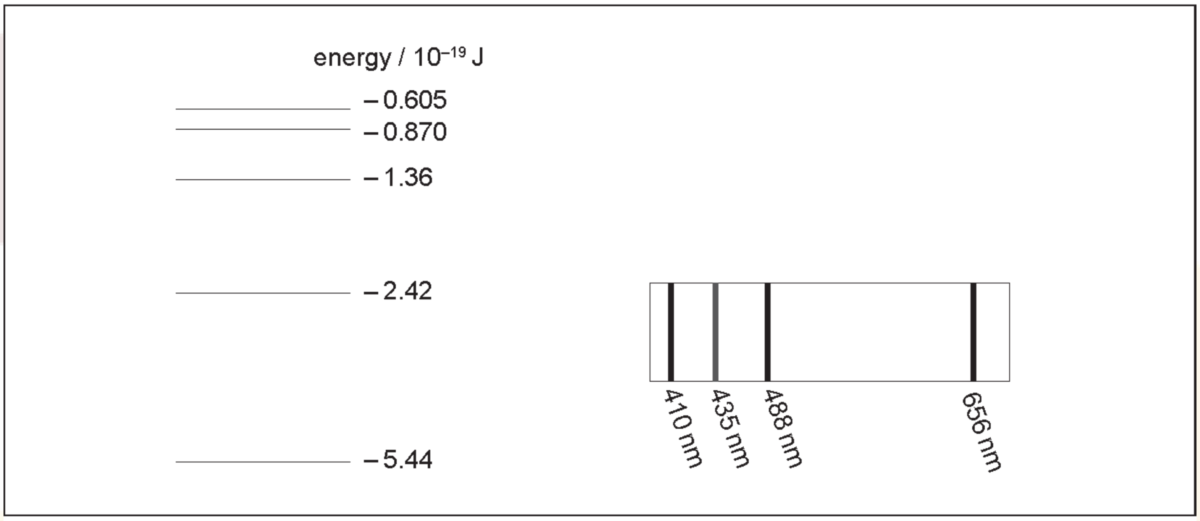
(b) (i) The orbital radius of Titan around Saturn is R and the period of revolution is T.

Show that $T^2 = \dfrac{4\pi^2 R^3}{GM}$ where M is the mass of Saturn. [2]

(ii) The orbital radius of Titan around Saturn is 1.2×10^{9} m and the orbital period is 15.9 days. Estimate the mass of Saturn. [2]

1 - (PHYSI/20_SL_Winter_2018_Q5) - *Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)*

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.



(a) Determine the energy of a photon of blue light (435nm) emitted in the hydrogen spectrum. [3]

(b) 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). [1]

(c) Explain your answer to (b). [2]

ANSWERS

1 – (PHYSI/21_SL_Summer_2017_Q1) – *Mechanics, Thermal Physics*

a	**i**	$\frac{1}{2}v^2 = 0.24gh$ ✓ $v = 11.9$ «ms^{-1}» ✓
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/$F_{gravitational}$ ***AND*** arrow vertically upwards from dot labelled reaction force/R/normal contact force/N/F_N ✓ W > R ✓

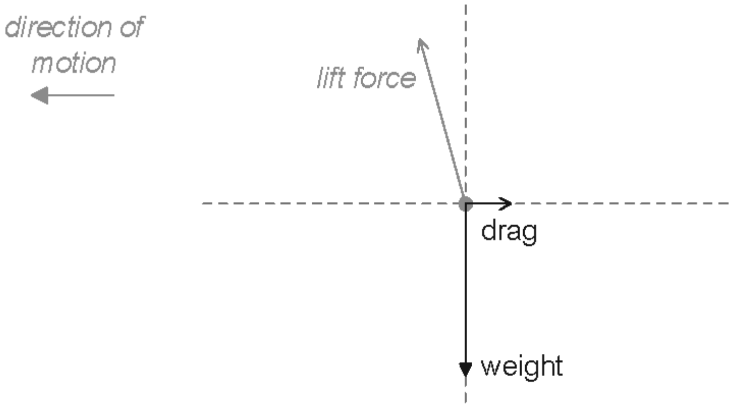
b	ii	***ALTERNATIVE 1*** recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓ = 468 «N» ✓ W/640 N (weight) is larger than the centripetal force required, so the skier does not lose contact with the ground ✓ ***ALTERNATIVE 2*** recognition that centripetal acceleration is required / $\frac{v^2}{r}$ 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 $a =$ «–»1.40 «ms^{-2}» ✓ friction force $= ma = 65 \times 1.4 = 91$ «N» ✓ coefficient of friction $= \dfrac{91}{65 \times 9.81} = 0.14$ ✓ ***ALTERNATIVE 2*** $KE = \dfrac{1}{2}mv^2$ = 0.5 x 65 x 8.2^2 = 2185 «J» ✓ friction force = KE/distance =2185/24 = 91«N» ✓ coefficient of friction $= \dfrac{91}{65 \times 9.81} = 0.14$ ✓
d	i	«76×9.6» $= 730$ ✓ Ns ***OR*** kg ms^{-1} ✓
d	ii	safety net extends stopping time ✓ $F = \dfrac{\Delta p}{\Delta t}$ 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_SL_Summer_2017_Q1) – *Mechanics*

a		correct use of kinematic equation/equations ✓ 148.5 ***or*** 149 ***or*** 150 «m» ✓
b		$a = \dfrac{27}{11}$ ***or*** 2.45 «m s^{-2}» ✓ $F - 160 = 492 \times 2.45$ ✓ 1370 «N» ✓

c		***ALTERNATIVE 1*** «work done to launch glider» $= 1370 \times 149$ «$= 204$ kJ» ✔ «work done by motor» $= \dfrac{204 \times 100}{23}$ ✔ «power input to motor» $= \dfrac{204 \times 100}{23} \times \dfrac{1}{11} = 80$ ***or*** 80.4 ***or*** 81 k«W» ✔ ***ALTERNATIVE 2*** use of average speed $13.5\ \text{m s}^{-1}$ ✔ «useful power output» $=$ force $\times$ average speed «$= 1370 \times 13.5$» ✔ power input $=$ «$1370 \times 13.5 \times \dfrac{100}{23} =$» 80 ***or*** 80.4 ***or*** 81 k«W» ✔ ***ALTERNATIVE 3*** work required from motor $=$ KE $+$ work done against friction «$= 0.5 \times 492 \times 27^2 + (160 \times 148.5)$» $= 204$ «kJ» ✔ «energy input» $= \dfrac{\text{work required from motor} \times 100}{23}$ ✔ power input $= \dfrac{883000}{11} = 80.3$ k«W» ✔

d		$\omega =$ «$\frac{v}{r} =$» $\frac{27}{0.6} = 45$ ✓ rad s^{-1} ✓
e		 drag correctly labelled and in correct direction ✓ weight correctly labelled and in correct direction ***AND*** no other incorrect force shown ✓

f		name Newton's first law ✓ vertical/all forces are in equilibrium/balanced/add to zero ***OR*** vertical component of lift mentioned ✓ as equal to weight ✓
g		any speed and any direction quoted together as the answer✓ quotes their answer(s) to 3 significant figures ✓ speed = 12.7 m s^{-1} ***or*** direction = 9.46° ***or*** 0.165 rad «below the horizontal» ***or*** gradient of $-\frac{1}{6}$ ✓

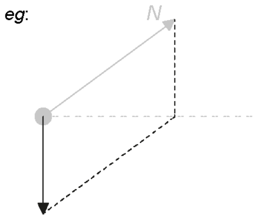
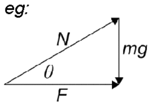
3 – (PHYSI/20_SL_Winter_2017_Q1) – *Mechanics*

a		arrow vertically downwards labelled weight «of sledge and/or girl»/W/mg/gravitational force/F_g/$F_{gravitational}$ *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) «v» ✓ 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» $\mu mg\cos(6.5)$ «5.9 N» ✓ «component of weight down slope» $mg\sin(6.5)$ « 6.1 N» ✓ «so $a \; \frac{F}{m}$ » acceleration $\frac{12}{5.5}$ 2.2 «ms $^{-2}$» ✓	*Ignore negative signs* *Allow use of g 10 m s^{-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_SL_Summer_2018_Q1) - *Mechanics*

a		use of conservation of energy ***OR*** $v^2\ \ u^2 \cdot 2as$ ✓ v «$\sqrt{2\times 60.0\times 9.81}$» 34.3«$ms^{-1}$» ✓		2
b	i	use of impulse $F_{ave}\ \ \Delta t\ \ \Delta p$ ***OR*** use of $F\ \ ma$ with average acceleration ***OR*** $F\ \ \frac{80.0\ \ 34.3}{0.759}$ ✓ 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 × 9.81 ✓ 4400«N» ✓	*Allow ECF from (b)(i).*	2
c	i	(loss in) gravitational potential energy (of block) into kinetic energy (of block) ✓	*<u>Must</u> see names of energy (gravitational potential energy and kinetic energy) – Allow for reasonable variations of terminology (eg energy of motion for KE).*	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.* *<u>Must</u> see either the block or the rope (or both) mentioned in connection with the appropriate energies.*	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

5 – (PHYSI/22_SL_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		$\frac{mg}{\tan\theta} \quad m\frac{v^2}{r}$ ✓ $r \quad R\cos\theta$ ✓ $v \quad \sqrt{\frac{gR\cos^2\theta}{\sin\theta}}$ / $\sqrt{\frac{gR\cos\theta}{\tan\theta}}$ / $\sqrt{\frac{9.81 \quad 8.0\cos22}{\tan22}}$ ✓ $v \quad 13.4 / 13$ «ms^{-1}» ✓	*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 ✓ so no / it is not possible ✓	*Must see correct justification to award MP2*	2
d		speed before collision $v =$ «$\sqrt{2gR} =$» 12.5 «ms^{-1}» ✓ «from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed «$v_c \quad \frac{12.5}{2} \quad 6.25ms^{-1}$» ✓ h «$\frac{v_c^2}{2g} \quad \frac{6.25^2}{2 \quad 9.81}$» 2.0 «m» ✓	*Allow 12.5 from incorrect use of kinematics equations* *Award* ***[3]*** *for a bald correct answer* *Award* ***[0]*** *for $mg(8) \quad 2mgh$ leading to $h \quad 4m$ if done in one step.* *Allow ECF from MP1* *Allow ECF from MP2*	3

6 – (PHYSI/20_SL_Winter_2018_Q1) – *Mechanics*

a		change in momentum each second = 6.6 10 ^{6} 5.2 10^{4} «= 3.4 10 ^{1} kg m s ^{1}» ✓ acceleration «$\frac{3.4 \cdot 10^{1}}{740}$ » 4.6 10 ^{4} «m s ^{2}» ✓		2
b	i	*ALTERNATIVE 1:* (considering the acceleration of the spacecraft) time for acceleration $\frac{30}{6.6 \quad 10^{6}}$ «4.6 10^{6}» «s» ✓ max speed «answer to (a) 4.6 10^{6} » 2.1 · 10^{3} «m s ^{1}» ✓ *ALTERNATIVE 2:* (considering the conservation of momentum) (momentum of 30 kg of fuel ions = change of momentum of spacecraft) 30 5.2 10^{4} 710 max speed ✓ max speed = 2.2 · 10^{3} «m s ^{1}» ✓		2
b	ii	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
d	i	force per unit mass ✓ acting on a small/test/point mass «placed at the point in the field» ✓		2
d	ii	satellite has a much smaller mass/diameter/size than the planet «so approximates to a point mass» ✓		1

