APOLLO

Physics
HL Workbook

First assessment 2025
Whole questions arranged by syllabus topic.
Original question and scheme crops preserve source diagrams.

APOLLO

Kinematics

13 questions

1. Instantaneous velocity is defined as...

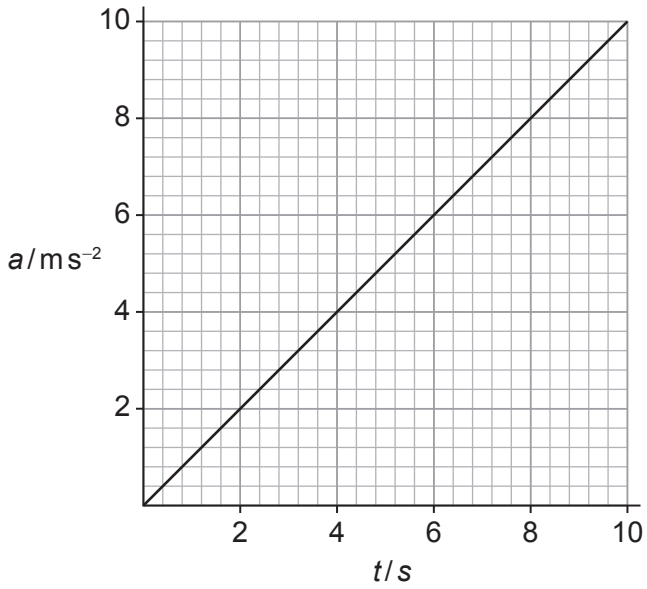
A. $\frac{\text{displacement}}{\text{time taken}}$.

B. rate of change of position.

C. $\frac{\text{distance moved}}{\text{time taken}}$.

D. rate of change of distance.

2. The variation with time t of the acceleration a of an object is shown. At $t = 0$ the object is at rest.



What is the speed of the object when $t = 8.0\,\text{s}$?

A. $1.0\,\text{m s}^{-1}$

B. $32\,\text{m s}^{-1}$

C. $50\,\text{m s}^{-1}$

D. $64\,\text{m s}^{-1}$

5. A satellite undergoes one circular orbit of the Earth every 24 hours.

What is the angular velocity of the satellite?

A. $4.4 \times 10^{-3}\,\text{rad}\,\text{s}^{-1}$

B. $1.7 \times 10^{-3}\,\text{rad}\,\text{s}^{-1}$

C. $7.3 \times 10^{-5}\,\text{rad}\,\text{s}^{-1}$

D. $1.2 \times 10^{-5}\,\text{rad}\,\text{s}^{-1}$

1. A ball is initially 50 m above the ground. The ball is thrown vertically upwards and takes 5.0 s to reach the ground. Air resistance is negligible.

What is the initial speed of the ball?

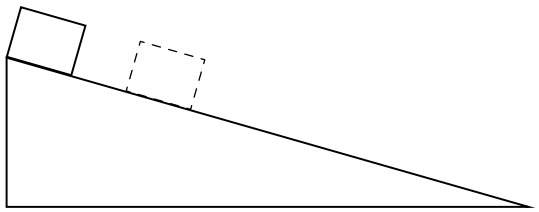
A. $10\,\mathrm{m\,s^{-1}}$

B. $15\,\mathrm{m\,s^{-1}}$

C. $25\,\mathrm{m\,s^{-1}}$

D. $35\,\mathrm{m\,s^{-1}}$

2. An object is sliding from rest down a frictionless inclined plane. The vertical displacement of the object is 1.5 m during the first second.



What is the vertical displacement during the next second?

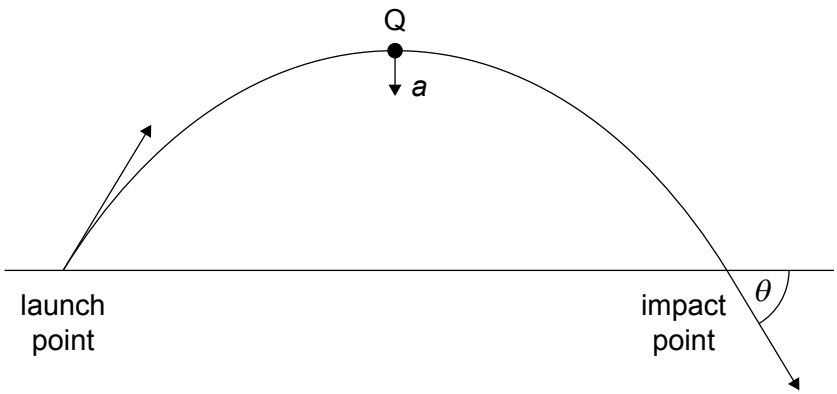
A. 1.5 m

B. 3.0 m

C. 4.5 m

D. 5.0 m

3. The diagram shows the path of a ball in the absence of air resistance. Q is the highest point of the ball's trajectory and *a* is the vertical acceleration at Q. At impact the velocity makes an angle θ to the horizontal.



Three statements about the actual motion of the ball when there is air resistance are:

I. Q is lower.

II. *a* remains the same.

III. θ increases.

Which statements are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Turn over

1. A car decelerates uniformly to rest. From an initial velocity v to a velocity $\frac{v}{2}$, it covers a distance d. How much further does it travel before coming to rest?

A. $\frac{d}{4}$

B. $\frac{d}{3}$

C. $\frac{d}{2}$

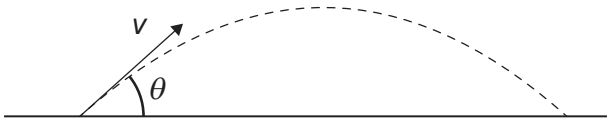
D. d

2. Two balls, P and Q, are projected from the edge of a cliff. P is projected horizontally at speed v and Q is projected vertically upwards at the same speed. The time taken for P to reach the ground is t_P and the speed at impact with the ground is v_P. **Air resistance is negligible**.

What is the time taken to reach the ground and the speed at impact with the ground for Q?

	Time taken	Speed at impact
A.	t_P	v_P
B.	t_P	Greater than v_P
C.	Greater than t_P	v_P
D.	Greater than t_P	Greater than v_P

1. A projectile is launched with an initial velocity v at an angle θ above the horizontal. The projectile lands at the same height from which it was released. Air resistance is negligible.



What is the time of flight of the projectile?

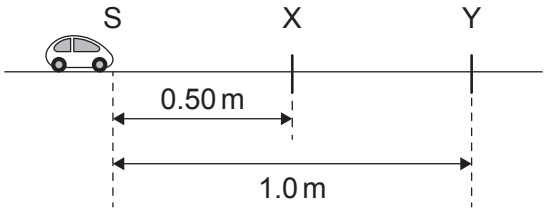
A. $\frac{v\sin\theta}{g}$

B. $\frac{2v\sin\theta}{g}$

C. $\frac{2v\cos\theta}{g}$

D. $\frac{2v\sin\theta\cos\theta}{g}$

2. A cart starts from rest at point S and moves in a straight line with a constant acceleration. Two points X and Y are 0.50 m and 1.0 m from S.



The cart passes X with speed v_X and passes Y with speed v_Y. What is $\frac{v_Y}{v_X}$?

A. $\sqrt{2}$

B. 2

C. $2\sqrt{2}$

D. 4

1. A stone is released from rest and falls vertically. Air resistance is negligible. What is correct about the stone during each consecutive second of its motion?

A. The change in velocity is constant.

B. The change in displacement is constant.

C. The change in acceleration decreases.

D. The change in speed increases.

2. A projectile is launched horizontally from the top of a cliff with a speed of $10\,m\,s^{-1}$. The projectile hits the ground at a distance of 30 m from the base of the cliff. Air resistance is negligible.

What is the height of the cliff?

A. 15 m

B. 30 m

C. 45 m

D. 90 m

1. A car has an initial speed of $16\,\text{m}\,\text{s}^{-1}$. It decelerates at $4.0\,\text{m}\,\text{s}^{-2}$ until it stops.

What is the distance travelled by the car?

A. 4 m

B. 16 m

C. 32 m

D. 64 m

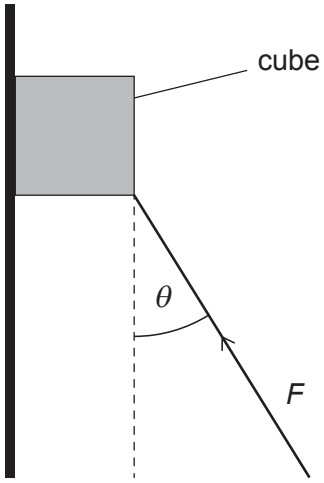
APOLLO

Forces and momentum

21 questions

3. A force acts on a cube of mass *m* that accelerates upwards along a vertical frictionless surface.

The magnitude of the force is *F* and it acts at θ to the vertical.



What is the magnitude of the acceleration of the cube?