7 – (PHYSI/20_SL_Winter_2018_Q3) – *Mechanics*

a		*ALTERNATIVE 1:* initial momentum *mv* $\sqrt{2 \quad 0.058 \quad 0.63}$ « 0.27 kg m s ^{1}» *OR* *mv* = 0.058 $\sqrt{2 \quad 9.81 \quad 1.1}$ «= 0.27 kg m s ^{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 «N» ✓ *ALTERNATIVE 2:* «$E_k = \frac{1}{2}mv^2 = 0.63$ J» v = 4.7 m s^{-1} ✓ acceleration «$\frac{\Delta v}{\Delta t}$ » $\frac{4.7}{55x10^{-3}}$ «85 m s^{-2}» ✓ 4.9 «N» ✓ *F* – *mg* 4.9 so *F* 5.5 «N» ✓		4

b		***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

8 **-** (PHYSI/21_SL_Summer_2019_Q1) **-** *Mechanics, Electricity & Magnetism*

a	i	time taken $\frac{2.0\times10^4}{7}$ «= 2860 s» = 2900«s» ✓	*Must see at least two s.f.*	1
a	ii	use of E = qV ***OR*** energy = $4.3\times10^3\times16$ «= 6.88×10^4 J» ✓ power = 241 «W» ✓	*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* ✓ 34 «N» ✓	*Award **[2]** for a bald correct answer.* *Accept 34 N – 36 N.*	2
b	i	66g sin(3°) = 34 «N» ✓		1
b	ii	total force 34 + 34 = 68 «N» ✓ 3.5 «ms^{-1}»✓	*If you suspect that the incorrect reference in this question caused confusion for a particular candidate, please refer the response to the PE.* *Look for ECF from aiii and bi.* *Accept 3.4 – 3.5 «ms^{-1}».* *Award **[0]** for solutions involving use of KE.* *Award **[0]** for v = 7 ms^{-1}.* *Award **[2]** for a bald correct answer.*	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*** $R_{circuit}$ = 1.85 Ω ✓ so internal resistance = $\frac{4.0}{6.5}$ = 0.62 «Ω» ✓	*For MP1 allow use of internal resistance equations that leads to 16V – 12V (=4V).* *Award **[2]** for a bald correct answer.*	2
e	i	$\frac{16}{5}$ = 3.2 «V» ✓		1
e	ii	***ALTERNATIVE 1:*** 2.5*r* = 0.62 ✓ *r* = 0.25 «Ω» ✓ ***ALTERNATIVE 2:*** $\frac{0.62}{5}$ = 0.124 «Ω» ✓ *r* = 2(0.124)= 0.248 «Ω» ✓	*Allow ECF from (d) and/or e(i).*	2

9 – (PHYSI/21_SL_Summer_2019_Q5) – *Mechanics, Oscillations & Waves*

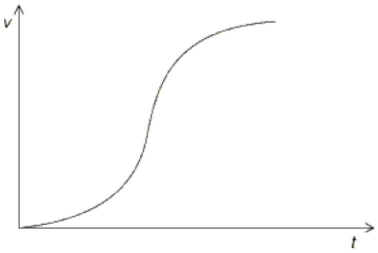
a	0.40 «m s^{-1}» ✓		**1**
b	initial energy 24 mJ and final energy 12 mJ ✓ energy is lost/unequal /change in energy is 12 mJ ✓ inelastic collisions occur when energy is lost ✓		**3**
c	maximum GPE at extremes, minimum in centre ✓		**1**

10 – (PHYSI/22_SL_Summer_2019_Q1) – *Mechanics*

a	i	$F = \frac{\Delta mv}{\Delta t}$ / $m\frac{\Delta v}{\Delta t}$ / $\frac{0.058\times 64.0}{25\times 10^{-3}}$ ✓ $F = 148$ «N» ≈ 150 «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 «W» ✓ ***ALTERNATIVE 2*** $P =$ average Fv / $148\times\frac{64.0}{2}$ ✓ $P = 4700$ / 4800 «W» ✓		**2**
b	i	horizontal component of velocity is $64.0\times\cos 7 = 63.52$ «m s^{-1}» ✓ $t =$ «$\frac{11.9}{63.52}$ =» 0.187 / 0.19 «s» ✓	*Do not award BCA. Check working.* *Do not award ECF from using 64 m s^{-1}.*	**2**
b	ii	***ALTERNATIVE 1*** $u_y = 64\sin 7$ / 7.80 «m s^{-1}» ✓ decrease in height $= 7.80\times 0.187+\frac{1}{2}\times 9.81\times 0.187^2$ / 1.63 «m» ✓ final height = «2.80 − 1.63» = 1.1 / 1.2 «m» ✓ «higher than net so goes over» ***ALTERNATIVE 2*** vertical distance to fall to net «= 2.80 − 0.91» = 1.89 «m» ✓ time to fall this distance found using «$1.89 = 7.8t+\frac{1}{2}\times 9.81\times t^2$» $t = 0.21$ «s» ✓ 0.21 «s» > 0.187 «s» ✓ «reaches the net before it has fallen far enough so goes over»	*Other alternatives are possible*	**3**

b	iii	***ALTERNATIVE 1*** Initial KE + PE = final KE / $\frac{1}{2}\times 0.058\times 64^2 + 0.058\times 9.81\times 2.80 = \frac{1}{2}\times 0.058\times v^2$ ✓ $v = 64.4$ «m s^{-1}» ✓ ***ALTERNATIVE 2*** $v_v =$ «$\sqrt{7.8^2 + 2\times 9.81\times 2.8}$» $= 10.8$ «m s^{-1}» ✓ «$v = \sqrt{63.5^2 + 10.8^2}$» $v = 64.4$ «m s^{-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_SL_Winter_2019_Q1) – *Mechanics*

	a		links 0.84 to Δp ✓ $v =$ «$\frac{0.84}{5.8\times 10^{-2}}$» $= 14.5$ «m s^{-1}» ✓	*Award **[2]** for bald correct answer*	2
	b		use of $\Delta t =$ «$(28-12)\times 10^{-3} =$» 16×10^{-3} «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 «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 × time*	3
	d		 graph must show increasing speed from an initial of zero all the time ✓ overall correct curvature ✓		2

12 – (PHYSI/20_SL_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 ✓ 1.7v (0.95 · 0.45) · 9.81 ✓ v 8.1 «m s ⁻¹» ***AND*** answer expressed to 2 sf only ✓	*Allow 8.2 from g = 10 ms⁻²*	3
b		vertical force= lift force – weight *OR* 0.45 · 9.81 *OR* = 4.4 «N» ✓ acceleration $\frac{0.45 \cdot 9.81}{0.95}$ 4.6 «ms⁻²» ✓		2

13 – (PHYSI/21_SL_Summer_2021_Q1) – *Mechanics*

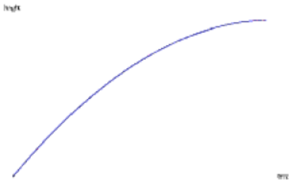
a	t = «$\sqrt{\frac{2d}{g}}$ » 0.22 «s» *OR* $t = \sqrt{\frac{2 \cdot 0.24}{9.8}}$ ✓	*Answer to 2 or more significant figures or formula with variables replaced by correct values*	1
b	increasing straight line from zero up to 0.2 s in x-axis ✓ with gradient 10 ✓		2
c	***ALTERNATIVE 1*** t $\frac{1.37}{12}$ = «0.114 s» ✓ y $\frac{1}{2} \cdot 10 \cdot 0.114^2$ 0.065m ✓ so (0.24-0.065)=0.175>0.15 OR 0.065 < (0.24-0.15) «so it goes over the net» ✓ ***ALTERNATIVE 2*** «0.24 0.15 0.09 $\frac{1}{2} \cdot 10 \cdot t^2$ so» t 0.134 s ✓ 0.134 · 12 1.6m ✓ 1.6 · 1.37 «so ball passed the net already» ✓	*Allow use of g 9.8.*	3

d	i	***ALTERNATIVE 1*** KE $\frac{1}{2}mv^2 \cdot mgh$ $\frac{1}{2}$0.0027 · 10.5² · 0.0027 · 9.8 · 0.18 ✓ 0.15 «J» ✓ ***ALTERNATIVE 2*** Use of v_x 10.5 *AND* v_y 1.88 to get v «$\sqrt{10.5^2 \cdot 1.88^2}$» 10.67 «m s⁻¹» ✓ *KE* $\frac{1}{2} \cdot 0.0027 \cdot 10.67^2$ 0.15 «J» ✓		2
d	ii	Δv = 21 «m s⁻¹» ✓ F $\frac{0.0027 \cdot 21}{0.01}$ *OR* 5.67 «N» ✓ any answer to 2 significant figures «N» ✓		3

14 – (PHYSI/22_SL_Summer_2021_Q1) – *Mechanics*

a		$\Delta p = 0.45 \times 19$ *OR* $a = \dfrac{19}{0.055}$ ✓ «$= F = \dfrac{0.45 \times 19}{0.055}$ »160 «N» ✓	*Allow **[2]** marks for a bald correct answer.* *Allow ECF for **MP2** if 19 sin22 **OR** 19 cos22 used.*	**2**
b	i	horizontal speed = 19 x cos 22 «= 17.6 m s^{-1}» ✓ time = «$\dfrac{\text{distance}}{\text{speed}} = \dfrac{11}{19\cos 22}$ =» 0.62 «s» ✓	*Allow ECF for **MP2***	**2**
b	ii	initial vertical speed = 19 x sin 22 «= 7.1 m s^{-1} » ✓ «7.12 x 0.624 - 0.5 x 9.81 x 0.624^2 =» 2.5 «m» ✓ ball does not hit wall *OR* 2.5 «m» > 2.4 «m» ✓	*Allow ECF from (b)(i) and from **MP1*** *Allow g = 10 m s^{-2}*	**3**
c		air resistance opposes «direction of» motion *OR* air resistance opposes velocity ✓ on the way up «vertical» acceleration is increased *OR* greater than g ✓ on the way down «vertical» acceleration is decreased *OR* smaller than g ✓	*Allow deceleration/acceleration but meaning must be clear*	**2**
d		13 «rad» s^{-1} ✓	*Unit must be seen for mark* *Accept Hz* *Accept 4 π «rad» s^{-1}*	**1**

15 – (PHYSI/20_SL_Winter_2021_Q1) – *Mechanics*

a		$H = «\frac{1}{2}gt^2$ =» 4.9 «m» ✓	*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	«g=» 9.80 «ms^{-2}» ✓	*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		« loss of KE is $\frac{1}{2} \times 0.25 \times (9.8^2 - 5^2)$ =» 8.9 «J» ✓	*Award **[1]** mark for an answer in the range 8.7 - 9.5*	**1**
d	i	Δp 0.250 · (9.8 · 5.0) ✓ F_{net} «$\frac{\Delta p}{\Delta t}$ $\frac{3.7}{0.1}$ =» 37 «N» ✓ N = 37 + 0.250 · 9.8 = 39.5«N» ✓	*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_SL_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* «3.5 x 2.4 = 3.5*g* -*T* » ***OR*** *T* = 3.5(g-2.4) ✓ 26 «N» ✓	*Accept 27* N *from g* = *10* m s^{-2}	**2**
c	**i**	proper use of kinematic equation ✓ $\sqrt{(2 \times 2.4 \times 0.95)}$ = 2.14 «m s^{-1}» ✓	*Must see either the substituted values **OR** a value for v to at least three s.f. for **MP2**.*	**2**
c	**ii**	use of $\omega = \frac{v}{r}$ to give 84 «rad s^{-1}» ***OR*** ω = 2.1 / 0.025 to give 84 «rad s^{-1}» ✓ quoted to 2sf only✓·		**2**
d		***ALTERNATIVE 1*** «$v^2 \cdot u^2 - 2as \rightarrow 0 \cdot 2.1^2 - 2a \times 0.35$» leading to *a*= 6.3 «m s^{-2}» ***OR*** « x=1/2(u+v)t » leading to t = 0.33 « s » ✓ F_{net} = « *ma* = 1.5 x 6.3 = » 9.45 «N» ✓ Weight down ramp = 1.5 x 9.8 x sin(30) = 7.4 «N» ✓ friction force = net force – weight down ramp = 2.1 «N» ✓ ***ALTERNATIVE 2*** kinetic energy initial = work done to stop 0.5 x 1.5 x (2.1)^2 = F_{NET} x 0.35 ✓ F_{net} = 9.45 «N» ✓ Weight down ramp = 1.5 x 9.8 x sin(30) = 7.4 «N» ✓ friction force = net force – weight down ramp = 2.1 «N» ✓	*Accept 1.95* N *from g* = *10* m s^{-2}. *Accept 2.42* N *from u* = *2.14* ms^{-1}.	**4**
e		static coefficient of friction > dynamic/kinetic coefficient of friction / $\mu_s > \mu_k$ ✓ «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 ✓		**3**