A. $\frac{(F\cos\theta - mg)}{m}$

B. $\frac{(F\sin\theta - mg)}{m}$

C. $\frac{(F\cos\theta - g)}{m}$

D. $\frac{(F\sin\theta - g)}{m}$

4. A sphere of density ρ and radius R rests on the bottom of a tank of water. The buoyancy force on the sphere is F_1.

A sphere of density 2ρ and radius $\frac{R}{2}$ is at the bottom of the same tank. The buoyancy force on the second sphere is F_2.

What is $\frac{F_1}{F_2}$?

A. 2

B. 4

C. 8

D. 16

6. An object of mass 5.0 kg is initially at rest. An impulse of 2.0 N s acts on the object.

What is the final kinetic energy of the object?

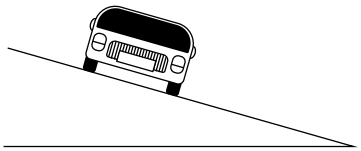
A. 0.40 J

B. 10 J

C. 20 J

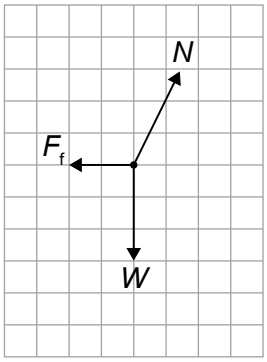
D. 40 J

4. A car of weight W is travelling at maximum speed in a circular path along a horizontal banked road. The surface exerts a normal force N and a friction force F_f.

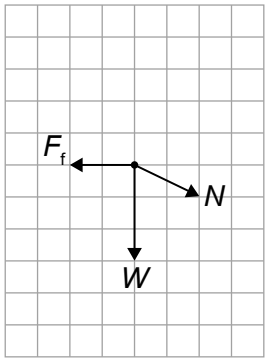


What is the correct free-body diagram for the car?

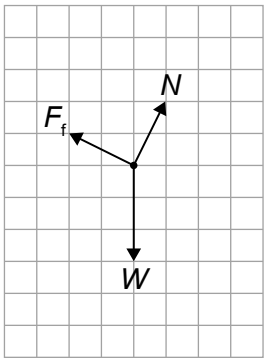
A.



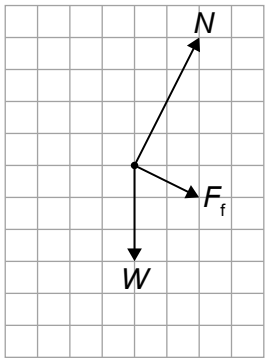
B.



C.



D.



5. Sphere X falls through a fluid with terminal velocity v. Sphere Y is made of the same material and falls through the same fluid. The radius of sphere Y is double that of sphere X.

What is the terminal velocity of sphere Y?

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

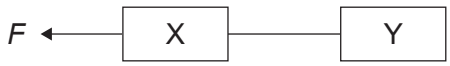
B. v

C. $2v$

D. $4v$

3. Two identical blocks, X and Y, each of mass 2.0 kg are connected by a string. They move on the same surface.

A force *F* accelerates the blocks at 0.5 m s^{-2}. The frictional force on block X is 4.0 N.



What is the tension in the string?

A. 1 N

B. 2 N

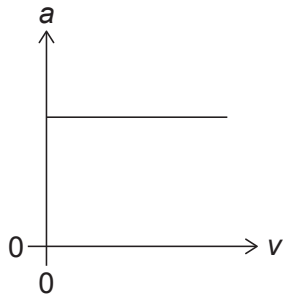
C. 5 N

D. 10 N

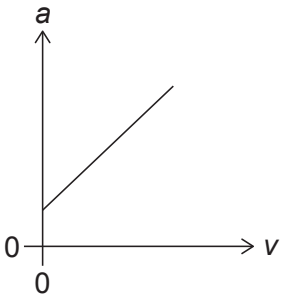
4. A raindrop falls from rest through air with velocity *v* and acceleration *a*.

Which graph best represents the variation of *a* with *v*?

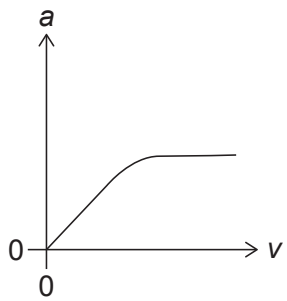
A.



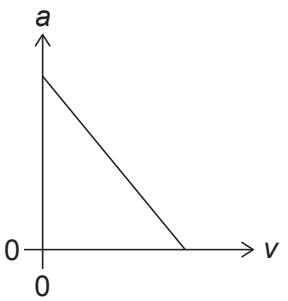
B.



C.



D.



5. A ball of mass m collides with a stationary ball of mass $3m$. After colliding, the two balls move together.

What is the percentage loss in kinetic energy of the system?

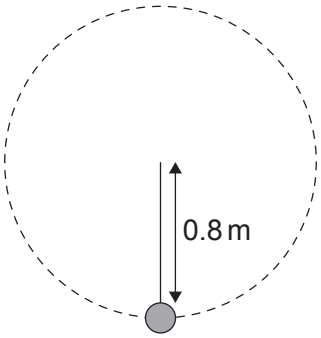
A. 0 %

B. 25 %

C. 50 %

D. 75 %

6. A ball of mass 0.4 kg is attached to a string of length 0.8 m. The ball is rotated in a vertical circle such that the speed at the lowest position is 6.0 m s^{-1}.



What is the tension in the string when the ball is at the lowest position?

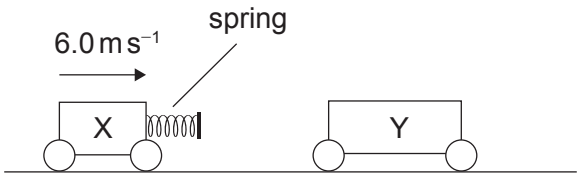
A. 4.0 N

B. 14 N

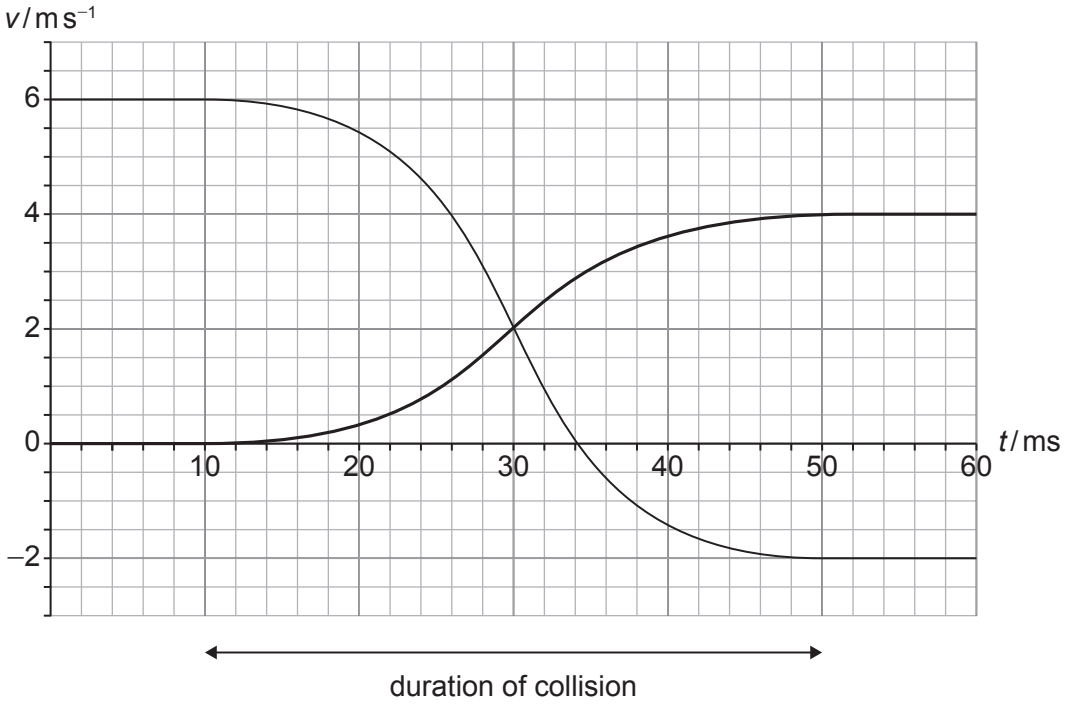
C. 18 N

D. 22 N

1. A cart X of mass 3.0 kg moving at 6.0 m s^{-1} collides with a stationary cart Y of mass 6.0 kg. A spring is attached to X as shown.



The graph shows the velocities of X and Y before, during and after the collision.



The collision lasted for 40 ms.

(a) Show that the collision is elastic. [2]

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(Question 1 continued)

(b) Determine

(i) the magnitude of the average force exerted on Y, [2]

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(ii) the average power delivered to Y, [2]

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(iii) the elastic energy stored in the spring at $t = 30\,\text{ms}$. [2]

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Question 1 - working space

1. A box of mass 1.2 kg is lying at rest on a surface. The coefficient of static friction between the box and the surface is 0.36 and the coefficient of dynamic friction between the box and the surface is 0.28.