17 – (PHYSI/22_SL_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 = $Av^2\rho$ = » 244 x 20 ***OR*** 4.9 «kN» ✓	*Allow use of 240*	**1**
c	i	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	ii	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**
d		***ALTERNATE 1*** « ω = » 4π rad s^{-1} ✓ « $a = r\omega^2$ = » 280 « m s^{-2} » ✓ ***ALTERNATE 2*** « $v = \frac{2\pi r}{T}$ » = 22.6 m s^{-1} ✓ « $a = \frac{v^2}{r}$ »= 280 « m s^{-2} » ✓	*Allow **ECF** from **MP1** for wrong ω (120 gives 2.6×10^4« m s^{-2} »)* *Allow **ECF** from **MP1** for wrong T (2 s gives 18 « m s^{-2} »)*	**2**

18 – (PHYSI/20_SL_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_SL_Summer_2017_Q1) – *Mechanics, Thermal Physics*

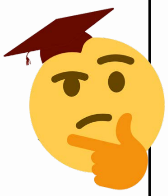
a	**i**	$\frac{1}{2}v^2 = 0.24gh$ ✓ $v = 11.9$ «ms^{-1}» ✓
a	**ii**	internal energy is the total KE «and PE» of the molecules/particles/atoms in an object ✓ temperature is a measure of the average KE of the molecules/particles/atoms ✓
b	**i**	arrow vertically downwards from dot labelled weight/W/mg/gravitational force/F_g/$F_{gravitational}$ ***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 $a =$ «–»1.40 «ms^{-2}» ✓ friction force $= ma = 65 \times 1.4 = 91$ «N» ✓ coefficient of friction $= \frac{91}{65 \times 9.81} = 0.14$ ✓ ***ALTERNATIVE 2*** $KE = \frac{1}{2}mv^2$ = 0.5 x 65 x 8.2^2 = 2185 «J» ✓ friction force = KE/distance =2185/24 = 91«N» ✓ coefficient of friction $= \frac{91}{65 \times 9.81} = 0.14$ ✓
d	i	«76×9.6» = 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/20_SL_Winter_2017_Q4) - *Oscillations & Waves, Thermal Physics*

a	i	«$v \quad c\frac{\sin i}{\sin r}$ » $\frac{3 \cdot 10^8 \cdot \sin(33)}{\sin(46)}$ ✓ $2.3 \quad 10^8$ «$m\,s^{\ 1}$» ✓	
a	ii	light strikes AB at an angle of 57° ✓ critical angle is «$\sin^{1}\left(\frac{2.3}{3}\right)$» 50.1° ✓ 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 ✓	*Judge angle of incidence angle of reflection by eye or accept correctly labelled angles* *With sensible refraction in correct direction*



b	i	mass «volume density» $(0.75)^3$ 920 « 388 kg» ✓ energy required to raise temperature 388 · 2100 · 20 « 1.63 · 10^7 J» ✓ energy required to melt 388 · 330 · 10^3 « 1.28 · 10^8 J» ✓ 1.4 10^8 «J» ***OR*** 1.4 10^5 «kJ» ✓	*Accept any consistent units* *Award **[3 max]** for answer which uses density as 1000 kg^{-3} (1.5 · 10^8 «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*

3 – (PHYSI/21_SL_Summer_2018_Q2) – *Thermal Physics*

a		«$\frac{3.0 \cdot 8.31 \quad 290}{0.15}$» 48 «kPa» ✓		1
b	i	mass «$\frac{860}{3100 \cdot 23}$» 0.012 «kg» ✓	*Award [1] for a bald correct answer.*	1
b	ii	$\frac{3}{2}$1.38 10^{23} 313 6.5 10^{21} «J» ✓		1
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

4 – (PHYSI/22_SL_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 «$\frac{pV}{kT}$ $\frac{5.3 \quad 10^5 \quad 2.1 \quad 10^{4}}{1.38 \quad 10^{23} \quad 310}$» 2.6 10^{22} ✓		1
a	iii	«For one atom U $\frac{3}{2}kT$» $\frac{3}{2}$ × 1.38 × 10^{-23} × 310 / 6.4 × 10^{-21} «J» ✓ U «2.6 · 10^{22} $\frac{3}{2}$ · 1.38 10^{23} 310» 170 «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 «5.3 10^5 · $\frac{2.1 \quad 10^{4}}{6.8 \quad 10^{4}}$» 1.6 10^5 «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

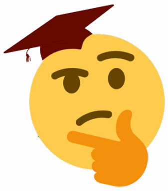
5 – (PHYSI/20_SL_Winter_2018_Q7) – *Thermal Physics*

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}» ✓ «$2.1\times10^{5}\times8\times10^{-3}$» $= 1.7$ «kW» ✓ ***ALTERNATIVE 2:*** $Q =$ «$0.25\times32\times10^{-3}\times2.1\times10^{5} =$» 1680 «J» ✓ power $=$ «$1680\text{ W} =$» 1.7 «kW» ✓		**2**
b	ii	$V =$ «$\frac{nRT}{p} =$» 4.9×10^{-3} «m^3» ✓		**1**
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**

6 – (PHYSI/21_SL_Summer_2019_Q4) – *Thermal Physics*

a		weight of cylinder $= Ahg\rho$ ✓ pressure $= \frac{F}{A} = \frac{Ahg\rho}{A}$ ✓	*Allow use of $A = \pi r^2$ in MP1.*	**2**
b	i	use of PV = nRT and V = Area × (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 $p_m = 0.035\times1.36\times10^{4}\times9.81$ $(= 4.67\times10^{3}\text{Pa})$ ✓ 1.03×10^{5} ✓ Pa ***OR*** Nm^{-2} ***OR*** $\text{kgm}^{-1}\text{s}^{-2}$ ✓	*Do not award for a bald correct answer. Working must be shown to award MP3.* *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 ✓	*Look for a correct statement that connects pressure to molecular movement/collisions.*	**1**

7 - (PHYSI/22_SL_Summer_2019_Q2) - *Thermal Physics*



a		$m = \frac{4.0\times10^{-3}}{6.02\times10^{23}}$ «kg» *OR* 6.64×10^{-27} «kg» ✓		1
b		$\frac{1}{2}mv^2 = \frac{3}{2}kT$ / $v = \sqrt{\frac{3kT}{m}}$ / $\sqrt{\frac{3\times1.38\times10^{-23}\times320}{6.6\times10^{-27}}}$ ✓ $v = 1.4\times10^3$ «$m s^{-1}$» ✓		2
c		$N = \frac{pV}{kT}$ / $\frac{5.1\times10^5\times3.2\times10^{-6}}{1.38\times10^{-23}\times320}$ *OR* $N = \frac{pVN_A}{RT}$ / $\frac{5.1\times10^5\times3.2\times10^{-6}\times6.02\times10^{23}}{8.31\times320}$ ✓ $N = 3.7\times10^{20}$ ✓		2
d	i	«$\frac{4\times10^{20}\times4.9\times10^{-31}}{3.2\times10^{-6}}$ =» 6×10^{-5} ✓		1
d	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 (d)(i) shows that volume of helium atoms is negligible compared to/much smaller than volume of helium gas/container «hence assumption is justified» ✓		2

8 - (PHYSI/20_SL_Winter_2019_Q2) - *Thermal Physics*

a		$N = \frac{pV}{kT}$ *OR* $N = \frac{1.0\times10^5\times0.36}{1.38\times10^{-23}\times295}$ ✓ $N = 8.8\times10^{24}$ ✓	*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 $\frac{p}{T}$ = constant *OR* $p = \frac{nRT}{V}$ *OR* $\frac{NkT}{V}$ ✓ $p = 9.4\times10^4$ «Pa» ✓	*Allow ECF from (a)* *Award **[2]** for bald correct answer*	2
b	ii	$F = A\times\Delta p$ ✓ $F = 0.72\times(1.0-0.94)\times10^5$ *OR* 4.3×10^3 «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

9 – (PHYSI/20_SL_Winter_2020_Q3) – *Thermal Physics*

a	i	«$15 \times 30 \times 60$» $= 27000$ «J» ✓		1
a	ii	$27 \times 10^{3} = 0.32 \times c \times (290 - 250)$ *OR* 2100 ✓ $J\ kg^{-1}\ K^{-1}$ *OR* $J\ kg^{-1}\ {}^{0}C^{-1}$ ✓	*Allow any appropriate unit that is* $\frac{energy}{mass \cdot temperature}$	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 «$= \frac{27 \times 10^{3}}{130 \times 10^{3}}$» $= 0.21$ «kg» ✓ unfrozen mass «$= 0.32 - 0.21$» $= 0.11$ «kg» ✓		2

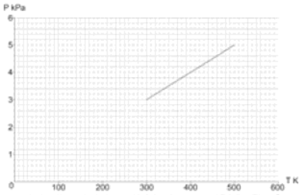
10 – (PHYSI/21_SL_Summer_2021_Q3) – *Thermal Physics, Electricity & Magnetism*

a	i	$E_k =$ «$\frac{3}{2}(1.38 \times 10^{-23})(373)$» $= 7.7 \times 10^{-21}$ «J» ✓ $v =$ «$\sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 373}{0.018}}$» $= 720$ «$m\ s^{-1}$» ✓		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	«$mL = Pt$» so «$L = \frac{1600 \times 200}{0.14}$» $= 2.3 \times 10^{6}$ «$J\ kg^{-1}$» ✓ $J\ kg^{-1}$ ✓		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 $mc\Delta T$ ✓ $0.86 \times 4200 \times (100 - T) = 0.3 \times 1800 \times (T - 10)$ ✓ $T_{eq} = 85.69$«°C» ≈ 86«°C» ✓	*Accept* T_{eq} *in Kelvin (359 K).*	3
d	i	$P = \frac{V^2}{R}$ so $\frac{220^2}{1600}$ so $R = 30.25$ «Ω» ✓	*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 $R_{eq} = 15$ «Ω» ✓ $P = 3200$ «W» ✓		2

11 – (PHYSI/22_SL_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		$\frac{100 \cdot 10^{3} \cdot 10^{-3}}{250 \cdot 8.31}$ «0.048 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

12 – (PHYSI/20_SL_Winter_2021_Q2) – *Thermal Physics*

a		the total «random» kinetic energy of the molecules/atoms/particles ✓		1
b	i	$p =$ «$\frac{nRT}{V} = \frac{0.24 \times 8.31 \times 300}{0.20} =$»$3.0 \times 10^{3}$ «Pa» ✓		1
b	ii	 straight line joining (300, 3) and (500, 5) ✓ drawn only in the range from 300 to 500 K ✓	*Allow **ECF** from **(b)(i)** for incorrect initial pressure.* *Allow tolerance of ± one grid square for the endpoints.*	2
c		temperature is the same for both gases ✓ «average» kinetic energy is the same «because $E_k = \frac{3}{2}kT$ ***OR*** E_k depends on T only» ✓	*Award **[1 max]** for a bald statement that kinetic energy is the same.*	2

13 – (PHYSI/21_SL_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*** kJs^{-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 K ✓ use of $A = 2\pi r l$ « = 0.236 m²» ✓ P = 87 «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**

14 – (PHYSI/22_SL_Summer_2022_Q2) – *Thermal Physics*

a		Correct conversion of T «T = 310 K» seen ✓ « use of $N = \frac{pV}{kT}$ to get » 2.3 × 10²³ ✓	*Allow **ECF** from **MP1** i.e., T in Celsius (Result is 2.7 x 10²⁴)* *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**