(a) Outline why the coefficients of friction have no units. [1]

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(b) Show that the minimum force needed to accelerate the box is about 4 N. [2]

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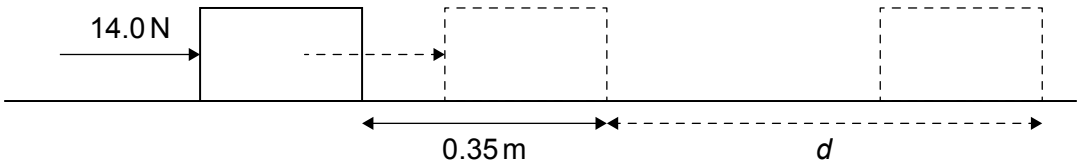
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A force of 14.0 N acts on the box for 0.35 m as shown. The force is then removed and the box continues to move. The box comes to rest after a further displacement *d*.

diagram not to scale



(c) Determine *d.* [3]

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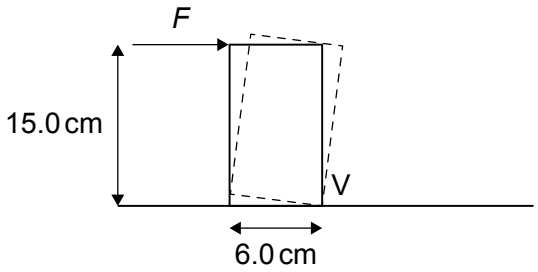
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(Question 1 continued)

The box is now standing up. The height of the box is 15.0 cm and its base is 6.0 cm. A person pushes the box with an increasing force *F* at the top until the box tips about the corner V without sliding, as shown.

diagram not to scale



(d) (i) Determine *F*. [2]

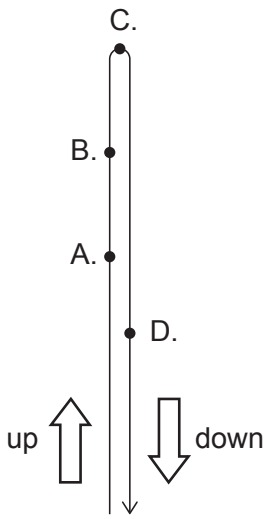
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(ii) Outline why the box does not slide. [1]

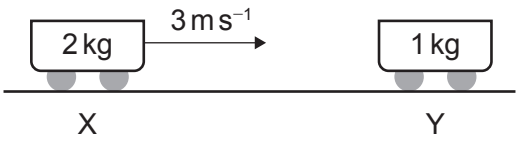
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Question 1 - working space

3. A ball is thrown vertically upwards. Air resistance is **not** negligible. Four positions of the ball are shown: A and B on the way up, C at the maximum height, and D on the way down. At which position does the acceleration of the ball have its greatest magnitude?



4. Cart X, of mass 2 kg, is moving at a speed of $3\,m\,s^{-1}$ to the right and collides on a horizontal track with cart Y of mass 1 kg. Y is initially stationary.



The velocity of Y immediately after the collision is $4\,m\,s^{-1}$ to the right. What is the velocity of X immediately after the collision?

A. $1\,m\,s^{-1}$ to the right

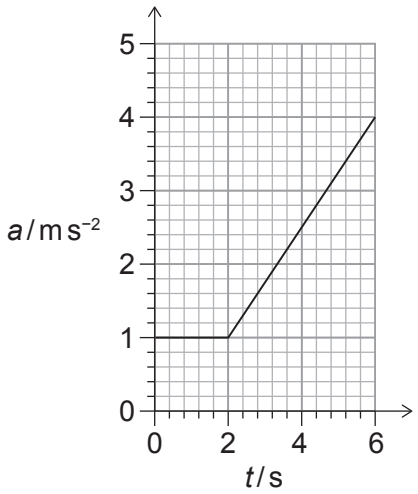
B. $1\,m\,s^{-1}$ to the left

C. $2\,m\,s^{-1}$ to the right

D. $2\,m\,s^{-1}$ to the left

Turn over

3. A force is applied to a mass of 3 kg. The graph shows the variation with time *t* of the acceleration *a* of the mass.



What is the average force acting on the mass?

A. 5 N

B. 6 N

C. 12 N

D. 24 N

4. An object of mass m, moving with a speed v, collides with a stationary object of mass m. The objects stick together.

What is the change in kinetic energy in the collision?

A. Zero

B. $\frac{mv^2}{8}$

C. $\frac{mv^2}{4}$

D. $\frac{3mv^2}{8}$

5. A mass *m* is attached to a string and moves in a vertical circle of constant radius *R*. At the top of the circle, the tension in the string is *T*. Air resistance is negligible.

What is the kinetic energy of *m* at the top of the circle?