15 – (PHYSI/20_SL_Winter_2022_Q2) – *Thermal Physics*

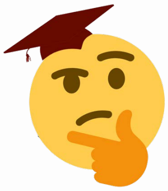
a	i	energy required = 250 × 4200 × (30 – 15) ✓ energy available = 0.30 × 680 × t × A ✓ A = «$\frac{250 \times 4200 \times 15}{0.30 \times 680 \times 60 \times 60}$ =» 21 «m²» ***OR*** 22 «m²» ✓	*Allow **ECF** from **MP1** and **MP2**.* *Accept the correct use of 0.30 in either **MP1** or **MP2**.*	**3**
a	ii	absorbed intensity = (1 – 0.2) × 680 «= 544» «W m⁻²» OR emitted intensity = 0.97x5.67x10⁻⁸xT⁴ ✓ $T = \sqrt[4]{\frac{544}{0.97 \times 5.67 \times 10^{-8}}} = 315$ «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 = 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		solar «energy» to electrical in a photovoltaic cell ***AND*** solar to thermal in a heating panel ✓		**1**

1 - (PHYSI/21_SL_Summer_2017_Q2) - *Oscillations & Waves*

a		when 2 waves meet the resultant displacement ✓ is the «vector» sum of their individual displacements ✓
b		$\lambda = \dfrac{4.7 \times 10^{-3} \times 0.35 \times 10^{-3}}{2.4}$ ✓ $= 6.9 \times 10^{-7}$ «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_SL_Summer_2017_Q3) - *Oscillations & Waves*

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	«$s = \dfrac{\lambda D}{d} = \dfrac{6.3 \times 10^{-7} \times 5.0}{1.5 \times 10^{-3}} =$» 2.1×10^{-3} «m» ✓
b	ii	correct read-off from graph of 25 ms ✓ $v =$ «$\dfrac{x}{t} = \dfrac{2.1 \times 10^{-3}}{25 \times 10^{-3}} =$» 8.4×10^{-2} «m s^{-1}» ✓



c		***ALTERNATIVE 1*** «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 ✓

3 – (PHYSI/20_SL_Winter_2017_Q4) – *Oscillations & Waves, Thermal Physics*

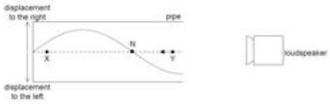
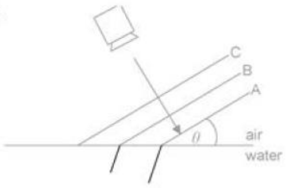
a	i	«v $c\frac{\sin i}{\sin r}$» $\frac{3 \cdot 10^8 \cdot \sin(33)}{\sin(46)}$ ✓ $2.3 \quad 10^8$ «m s^{-1}» ✓	
a	ii	light strikes AB at an angle of 57° ✓ critical angle is «$\sin^{-1}\left(\frac{2.3}{3}\right)$» 50.1° ✓ angle of incidence is greater than critical angle so total internal reflection ***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 ✓	*Judge angle of incidence angle of reflection by eye or accept correctly labelled angles* *With sensible refraction in correct direction*

b	i	mass «*volume density*» $(0.75)^3$ 920 « 388 kg» ✓ energy required to raise temperature 388 · 2100 · 20 « 1.63 · 10^7 J» ✓ energy required to melt 388 · 330 · 10^3 « 1.28 · 10^8 J» ✓ 1.4 10^8 «J» ***OR*** 1.4 10^5 «kJ» ✓	*Accept any consistent units* *Award **[3 max]** for answer which uses density as 1000 kg^{-3} (1.5 · 10^8 «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*

4 – (PHYSI/21_SL_Summer_2018_Q3) – *Oscillations & Waves*

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	evidence of solving for D «$D\ \frac{sd}{\lambda}$» ✓ «$\frac{4.50\ 10^{-3}\ \ 0.300\ 10^{-3}}{633.0\ \ 10^{-9}} \cdot 2$» $= 4.27$ «m» ✓	*Award [1] max for 2.13 m.*	2
b	i	$\frac{633.0}{1.33}$ 476 «nm» ✓		1
b	ii	distance between peaks decreases ✓ intensity decreases ✓		2

5 – (PHYSI/22_SL_Summer_2018_Q3) – *Oscillations & Waves*

a	i	the incident wave «from the speaker» and the reflected wave «from the closed end» superpose/combine/interfere ✓	*Allow superimpose/add up* *Do not allow meet/interact*	1
a	ii	Horizontal arrow from X to the right ✓	*MP2 is dependent on MP1* *Ignore length of arrow*	1
a	iii	P at a node ✓		1
a	iv	wavelength is $\lambda =$ «$\frac{4\times 0.30}{3} =$» 0.40 «m» ✓ $f =$ «$\frac{340}{0.40} =$» 850 «Hz» ✓	*Award **[2]** for a bald correct answer* *Allow ECF from MP1*	2
b	i	$\frac{\sin\theta_c}{340} = \frac{1}{1500}$ ✓ $\theta_c = 13$ «°» ✓	*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 ✓ greater separation ✓	*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

6 – (PHYSI/20_SL_Winter_2018_Q4) – *Oscillations & Waves*

a		«air molecule» moves to the right and then back to the left ✓ returns to X/original position ✓		2
b		wavelength 2 1.4 « 2.8 m» ✓ c = « $f\lambda$ =» 120 2.8 « = 340 m s ^{1} » ✓ K = « ρc^2 = 1.3 340^2 =» 1.5 10^5 ✓		3
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 nλ ***OR*** minimum when two waves occur 180° out of phase/path difference is (n + ½) λ ✓		2

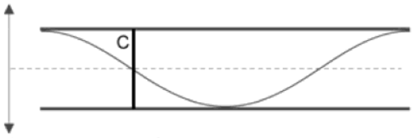
7 – (PHYSI/21_SL_Summer_2019_Q3) – *Oscillations & Waves*

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 ✓	*Ignore references to nodes/antinodes.*	2
b		path difference = 0.062 «m» ✓ so wavelength = 0.031 «m» ✓ frequency = 9.7 × 10^9 «Hz» ✓	*If no unit is given, assume the answer is in Hz. Accept other prefixes (eg 9.7 GHz)* *Award **[2 max]** for 4.8 x 10^9 Hz.*	3
c		intensity varies with distance ***OR*** points are different distances from the slits ✓	*Accept "Intensity is modulated by a single slit diffraction envelope".*	1

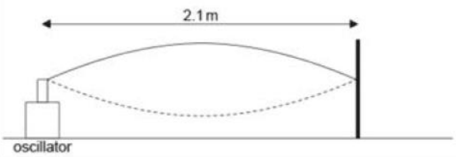
8 – (PHYSI/21_SL_Summer_2019_Q5) – *Mechanics, Oscillations & Waves*

a	0.40 «m s $^{-1}$» ✓		1
b	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
c	maximum GPE at extremes, minimum in centre ✓		1

9 – (PHYSI/22_SL_Summer_2019_Q3) – *Oscillations & Waves*

a		Expression or statement showing acceleration is proportional to displacement ✓ so «$7.9\times\frac{2.3}{3.2}$» $= 5.7$ «m s^{-2}» ✓		2
b		$\sin\theta = \frac{340}{6010}\times\sin 54^{0}$ ✓ $\theta = 2.6^{0}$ ✓		2
c	i	$f = 250$ «Hz» ***OR*** Same ***OR*** Unchanged ✓		1
c	ii	$\lambda =$ «$\frac{340}{250} =$» $1.36 \approx 1.4$ «m» ✓		1
d		any point labelled C on the vertical line shown below ✓ *eg:* displacement to the right  displacement to the left		1

10 – (PHYSI/20_SL_Winter_2019_Q3) – *Oscillations & Waves*

a	i	$v =$ «$\frac{0.05}{0.20\times10^{-3}} =$» 250 «m s^{-1}» ✓		1
a	ii	$\lambda = 0.30$ «m» ✓ $f =$ «$\frac{250}{0.30} =$» 830 «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

11 – (PHYSI/20_SL_Winter_2020_Q4) – *Oscillations & Waves*

a		wavelength $= \frac{340}{850} \cdot\cdot$ 0.40 «m» ✓ path difference = 1.8 «m» ✓ 1.8 «m» = 4.5λ *OR* $\frac{1.8}{0.20}$ = 9 «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» $\frac{I_A}{I_0} - \frac{1}{4}$ ✓		**2**

12 – (PHYSI/21_SL_Summer_2021_Q6) – *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	$\lambda = 2\,l = 2\ 0.62$ = «1.24 m» ✓ $v = f\lambda = 195\ 1.24 = 242$ «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**

13 – (PHYSI/22_SL_Summer_2021_Q5) – *Oscillations & Waves*

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	λ= 0.74 «m» ✓ f = « $\frac{c}{\lambda} = \frac{320}{0.74}$ =» 430 «Hz» ✓	*Allow ECF from **MP1***	**2**

14 – (PHYSI/20_SL_Winter_2021_Q3) – *Oscillations & Waves*

a		$T = 4 \times 10^{-3}$ «s» or $f = 250$ «Hz» ✓ $\lambda = 340 \times 4.0 \times 10^{-3} = 1.36 \approx 1.4$ «m» ✓	*Allow ECF from **MP1**.* *Award **[2]** for a bald correct answer.*	2
b	i	«−» $\frac{\pi}{2}$ / 90° *OR* $\frac{3\pi}{2}$ / 270° ✓		1
b	ii	1.5 «m s^{-1}» ✓		1
b	iii	8.0 *OR* 8.5 «μm» ✓	*From the graph on the paper, value is 8.0. From the calculated correct trig functions, value is 8.49.*	1
c	i	$L =$ «$\frac{3}{4}\lambda$ =» 0.90 «m» ✓		1
c	ii	to the right ✓ displacement is getting less negative *OR* change of displacement is positive ✓		2
c	iii	horizontal line drawn at the equilibrium position ✓		1

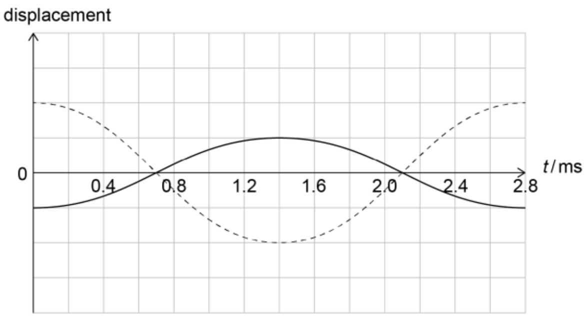
15 – (PHYSI/21_SL_Summer_2022_Q3) – *Oscillations & Waves*

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 x lambda ***OR*** minimum when waves arrive «180° or π » out of phase / path difference = (n+½) x 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 cm ✓ $f =$ «$\frac{c}{\lambda} = \frac{340}{0.13} =$» 2.6 «kHz» ✓	*Allow ½ of wavelength from **(b)** or data from graph.*	2

16 – (PHYSI/22_SL_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» ✓ $f = «\frac{340}{0.24} =» 1.4$ «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*** [redacted]	**3 max**

17 – (PHYSI/20_SL_Winter_2022_Q3) – *Oscillations & Waves*

a	i	oscillation in antiphase ✓ smaller amplitude than P ✓ 		**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* m^2 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		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 and antinodes *OR* travelling waves don't ✓ points in an internodal region have same phase in standing waves *OR* different phase in travelling waves ✓		**2 max**

1 – (PHYSI/21_SL_Summer_2017_Q4) – *Electricity & Magnetism*

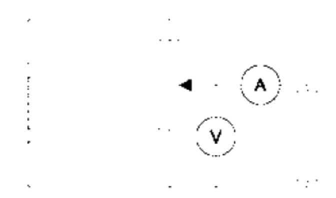
a	i	I «$= \frac{8.5\times10^{3}}{240}$» $= 35$«A» ✓
a	ii	$R = \frac{1.7\times10^{-8}\times10}{6.0\times10^{-6}}$ ✓ $= 0.028$ «Ω» ✓
b		«as temperature increases» there is greater vibration of the metal atoms/lattice/lattice ions ***OR*** increased collisions of electrons ✓ drift velocity decreases «so current decreases» ✓ «as V constant so» R increases ✓
c		recognition that power = flow rate $\times\, c\Delta T$ ✓ flow rate «$= \frac{\text{power}}{c\Delta T}$» $= \frac{8.5\times10^{3}}{4200\times35}$ ✓ $= 0.058$ «kg s^{-1}» ✓ kg s^{-1} / g s^{-1} / l s^{-1} / ml s^{-1} / m^{3} s^{-1} ✓

2 - (PHYSI/22_SL_Summer_2017_Q5) - *Electricity & Magnetism*

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 $= \dfrac{1.7 \times 10^{-3} \times 35 \times 10^{3}}{64}$ «$= 9.3 \times 10^{-6}\ \text{m}^2$» ✓
b	ii	«resistance of cable $= 2\,\Omega$» power dissipated in cable $= 730^2 \times 2$ «$= 1.07$ MW» ✓ power loss per meter $= \dfrac{1.07 \times 10^{6}}{35 \times 10^{3}}$ ***or*** 30.6 «W m^{-1}» ✓
b	iii	$30 = m \times 390 \times 3.5 \times 10^{-2}$ ✓ 2.2 k«g» ✓

3 - (PHYSI/20_SL_Winter_2017_Q3) - *Electricity & Magnetism*

a	i	« $l \quad \dfrac{RA}{\rho} \quad \dfrac{82 \;\; 8 \;\; 10^{3} \cdot 2 \cdot 10^{6}}{4.1 \cdot 10^{5}}$ » 0.032 «m» ✓	
a	ii	power 1500 8 10^{3} 0.032 « 0.384 » ✓ «current $\sqrt{\dfrac{\text{power}}{\text{resistance}}} \quad \sqrt{\dfrac{0.384}{82}}$ » 0.068 «A» ✓	*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*

c		complete functional circuit with ammeter in series with resistor and voltmeter across it ✓ potential divider arrangement correct ✓	eg: 	

4 – (PHYSI/21_SL_Summer_2018_Q4) – *Electricity & Magnetism*

a		$1.7 \quad 10^{-8} \quad \frac{0.10}{(0.02 \quad 10^{-2})^2}$ ✓ 0.043 «Ω» ✓		2
b		v « $\frac{I}{neA}$ » $\frac{2}{8.5 \quad 10^{28} \quad 1.60 \quad 10^{-19} \quad 0.02^2}$ ✓ 0.368 «cms^{-1}» ✓ 0.37 «cms^{-1}» ✓	*Award [2 max] if answer is not expressed to 2 sf.*	3

5 – (PHYSI/21_SL_Summer_2018_Q5) – *Electricity & Magnetism, Circular Motion & Gravitation*

a		out of the page plane / ⊙ ✓	*Do not accept just "up" or "outwards".*	1
b		$1.60 \quad 10^{-19} \quad 6.8 \quad 10^{6} \quad 8.5 \quad 9.2 \quad 10^{-13}$ «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

6 – (PHYSI/22_SL_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 · 80 ✓ « 28 Ω»		2
b	ii	current leaving 12 V cell is $\frac{12}{80}$ 0.15 « A » ***OR*** $E \quad \frac{12}{80} \quad 28$ ✓ E «0.15 28 » 4.2 « 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

7 – (PHYSI/20_SL_Winter_2018_Q2) – *Electricity & Magnetism*

a		***ALTERNATIVE 1:*** $r \quad \sqrt{\frac{\rho l}{\pi R}} \quad O \quad \sqrt{\frac{7.2 \quad 10^{7} \quad 12.5}{\pi \quad 0.1}}$ ✓ $r \quad 5.352 \quad 10^{3}$ ✓ $5.4 \quad 10^{3}$ «m» ✓ ***ALTERNATIVE 2:*** $A \quad \frac{7.2 \quad 10^{7} \quad 12.5}{0.1}$ ✓ $r \quad 5.352 \quad 10^{3}$ ✓ $5.4 \quad 10^{3}$ «m» ✓		3
b		current in lamp $\frac{5}{24}$ «= 0.21» «A» ***OR*** $n \quad 24 \cdot \frac{8}{5}$ ✓ so «38.4 and therefore» 38 lamps ✓		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

8 – (PHYSI/21_SL_Summer_2019_Q1) – *Mechanics, Electricity & Magnetism*

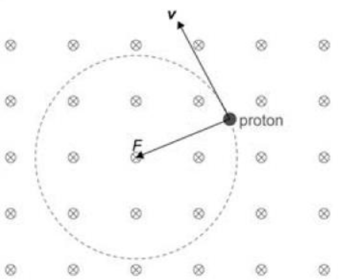
a	i	time taken $\frac{2.0 \times 10^{4}}{7}$ «= 2860 s» = 2900«s» ✓	*Must see at least two s.f.*	1
a	ii	use of E = qV ***OR*** energy = $4.3 \times 10^{3} \times 16$ «= 6.88×10^{5} J» ✓ power – 241 «W» ✓	*Accept 229 W – 241 W depending on the exact value of t used from ai.* *Must see at least three s.f.*	2
a	iii	use of power – force x speed ***OR*** *force x distance – power x time* ✓ 34 «N» ✓	*Award **[2]** for a bald correct answer.* *Accept 34 N – 36 N.*	2
b	i	66g sin(3°) = 34 «N» ✓		1
b	ii	total force 34 + 34 = 68 «N» ✓ 3.5 «ms^{-1}»✓	*If you suspect that the incorrect reference in this question caused confusion for a particular candidate, please refer the response to the PE.* *Look for ECF from aiii and bi.* *Accept 3.4 – 3.5 «ms^{-1}».* *Award **[0]** for solutions involving use of KE.* *Award **[0]** for v = 7 ms^{-1}.* *Award **[2]** for a bald correct answer.*	2

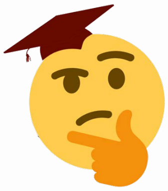
c		«maximum» distance will decrease *OWTTE* ✓ because opposing/resistive force has increased ***OR*** because more energy is transferred to GPE ***OR*** because velocity has decreased ***OR*** increased mass means more work required «to move up the hill» ✓		2
d		4 V dropped across battery ***OR*** $R_{circuit} = 1.85\ \Omega$ ✓ so internal resistance $= \frac{4.0}{6.5} = 0.62$ «Ω» ✓	*For MP1 allow use of internal resistance equations that leads to 16V – 12V (=4V).* *Award **[2]** for a bald correct answer.*	2
e	i	$\frac{16}{5} = 3.2$ «V» ✓		1
e	ii	***ALTERNATIVE 1:*** $2.5r = 0.62$ ✓ $r = 0.25$ «Ω» ✓ ***ALTERNATIVE 2:*** $\frac{0.62}{5} = 0.124$ «Ω» ✓ $r = 2(0.124) = 0.248$ «Ω» ✓	*Allow ECF from (d) and/or e(i).*	2

9 – (PHYSI/22_SL_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

10 – (PHYSI/22_SL_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		«$qvB = \frac{mv^2}{R} \Rightarrow$» $R = \frac{mv}{qB}$ / $\frac{1.673 \times 10^{-27} \times 2.16 \times 10^{6}}{1.60 \times 10^{-19} \times 0.042}$ ✓ $R = 0.538$ «m» ✓ $R = 0.54$ «m» ✓		3



11 – (PHYSI/20_SL_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	$qvB = \frac{mv^2}{R}$ ✓ $R = \frac{1.67\times10^{-27}\times2.0\times10^6}{1.6\times10^{-19}\times0.35}$ ***OR*** 0.060 «m»	*Award MP2 for full replacement or correct answer to at least 2 significant figures*	**2**
	b	ii	$T = \frac{2\pi R}{v}$ ✓ $T =$ «$\frac{2\pi\times0.06}{2.0\times10^6}$ =» 1.9×10^{-7} «s» ✓	*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**

12 – (PHYSI/20_SL_Winter_2019_Q5) – *Electricity & Magnetism*

	a		$E = \frac{k\times q}{r^2}$ ✓ $E = \frac{8.99\times10^9\times6.0\times10^{-3}}{0.4^2}$ ***OR*** $E = 3.37\times10^8$ «NC^{-1}» ✓	*Ignore any negative sign.*	**2**
	b	i	$F = q\times E$ ***OR*** $F = 1.6\times10^{-19}\times3.4\times10^8 = 5.4\times10^{-11}$ «N» ✓ $a =$ «$\frac{5.4\times10^{-11}}{9.1\times10^{-31}}$ =» 5.9×10^{19} «ms^{-2}» ✓	*Ignore any negative sign.* *Award **[1]** for a calculation leading to $a = 3.7\times10^{38}$ «ms^{-2}»* *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» ✓ decreasing acceleration ✓ increasing speed ✓	*Allow ECF from MP1 if a candidate mistakenly evaluates the force as attractive so concludes that the acceleration will increase*	**3**

13 – (PHYSI/20_SL_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» ✓		1
b	i	*ALTERNATIVE 1* voltage across X = 2.3 «V» ✓ voltage across R «= 4.0 − 2.3» = 1.7 «V» ✓ resistance of variable resistor « $=\frac{1.7}{0.020}$ » = 85 «Ω» ✓ *ALTERNATIVE 2* overall resistance « = $\frac{4.0}{0.020}$ » = 200«Ω» ✓ resistance of X « $=\frac{2.3}{0.020}$ » = 115 «Ω» ✓ resistance of variable resistor «= 200 − 115» = 85 «Ω» ✓		3
b	ii	power «= 4.0 × 0.020» = 0.080 «W» ✓		1
c	i	from 0 to 60 mA ✓		1
c	ii	allows zero current through component X / potential divider arrangement ✓ provides greater range «of current through component X» ✓		2

14 – (PHYSI/21_SL_Summer_2021_Q3) – *Thermal Physics, Electricity & Magnetism*

a	i	E_K = « $\frac{3}{2}(1.38 \times 10^{-23})(373)$ » = 7.7×10^{-21} «J» ✓ v = « $\sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 373}{0.018}}$ » = 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	«$mL = Pt$» so «$L = \frac{1600 \times 200}{0.14}$ » = 2.3×10^6 «J kg^{-1}» ✓ 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 mcΔT ✓ $0.86 \times 4200 \times (100 - T) = 0.3 \times 1800 \times (T - 10)$ ✓ T_{eq} = 85.69«°C» ≈ 86«°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 «Ω» ✓	*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 «Ω» ✓ P = 3200 «W» ✓		2

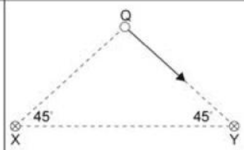
15 – (PHYSI/22_SL_Summer_2021_Q3) – *Electricity & Magnetism*

a		identifies units of σ as C m^{-2}✓ $\frac{C}{m^2} \cdot \frac{Nm^2}{C^2}$ seen and reduced to N C^{-1}✓	*Accept any analysis (eg dimensional) that yields answer correctly*	**2**
b	i	horizontal force F on ball = T sin 30 ✓ $T = \frac{mg}{\cos 30}$ ✓ F «$=mg$ tan 30 = 0.025 x 9.8 x tan 30» = 0.14 «N»✓	*Allow g= 10 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	$E = \frac{0.14}{1.2 \times 10^{-6}}$ « $= 1.2 \times 10^{5}$» ✓ $\sigma =$ « $\frac{2 \times 8.85 \times 10^{-12} \times 0.14}{1.2 \times 10^{-6}}$ » = 2.1 x 10^{-6} «C m^{-2}»✓	*Allow **ECF** from the calculated F in (b)(i)* *Award **[2]** for a bald correct answer.*	**2**
c		$\frac{Q}{0.22^2} = \frac{1.2 \times 10^{-6}}{0.18^2}$ ✓ «+»1.8 x 10^{-6} «C» ✓ 2sf ✓	*Do not award **MP2** if charge is negative* *Any answer given to 2 sig figs scores **MP3***	**3**

16 – (PHYSI/22_SL_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 $V = \varepsilon - Ir$*	**2**
b		***ALTERNATIVE 1*** pd dropped across cell = 6.5 «V» ✓ internal resistance = $\frac{6.5}{0.9}$ ✓ 7.2 «Ω» ✓ ***ALTERNATIVE 2*** $\varepsilon = I(R + r)$ so $\varepsilon = V + Ir$ ✓ 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 x 0.35 x 0.45 = «107 W» ✓ power in external circuit = 14.5 x 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**