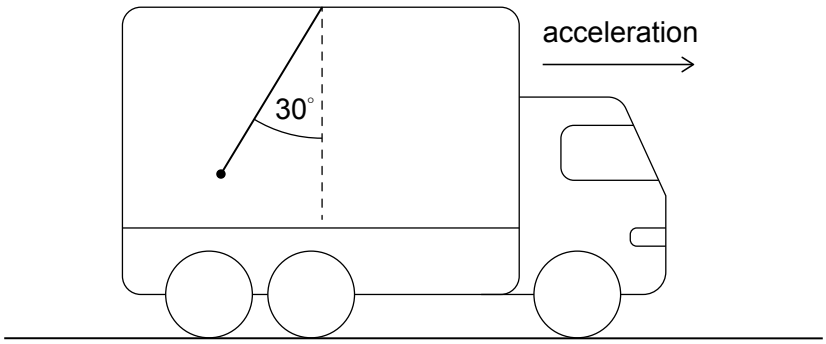
A. $\frac{R(T-mg)}{2}$

B. $\frac{R(T+mg)}{2}$

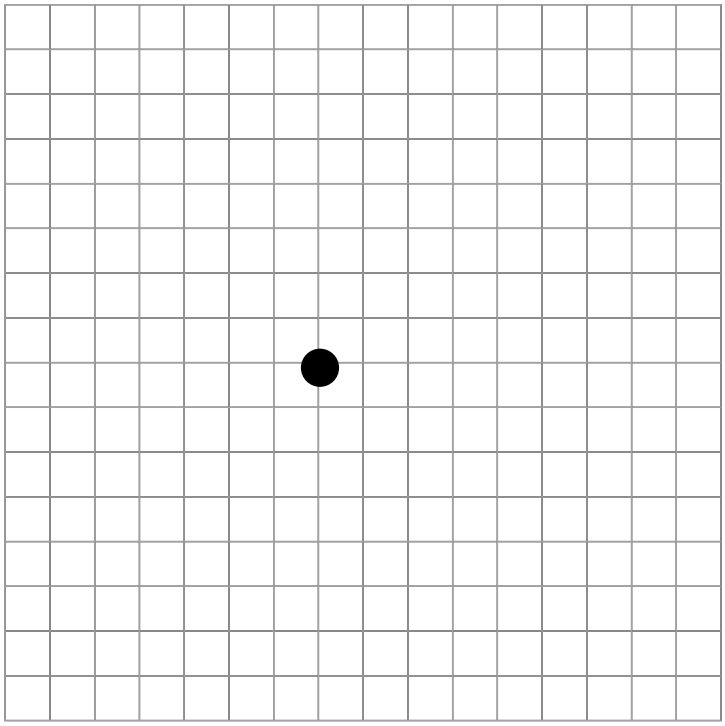
C. $R(T-mg)$

D. $R(T+mg)$

2. A ball is connected to a string that is attached to the ceiling of a truck. The truck accelerates to the right on a horizontal road. The string makes an angle of 30° with the vertical.



(a) (i) Draw a labelled free-body diagram of the forces on the ball. [2]



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(Question 2 continued)

(ii) Determine the acceleration of the truck. [2]

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(b) The truck now moves at **constant** speed up an incline that makes an angle of 10° to the horizontal. State and explain the angle between the string and the vertical. [2]

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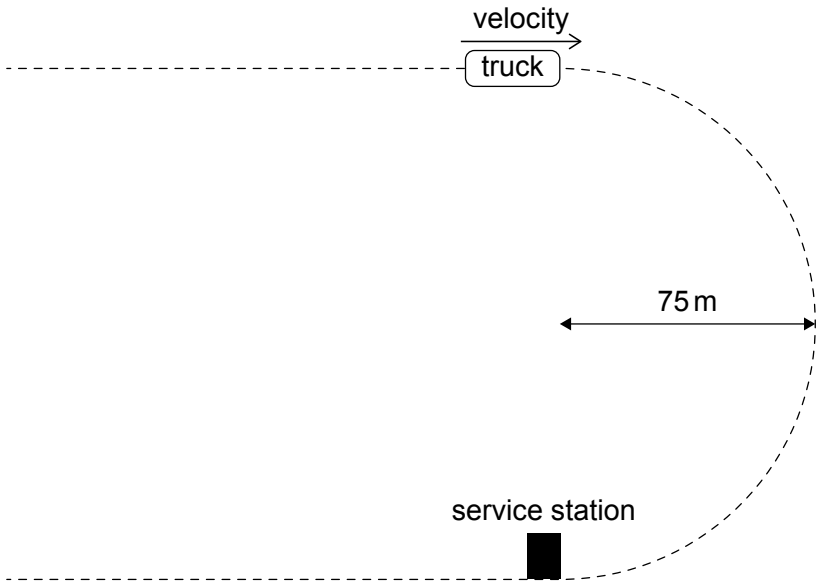
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Answers written on this page
will not be marked.

(Question 2 continued)

On another occasion, the truck enters a horizontal semicircular road of radius of 75 m. The coefficient of static friction between the road and the tyres is 0.60.



(c) Calculate the maximum speed at which the truck can travel on this road. [2]

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(d) The truck runs out of fuel just as it enters the semicircle with speed 15 m s^{-1}. The resultant force opposing the motion has magnitude 520 N. The mass of the truck is 1400 kg. A service station is at the other end of the semicircle.

Determine whether the truck will be able to reach the service station. [3]

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Turn over

Question 2 - working space

2. A block of mass 2.0 kg accelerates from a speed of 15 m s^{-1} to a speed of 20 m s^{-1} without changing its direction.

What impulse acts on the block?

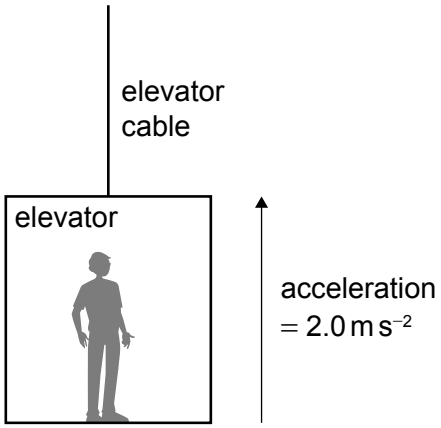
A. 2.5 N s

B. 5.0 N s

C. 10 N s

D. 17.5 N s

5. A person stands in an elevator (lift). The total mass of the person and the elevator is 800 kg. The elevator accelerates upward at $2.0\,\text{m}\,\text{s}^{-2}$.



What is the tension in the cable?

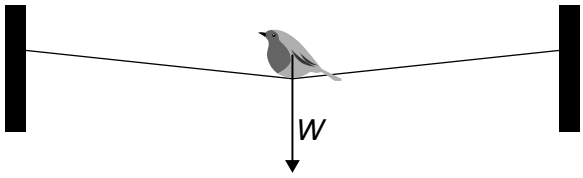
A. 1.6 kN

B. 6.4 kN

C. 8.0 kN

D. 9.6 kN

8. A bird of weight W sits on a thin rope at its midpoint. The rope is almost horizontal and has negligible mass.



The tension in the rope is

A. less than $\frac{W}{2}$

B. equal to $\frac{W}{2}$

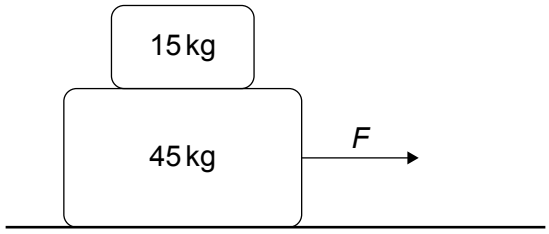
C. between $\frac{W}{2}$ and W

D. greater than W

1. A block of mass 45 kg is placed on a horizontal table. There is no friction between the block and the table.

An object of mass 15 kg is placed on top of the block.

A force *F* acts on the block so that it accelerates. The acceleration of the object and the acceleration of the block are the same so that they do not move relative to each other.



The coefficient of static friction between the block and the object is 0.60.

(a) State the nature and direction of the force that accelerates the 15 kg object. [1]

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(b) Determine the largest magnitude of *F* for which the block and the object do not move relative to each other. [3]

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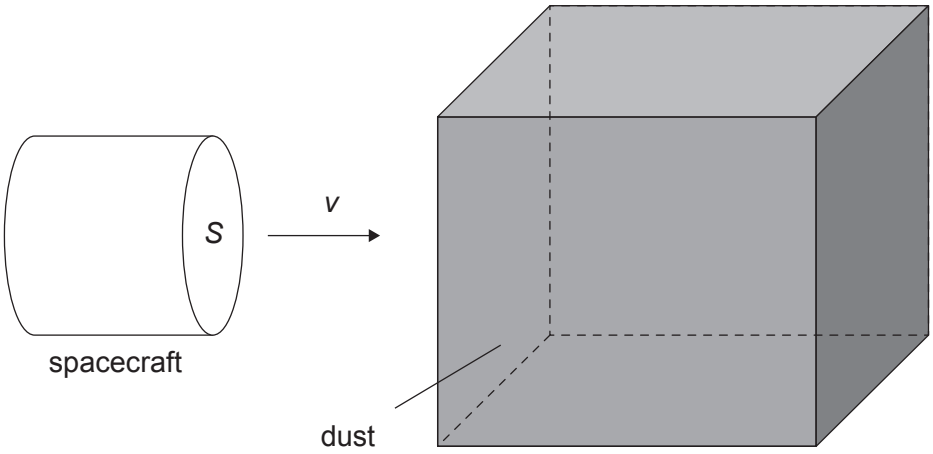
Question 1 - working space