17 - (PHYSI/20_SL_Winter_2021_Q4) - *Electricity & Magnetism*

a		«$V = \frac{4.5}{0.25}$ =»18«V» ✓		1
b	i	$F = \frac{8.99 \times 10^9 \times 68 \times 10^{-6} \times 0.25 \times 10^{-6}}{0.48^2}$ ✓ $F = 0.66$ «N» ✓	*Award **[2]** marks for a bald correct answer.* *Allow symbolic k in substitutions for **MP1**.* *Do **not** allow **ECF** from incorrect or not squared distance.*	2
b	ii	Q moves to the right/away from P «along a straight line» ***OR*** Q is repelled from P ✓ with increasing speed/Q accelerates ✓ acceleration decreases ✓		2 max
c	i	 arrow of any length as shown ✓		1
c	ii	«using components or Pythagoras to get» $B = 21$ «mT» ✓ directed «horizontally» to the right ✓	*If no unit seen, assume* mT.	2

18 - (PHYSI/21_SL_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 «V» ✓ ***ALTERNATIVE 2*** «current = $\frac{6}{60+40}$» = 0.06 «A» ✓ 40 x 0.06 = 2.4 «V» ✓		2

b		***ALTERNATIVE 1*** Pd across Q = 2.4 V so I = 0.15 « A » ✓ and pd across S is 6.0 – 2.4 = 3.6 « V » ✓ $R = \frac{V}{I} = \frac{3.6}{0.15} = 24$ «Ω» ✓ ***ALTERNATIVE 2*** pd at PR junction = pd at QS junction ✓ so $\frac{S}{Q} = \frac{R}{P}$ ***OR*** $S = \frac{16 \times 60}{40}$ ✓ 24 «Ω» ✓ ***ALTERNATIVE 3*** $I = \frac{40 \cdot 0.06}{16} = 0.15$ «A» ✓ 6.0 = (16+S)(0.15) ***OR*** $2.4 = (6)(\frac{16}{S+16})$ ✓ R= 24 «Ω» ✓	*Allow* ***ECF*** *for* ***MP3*** *from incorrect* ***MP1*** *or* ***MP2***.	3
c	i	recognition that 4L leads to 4R / «$\frac{\rho 4L}{A}$» = 4R ✓ «because the volume of S is constant new area is» $\frac{A}{4}$ ✓ 16 x 24 = 384 «Ω» ✓		3

c	ii	«total» power has decreased ✓ Because current in the branch has decreased «and $P=I^2R$ » ***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

19 – (PHYSI/22_SL_Summer_2022_Q4) – *Electricity & Magnetism*

a		« conservation of » charge ✓ « conservation of » energy ✓	*Allow* ***[1]*** *max if they explicitly refer to Kirchhoff' laws linking them to the conservation laws incorrectly.*	2
b	i	12 V ✓		1
b	ii	I = 2.0 A ***OR*** 12 = I (r +4) ***OR*** 4 = Ir ***OR*** 8 = 4I ✓ «Correct working to get » r = 2.0 «Ω» ✓	*Allow* ***ECF*** *from* ***(b)(i)***	2
c		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 «A» seen✓ V = 8.0 «V» ✓	*Allow any valid method*	3

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 x 5 x 0.25 x 3600 ***OR*** 27000 «J» ✓ «available power =» 380 x 0.4 x 0.15 x 0.18 ***OR*** 4.1 «W» ✓ $t = «\frac{27000}{4.1} =» 6600$ «s» ✓ ***ALTERNATIVE 2*** «energy needed from Sun =» $\frac{VIt}{eff}$ ***OR*** $\frac{6 \times 5 \times 0.25 \times 3600}{0.18}$ ***OR*** 150000 «J» ✓ « incident power=» 380 x 0.4 x 0.15 ***OR*** 22.8 «W» ✓ $t = «\frac{150000}{22.8} =» 6600$ «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

20 – (PHYSI/20_SL_Winter_2022_Q5) – *Electricity & Magnetism*

a		infinite resistance ***OR*** no current is flowing through it ✓		**1**
b	**i**	current $= \frac{1.47}{50.0} = 2.94 \times 10^{-2}$ «A» ✓ $r = \frac{1.49}{2.94 \times 10^{-2}} - 50.0$ ***OR*** 0.68 «Ω» ✓	*For **MP2**, allow any other correctly substituted expression for r*	**2**
b	**ii**	$1.49 \times 2.94 \times 10^{-2}$ ***OR*** $\frac{1.49^2}{50.0 + 0.68}$ ***OR*** $(2.94 \times 10^{-2})^2 (50.0 + 0.68)$ ✓ 0.0438 «W» ✓	*Accept use of 0.7 Ω in **MP1***	**2**
c	**i**	charge/carriers are moving in a magnetic field ✓ there is a magnetic force on them / quote $F = qvB$ ***OR*** this creates a magnetic field that interacts with the external magnetic field ✓	*Accept electrons* *For **MP2**, the force must be identified as acting on charge / carriers*	**2**
c	**ii**	magnetic needle is deflected by nearby currents ***OR*** two «parallel» current-carrying wires exert a force on each other ***OR*** magnetic field due to a current can be measured directly with a probe ✓	*Only accept argument that refers to an observation or experiment*	**1**

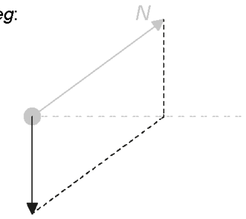
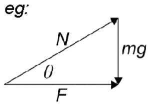
1 – (PHYSI/20_SL_Winter_2017_Q5) – *Circular Motion & Gravitation, Energy Production*

a		$\frac{mv^2}{r}$ $G\frac{Mm}{r^2}$ ✓ leading to T^2 $\frac{4\pi^2 r^3}{GM}$ ✓ T 5320 «s» ✓ ***Alternative 2*** «v $\sqrt{\frac{Gm_E}{r}}$» $\sqrt{\frac{6.67 \cdot 10^{11} \cdot 6.0 \cdot 10^{24}}{6600 \quad 10^3}}$ ***OR*** 7800 «ms^{-1}» ✓ distance $2\pi r$ 2π 6600 10^3 «m» ***or*** 4.15 10^7 «m» «T $\frac{d}{v}$ $\frac{4.15 \quad 10^7}{7800}$» 5300 «s»	*Accept use of ω instead of v*
b	i	T «$\frac{2.90 \cdot 10^{3}}{\lambda_{max}}$» $\frac{2.90 \cdot 10^{3}}{10.1 \cdot 10^{6}}$ ✓ 287 «K» ***or*** 14 «°C» ✓	*Award **[0]** for any use of wavelength from Sun* *Do not accept 287 °C*
b	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» ✓	
c		peer review ✓ international collaboration ✓ full details of experiments published so that experiments can repeated ✓	

2 – (PHYSI/21_SL_Summer_2018_Q5) – *Electricity & Magnetism, Circular Motion & Gravitation*

a		out of the page plane / ⊙ ✓	*Do not accept just "up" or "outwards".*	1
b		1.60 10^{19} 6.8 10^6 8.5 9.2 10^{13} «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

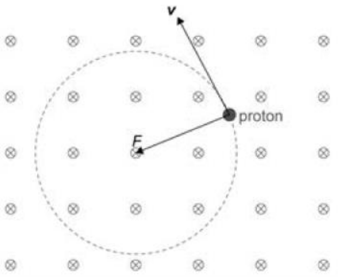
3 – (PHYSI/22_SL_Summer_2018_Q1) – *Mechanics, Circular Motion & Gravitation*

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		$\frac{mg}{\tan\theta} \quad m\frac{v^2}{r}$ ✓ $r \quad R\cos\theta$ ✓ $v \quad \sqrt{\frac{gR\cos^2\theta}{\sin\theta}}\ /\ \sqrt{\frac{gR\cos\theta}{\tan\theta}}\ /\ \sqrt{\frac{9.81 \quad 8.0\cos 22}{\tan 22}}$ ✓ $v \quad 13.4 / 13$ «ms^{-1}» ✓	*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 ✓ so no / it is not possible ✓	*Must see correct justification to award MP2*	2
d		speed before collision v = «$\sqrt{2gR}$ =» 12.5 «ms^{-1}» ✓ «from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed «$v_c \quad \frac{12.5}{2} \quad 6.25ms^{-1}$» ✓ h «$\frac{v_c^2}{2g} \quad \frac{6.25^2}{2 \quad 9.81}$» 2.0 «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 $4m$ if done in one step.* *Allow ECF from MP1* *Allow ECF from MP2*	3

4 – (PHYSI/21_SL_Summer_2019_Q6) – *Circular Motion & Gravitation, 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.* *Award **[0]** for simple definition of "albedo".*	1
c	i	gravitational attraction/force/field «of the planet/Moon» ✓	*Do not accept "gravity".*	1
c	ii	the force/field and the velocity/displacement are at 90° to each other ***OR*** there is no change in GPE of the moon ✓	*Award **[0]** for any mention of no net force on the satellite.* *Do not accept acceleration is perpendicular to velocity.*	1

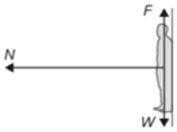
5 – (PHYSI/22_SL_Summer_2019_Q5) – *Electricity & Magnetism, Circular Motion & Gravitation*

a	i	*F* towards centre ✓		1
a	ii	*v* tangent to circle and in the direction shown in the diagram ✓		1
b		$«qvB = \frac{mv^2}{R} \Rightarrow» R = \frac{mv}{qB}$ / $\frac{1.673\times10^{-27}\times2.16\times10^{6}}{1.60\times10^{-19}\times0.042}$ ✓ $R = 0.538$ «m» ✓ $R = 0.54$ «m» ✓		3

6 **–** (PHYSI/20_SL_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**	$qvB = \frac{mv^2}{R}$ ✓ $R = \frac{1.67 \times 10^{-27} \times 2.0 \times 10^{5}}{1.6 \times 10^{-19} \times 0.35}$ ***OR*** 0.060 «m»	*Award MP2 for full replacement or correct answer to at least 2 significant figures*	**2**
	b	**ii**	$T = \frac{2\pi R}{v}$ ✓ $T =$ «$\frac{2\pi \times 0.06}{2.0 \times 10^{5}}$ =» 1.9×10^{-7} «s» ✓	*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**

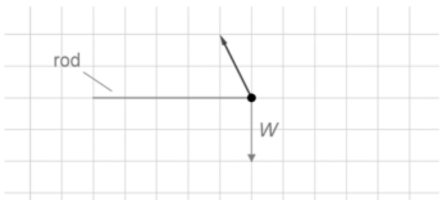
7 **–** (PHYSI/20_SL_Winter_2020_Q2) **–** *Circular Motion & Gravitation*

	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 « $\sqrt{\frac{9.81}{0.40 \times 3.5}}$ » = 2.6 «rad s^{-1}» ✓ actual angular velocity « $\frac{2\pi}{\frac{60}{28}}$ » = 2.9 «rad s^{-1}» ✓ actual angular velocity is greater than the minimum. so the person does not slide ✓ ***ALTERNATIVE 2*** Minimum friction force = *mg* «9.81m» ✓ Actual friction force « $\mu mR\omega^2 = 0.40\,m \times 3.5 \left(2\pi \frac{28}{60}\right)^2$ » = 12.0 m ✓ Actual friction force is greater than the minimum frictional force so the person does not slide ✓	*Allow 2.7 from g = 10 ms^{-2}*	**3**

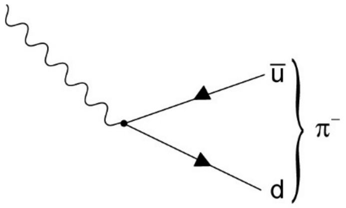
8 – (PHYSI/21_SL_Summer_2021_Q2) – *Circular Motion & Gravitation*

a	i	«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
a	ii	gravitational force/force of gravity ✓		1
b		use of $\frac{GM}{R^2}$ ✓ 6.4 «Nkg^{-1} or ms^{-2}» ✓		2

9 – (PHYSI/20_SL_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 $F_{rod} = F_c - W$ ✓ at the bottom, $F_{rod} = F_c + W$ ✓ 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_SL_Summer_2017_Q5) – *Atomic,nuclear & Particle Physics*

a		*Meson:* quark-antiquark pair ✓ *Baryon:* 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 ✓

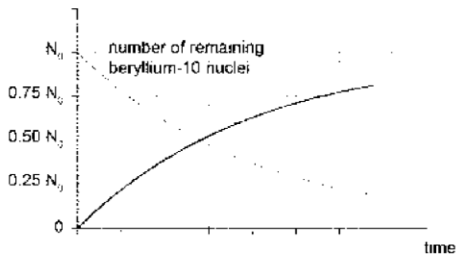
2 - (PHYSI/22_SL_Summer_2017_Q4) - *Atomic,nuclear & Particle Physics*

a		222 ***AND*** 4 ✔
b		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		conversion of temperature to 291 K ✔ $p = 4.5 \times 10^{-9} \times 8.31 \times$ «$\frac{291}{1.3 \times 10^{-5}}$» ***OR*** $p = 2.7 \times 10^{15} \times 1.38 \times 10^{-23} \times$ «$\frac{291}{1.3 \times 10^{-5}}$» ✔ 0.83 ***or*** 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 ***or*** quotes $E = hf$ ***or*** $E = \frac{hc}{\lambda}$ 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 ✔

3 - (PHYSI/20_SL_Winter_2017_Q2) - *Atomic,nuclear & Particle Physics*

a		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» ✓	*Do not credit answers referring to energy*
b		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 ✓	*Accept leptons experience the weak force* *Allow "interaction" for "force"*

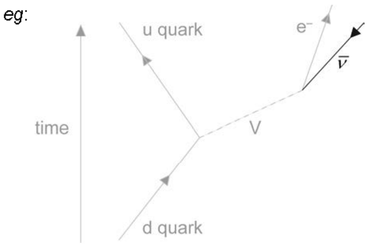
4 - (PHYSI/21_SL_Summer_2018_Q6) - *Atomic,nuclear & Particle Physics, Energy Production*

a		${}^{10}_{4}Be \rightarrow {}^{10}_{5}B + \beta + \overline{V}_e$ conservation of mass number ***AND*** charge ${}^{10}_{5}B$, ${}^{10}_{4}Be$ ✓	*Correct identification of both missing values required for **[1]**.*	1
b	i	correct shape *ie* increasing from 0 to about $0.80N_0$ ✓ crosses given line at $0.50N_0$ ✓ 		2

b	ii	***ALTERNATIVE 1*** fraction of Be $\frac{1}{8}$, 12.5%, or 0.125 ✓ therefore 3 half lives have elapsed ✓ $t_{\frac{1}{2}}$ $\frac{4.3\ \ 10^6}{3}$ 1.43 10^6 «≈ 1.4 10^6» «y» ✓ ***ALTERNATIVE 2*** fraction of Be $\frac{1}{8}$, 12.5%, or 0.125 ✓ $\frac{1}{8}$ e $(4.3\ \ 10^6)$ leading to λ 4.836 10^{7} «y» ✓ $\frac{ln2}{\lambda}$ $1.43 \cdot 10^6$ «y» ✓	*Must see at least one extra sig fig in final answer.*	3
b	iii	1.9×10^{11} ✓		1

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	$\lambda \; \frac{2.90 \cdot 10^{3}}{253}$ ✓ $1.1 \;\; 10^{5}$ «m» ✓	*Allow ECF from MP1 (incorrect temperature).*	2
c	iv	correct units for Intensity (allow *W, Nms^{-1} OR Js^{-1} in numerator)* ✓ rearrangement into proper SI units = kgs^{-3} ✓	*Allow ECF for MP2 if final answer is in fundamental units.*	2

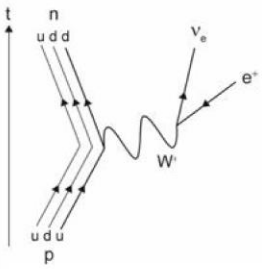
5 **–** (PHYSI/22_SL_Summer_2018_Q6) **–** *Atomic,nuclear & Particle Physics*

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	i	the energy needed to separate the nucleons of a nucleus ***OR*** energy released when a nucleus is formed from its nucleons ✓	*Allow neutrons **AND** protons for nucleons* *Don't allow constituent parts*	1
b	ii	$Q = 106 \times 8.550 - 106 \times 8.521 = 3.07$ «MeV» ✓ «$Q \approx 3$ MeV»		1
c	i	line <u>with arrow</u> as shown labelled anti-neutrino/$\bar{\nu}$ ✓	*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* *eg:*  	1
c	ii	$V = W^{-}$ ✓		1

6 **–** (PHYSI/20_SL_Winter_2018_Q5) **–** *Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)*

a		identifies $\lambda = 435$ nm ✓ E «$\frac{hc}{\lambda}$» $\frac{6.63 \;\; 10^{34} \;\; 3 \;\; 10^{8}}{4.35 \;\; 10^{7}}$ ✓ $4.6 \;\; 10^{19}$ «J» ✓		
b		–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
c		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 ✓	*Allow ECF from (a)(i)*	2 3

7 – (PHYSI/21_SL_Summer_2019_Q2) – *Atomic,nuclear & Particle Physics*

a	**i**	${}^{30}_{15}P \rightarrow \left({}^{30}_{14}Si\right)$ ✓ $+{}^{0}_{+1}e + \nu_e$ ✓	*Subscript on neutrino not necessary to award MP2.* *Allow the use of β for e.* *Do not allow an anti-neutrino for MP2.*	**2**
a	**ii**	 correct change of either u to d ✓ W⁺ shown ✓ correct arrow directions for positron and electron neutrino ✓	*Allow ECF from MP2 in ai for MP3.*	**3**
a	**iii**	quarks cannot be directly observed as free particles/must remain bound to other quarks/quarks cannot be isolated ✓ because energy given to nucleon creates other particles rather than freeing quarks/***OWTTE*** ✓		**2**

b		models need testing/new information may change models/new technology may bring new information/Models can be revised/***OWTTE*** ✓	*Look for responses that suggest changes/improvements to models.* *Don't accept answers specifically about the Standard Model.* *Don't accept answers about simply proving the model correct.*	**1**

8 – (PHYSI/22_SL_Summer_2019_Q6) – *Atomic,nuclear & Particle Physics*

a		proton / ${}^{1}_{1}H$ / p ✓		**1**
b	**i**	«3 × 2.78 2 × 2 × 1.12» See 3 × 2.78 / 8.34 ***OR*** 2 × 2 × 1.12 / 4.48 ✓ 3.86 «MeV» ✓		**2**
b	**ii**	the deuterium nuclei are positively charged/repel ✓ 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 ✓ high temperatures are required to give high KEs/energies ✓		**2 max**
c	**i**	1 / -e ✓		**1**
c	**ii**	3 ✓		**1**

9 – (PHYSI/20_SL_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* *OWTTE*	**2**
	b	**i**	234×7.6 ***OR*** 4×7.07 ✓ $BE_U =$ «$234 \times 7.6 + 4 \times 7.07 - 4.27 =$» 1802 «MeV» ✓ $\frac{BE_U}{A} =$ «$\frac{1802}{238} =$» 7.57 «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 «$\frac{E_{Th}}{E_{He}} = \frac{\frac{p^2}{2m_{Th}}}{\frac{p^2}{2m_{He}}} = \frac{234}{4}$» 58.5 ✓	*Award **[2]** for bald correct answer*	**2**

10 – (PHYSI/20_SL_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**	$140 \times 8.29 + 94 \times 8.59 - 235 \times 7.59$ ***OR*** 184 «MeV» ✓		**1**
b	**i**	see «energy =» $180 \times 10^{6} \times 1.60 \times 10^{[illegible]}$ ***AND*** «mass =» $235 \times 1.66 \times 10^{[illegible]}$ ✓ 7.4×10^{13} «J kg^{-1}» ✓		**2**
b	**ii**	energy produced in one day $= \frac{1.2 \times 10^{5} \times 24 \times 3600}{0.36} = 2.9 \times 10^{14}$ «J» ✓ mass $= \frac{2.9 \times 10^{14}}{7.4 \times 10^{13}} = 3.9$ «kg» ✓		**2**
c	**i**	39 ✓	*Do not allow ${}^{94}_{[illegible]}X$ unless the proton number is indicated.*	**1**
c	**ii**	75 «s» ✓		**1**
c	**iii**	***ALTERNATIVE 1*** 10 min $= 8\, t_{1/2}$ ✓ mass remaining $= 1.0 \times \left(\frac{1}{2}\right)^{[illegible]} = 3.9 \times 10^{[illegible]}$ «kg» ✓ ***ALTERNATIVE 2*** decay constant «$= \frac{\ln 2}{75} =$» $9.24 \times 10^{[illegible]}$ «s^{-1}» ✓ mass remaining $= 1.0 \times e^{[illegible]} = 3.9 \times 10^{-3}$ «kg» ✓		**2**

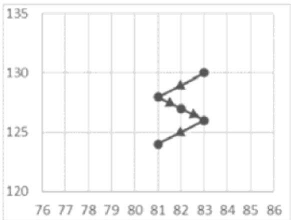
11 – (PHYSI/21_SL_Summer_2021_Q5) – *Atomic,nuclear & Particle Physics*

a		${}^{238}_{92}U \rightarrow$ «${}^{234}_{90}$»Th + «${}^{4}_{2}$»α ✓	*Allow He for alpha.*	1
b		udd → uud *OR* down quark changes to up quark ✓		1
c	i	links temperature to kinetic energy/speed of particles ✓ energy required to overcome «Coulomb» electrostatic repulsion ✓		2
c	ii	«energy is released when» binding energy per nucleon increases		1
c	iii	any use of (value from graph) x (number of nucleons) ✓ «235 · 7.6 – (89 · 8.6 + 144 · 8.2) =» 160 «MeV» ✓		2

12 – (PHYSI/21_SL_Summer_2021_Q7) – *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

13 – (PHYSI/22_SL_Summer_2021_Q4) – *Atomic,nuclear & Particle Physics*

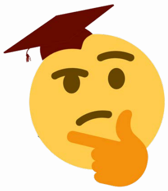
a		${}^{206}_{82}Pb$ ✓ ${}^{0}_{-1}e$ ***AND*** ${}^{0}_{0}\nu_e$ ✓		2
b		Reference to proton repulsion ***OR*** nucleon attraction ✓ strong force is short range ***OR*** electrostatic/electromagnetic force is long range ✓ more neutrons «than protons» needed «to hold nucleus together» ✓		2 max
c		 any 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

14 – (PHYSI/20_SL_Winter_2021_Q5) – *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
b	i	correct mass numbers for uranium (234) and alpha (4) ✓ 234 · 7 600 · 4 · 7 074 238 7 568 «MeV» ✓ energy released 5 51 «MeV» ✓	*Ignore any negative sign*	3
b	ii	$«\frac{KE_{\alpha}}{KE_{U}} = \frac{\frac{p^2}{2m_{\alpha}}}{\frac{p^2}{2m_{U}}}»$ *OR* $\frac{m_U}{m_{\alpha}}$ ✓ $«\frac{234}{4}» 58.5$ ✓	*Award **[2]** marks for a bald correct answer* *Accept* $\frac{117}{2}$ *for **MP2**.*	2

15 – (PHYSI/21_SL_Summer_2022_Q5) – *Atomic,nuclear & Particle Physics*

a		3 quarks / example with three quarks «eg up up down» ✓ 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 ✓		2
b		A «Decay of the strange antiquark is a» weak «interaction» ✓ B «Decay of the u to a gluon and eventually to d and anti-d is a» strong «interaction» ✓		2
c		weak «interaction» ✓ 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 ✓		2



16 – (PHYSI/22_SL_Summer_2022_Q5) – *Atomic,nuclear & Particle Physics*

a		background count rate is subtracted «from each reading» ✓	*OWTTE*	1
b		thickness is 0.25 «mm» ✓ 380 «count min^{-1}» ✓	***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		${}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + {}^{0}_{-1}\beta$ ✓ $+ \bar{\nu}_e$ ✓	*Accept β or e in* ***MP1***. *Do* ***not*** *penalize if proton / nucleon numbers or electron subscript in antineutrino are missing.*	2

17 – (PHYSI/20_SL_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	$(m_{polonium} - m_{lead} - m_{\alpha})c^2$ ***OR*** (209.93676 − 205.92945 − 4.00151) ***OR*** mass difference = 5.8x10^{-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 x 10^{-13}* J	2

b	ii	***ALTERNATIVE 1*** energy ratio expressed in terms of momentum, e.g. $\frac{E_{\alpha}}{E_{lead}} = \frac{p_{\alpha}^2 / 2m_{\alpha}}{p_{lead}^2 / 2m_{lead}}$ ✓ $p_{\alpha} = p_{lead}$ hence $\frac{E_{\alpha}}{E_{lead}} = \frac{m_{lead}}{m_{\alpha}}$ ✓ $\frac{m_{lead}}{m_{\alpha}} = \frac{206}{4} = 51.5 \Rightarrow E_{\alpha} = 51.5E_{lead}$ «so α has a much greater KE» ***OR*** m_{lead} «much» greater than m_{alpha} «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 KE ∝ v^2 «so α has a much greater KE» ✓		3
b	iii	alpha particle ✓ is electrically charged hence more likely to interact with electrons «in the surrounding material» ✓		2

1 - (PHYSI/21_SL_Summer_2017_Q3) - *Energy Production*

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 $= 240 \times 25000 =$ «6.0 MW» ✓ efficiency $«= \frac{1.6}{6.0}» = 0.27 / 27\%$ ✓
c	i	area $= \pi \times 17^2$ «$= 908\,\text{m}^2$» ✓ power $= \frac{1}{2} \times 908 \times 1.3 \times 7.5^3$ «$= 0.249\,\text{MW}$» ✓ number of turbines $«= \frac{1.6}{0.249} = 6.4» = 7$ ✓
	ii	«efficiency is less than 100 % as» not all KE of air can be converted 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_SL_Summer_2017_Q2) – *Energy Production*

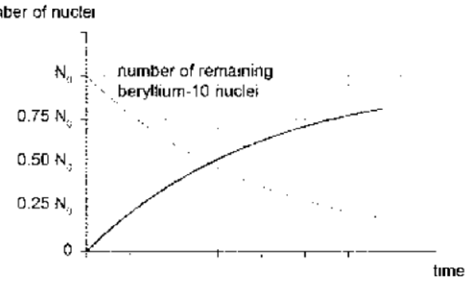
a		PE of water is converted to KE of moving water/turbine to electrical energy «in generator/turbine/dynamo» ✔ idea of pumped storage, *ie*: pump water back during night/when energy cheap to buy/when energy not in demand/when there is a surplus of energy ✔
b		total energy $=$ «$2.7\times10^{3}\times1.5\times10^{10}=$» 4.05×10^{13} «J» ✔ time $=$ «$\frac{4.0\times10^{13}}{4\times2.5\times10^{8}}=$» $11.1\,\text{h}$ *or* $4.0\times10^{4}\,\text{s}$ ✔
c		friction/resistive losses in walls of pipe/air resistance/turbulence/turbine and generator bearings ✔ thermal energy losses, in electrical resistance of components ✔ water requires kinetic energy to leave system so not all can be transferred ✔
d		area required $=\frac{1\times10^{9}}{0.22\times180}$ «$=2.5\times10^{7}\,\text{m}^2$» ✔ length of one side $=\sqrt{\text{area}}=5.0\,\text{k}$«m» ✔

3 – (PHYSI/20_SL_Winter_2017_Q5) – *Circular Motion & Gravitation, Energy Production*

a		$\frac{mv^2}{r} \quad G\frac{Mm}{r^2}$ ✔ leading to $T^2 \quad \frac{4\pi^2 r^3}{GM}$ ✔ $T \quad 5320$ «s» ✔ ***Alternative 2*** «$v \quad \sqrt{\frac{Gm_E}{r}}$» $\sqrt{\frac{6.67 \cdot 10^{\ 11} \cdot 6.0 \cdot 10^{24}}{6600 \quad 10^{3}}}$ *OR* 7800 «ms^{-1}» ✔ distance $\quad 2\pi r \quad 2\pi \quad 6600 \quad 10^{3}$ «m» *or* $4.15 \quad 10^{7}$ «m» «$T \quad \frac{d}{v} \quad \frac{4.15 \quad 10^{7}}{7800}$» 5300 «s»	*Accept use of ω instead of v*

b	i	T « $\frac{2.90 \cdot 10^{3}}{\lambda_{max}}$ » $\frac{2.90 \cdot 10^{3}}{10.1 \cdot 10^{6}}$ ✓ 287 «K» *or* 14 «°C» ✓	*Award [0] for any use of wavelength from Sun* *Do not accept 287 °C*
b	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» ✓	
c		peer review ✓ international collaboration ✓ full details of experiments published so that experiments can repeated ✓	

4 – ** (PHYSI/21_SL_Summer_2018_Q6) **– *Atomic,nuclear & Particle Physics, Energy Production*

a		${}^{10}_{4}Be \rightarrow {}^{10}_{5}B + \beta + \overline{V}_e$ conservation of mass number ***AND*** charge ${}^{10}_{5}B$, ${}^{10}_{4}Be$ ✓	*Correct identification of both missing values required for* ***[1]****.*	1
b	i	correct shape *ie* increasing from 0 to about $0.80N_0$ ✓ crosses given line at $0.50N_0$ ✓ 		2
b	ii	***ALTERNATIVE 1*** fraction of Be $\frac{1}{8}$, 12.5%, or 0.125 ✓ therefore 3 half lives have elapsed ✓ $t_{\frac{1}{2}}$ $\frac{4.3 \quad 10^{6}}{3}$ $1.43 \quad 10^{6}$ «≈ $1.4 \quad 10^{6}$» «y» ✓ ***ALTERNATIVE 2*** fraction of Be $\frac{1}{8}$, 12.5%, or 0.125 ✓ $\frac{1}{8}$ e $(4.3 \quad 10^{6})$ leading to λ $4.836 \quad 10^{7}$ «y» ✓ $\frac{ln2}{\lambda}$ $1.43 \cdot 10^{6}$ «y» ✓	*Must see at least one extra sig fig in final answer.*	3
b	iii	1.9×10^{11} ✓		1

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	$\lambda \quad \frac{2.90 \cdot 10^{3}}{253}$ ✓ $1.1 \quad 10^{5}$ «m» ✓	*Allow ECF from MP1 (incorrect temperature).*	2
c	iv	correct units for Intensity (allow *W, Nms^{1} OR Js^{1} in numerator)* ✓ rearrangement into proper SI units = kgs^{-3} ✓	*Allow ECF for MP2 if final answer is in fundamental units.*	2

5 – (PHYSI/22_SL_Summer_2018_Q5) – *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} Jkg^{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 $\frac{1.2 \quad 10^{5}}{60}$ 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% ✓		
b		water is pumped back up at times when the demand for/price of electricity is low ✓		1

6 – (PHYSI/21_SL_Summer_2019_Q6) – *Circular Motion & Gravitation, Energy Production*

a	i	$T \quad \left(\frac{1360}{\sigma}\right)^{0.25}$ ✓ 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.* *Award **[0]** for simple definition of "albedo".*	1
c	i	gravitational attraction/force/field «of the planet/Moon» ✓	*Do not accept "gravity".*	1
c	ii	the force/field and the velocity/displacement are at 90° to each other ***OR*** there is no change in GPE of the moon ✓	*Award **[0]** for any mention of no net force on the satellite.* *Do not accept acceleration is perpendicular to velocity.*	1

7 – (PHYSI/22_SL_Summer_2019_Q7) – *Energy Production*

a		$5.67 \times 10^{-8} \times 289^4$ ***OR*** $= 396$ «W m^{-2}» ✓ «$\approx 400\,\text{W m}^{-2}$»		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**

8 – (PHYSI/20_SL_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» $= 1.4 \times 10^5$ «W» ***OR*** P «in outgoing beam» $= 1.9 \times 10^4$ «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**

9 – (PHYSI/20_SL_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	$140 \times 8.29 + 94 \times 8.59 - 235 \times 7.59$ ***OR*** 184 «MeV» ✓		**1**
	b	i	see «energy =» $180 \times 10^6 \times 1.60 \times 10^{-19}$ ***AND*** «mass =» $235 \times 1.66 \times 10^{-27}$ ✓ 7.4×10^{13} «J kg^{-1}» ✓		**2**
	b	ii	energy produced in one day $= \frac{1.2 \times 10^5 \times 24 \times 3600}{0.36} = 2.9 \times 10^{14}$ «J» ✓ mass $= \frac{2.9 \times 10^{14}}{7.4 \times 10^{13}} = 3.9$ «kg» ✓		**2**
	c	i	39 ✓	*Do not allow* $^{94}_{39}\text{X}$ *unless the proton number is indicated.*	**1**
	c	ii	75 «s» ✓		**1**
	c	iii	***ALTERNATIVE 1*** 10 min $= 8\,t_{1/2}$ ✓ mass remaining $= 1.0 \times \left(\frac{1}{2}\right)^8 = 3.9 \times 10^{-3}$ «kg» ✓ ***ALTERNATIVE 2*** decay constant = «$\frac{\ln 2}{75}$ =» 9.24×10^{-3} «s^{-1}» ✓ mass remaining $= 1.0 \times e^{-9.24 \times 10^{-3} \times 600} = 3.9 \times 10^{-3}$ «kg» ✓		**2**

10 – (PHYSI/21_SL_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 $e\sigma AT^4$ *OR* $\frac{P}{4\pi d^2}\cdot\frac{A}{4}\cdot(1-\alpha_p)$ ✓ with correct manipulation to show the result ✓		**2**
b		$\sqrt[4]{\frac{1.36\times10^3\times0.87}{4\times5.67\times10^{-8}}}$ ✓ T = 268.75 «K» ≈ 270 «K» ✓		**2**

11 – (PHYSI/22_SL_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* $V=\varepsilon-Ir$	**2**
b		***ALTERNATIVE 1*** pd dropped across cell = 6.5 «V» ✓ internal resistance = $\frac{6.5}{0.9}$ ✓ 7.2 «Ω» ✓ ***ALTERNATIVE 2*** $\varepsilon = I(R+r)$ so $\varepsilon = V + Ir$ ✓ 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 x 0.35 x 0.45 = «107 W» ✓ power in external circuit = 14.5 x 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**

12 – (PHYSI/20_SL_Winter_2021_Q6) – *Energy Production*

	a	i	incident intensity $\frac{1360}{9.3^2}$ ***OR*** 15.7 ≈ 16 «W m » ✓	*Allow the use of 1400 for the solar constant.*	1
	a	ii	exposed surface is ¼ of the total surface ✓ absorbed intensity = (1-0.22) × incident intensity ✓ 0.78 × 0.25 × 15.7 ***OR*** 3.07 «W m^{-2}» ✓	*Allow 3.06 from rounding and 3.12 if they use 16 Wm^{-2}*	3
	a	iii	σT^4 3.07 ***OR*** T 86 «K» ✓		1
	b	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
	b	ii	T = 15.9 x 24 x 3600 «s» ✓ M $\frac{4\pi^2(1.2 \cdot 10^{\cdot})^{\cdot}}{6.67 \cdot 10^{\cdot\cdot} \cdot (15.9 \cdot 24 \cdot 3600)^{\cdot}}$ 5.4 · 10$^{\cdot\cdot}$ «kg» ✓	*Award* ***[2]*** *marks for a bald correct answer.* *Allow* ***ECF*** *from* ***MP1***	2

1 - (PHYSI/20_SL_Winter_2018_Q5) - *Atomic,nuclear & Particle Physics, Quantum & Nuclear Physics (ahl)*

a		identifies $\lambda = 435$ nm ✓ $E \quad « \frac{hc}{\lambda} » \frac{6.63 \quad 10^{34} \quad 3 \quad 10^{8}}{4.35 \quad 10^{7}}$ ✓ $4.6 \quad 10^{19}$ « J » ✓		
b		–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**
c		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 ✓	*Allow ECF from (a)(i)*	**2** **3**