APOLLO

Work, energy and power

6 questions

8. (a) A cylindrical spacecraft of cross-sectional area S moves with velocity v. The spacecraft enters a region of dust of density ρ. All the dust that comes into contact with the forward cross-sectional area of the spacecraft sticks to the spacecraft increasing its mass.



(i) Show that in time Δt the mass of the spacecraft will increase by an amount $\rho S v \Delta t$. [1]

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(ii) Deduce that the spacecraft will experience a drag force $\rho S v^2$ opposite to its velocity. [2]

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(This question continues on the following page)

(Question 8 continued)

(b) A satellite of mass m is in a circular orbit of radius r around Earth. Earth has mass M.

(i) Show that the total energy of the satellite is given by $E_T = -\frac{GMm}{2r}$. [2]

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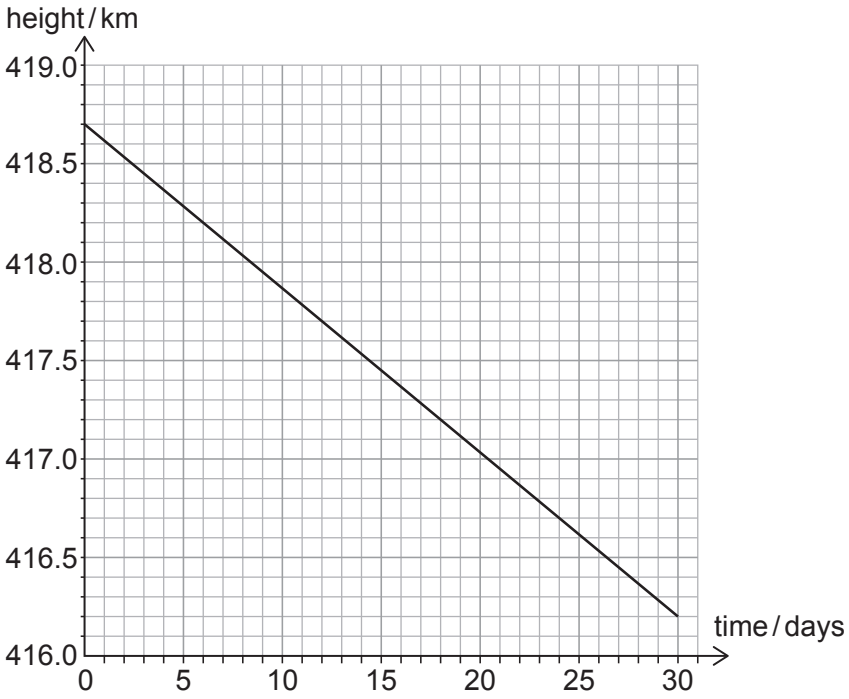
(ii) The satellite experiences a drag force due to the atmosphere of Earth. With reference to the results in (a) and (b)(i), state and explain the likely fate of this satellite. [4]

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(This question continues on the following page)

(Question 8 continued)

(c) The graph shows the variation with time of the height of the International Space Station (ISS) during a 30-day period.



The following data are available:

$$\text{Mass of Earth} = 5.98 \times 10^{24}\,\text{kg}$$
$$\text{Mass of the ISS} = 4.20 \times 10^{5}\,\text{kg}$$
$$\text{Radius of the Earth} = 6.38 \times 10^{6}\,\text{m}$$

For the 30-day period indicated in the graph the loss of total energy of the ISS is $4.5 \times 10^{9}\,\text{J}$.

(i) Calculate the average rate at which the energy of the ISS is being dissipated. [2]

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(This question continues on the following page)

(Question 8 continued)

(ii) Show, using the average height during the 30-day period, that the speed of the ISS is about $8 \times 10^3\,\text{m}\,\text{s}^{-1}$. [2]

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(iii) Estimate the increase in the temperature of the ISS assuming all the lost energy went into thermal energy of the ISS. Take the specific heat capacity of the ISS to be $500\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$. [2]

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(iv) Estimate, using the answers to (c)(i) and (c)(ii), the average drag force that acted on the ISS. [3]

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(Question 8 continued)

(d) At the end of the 30-day period, rockets are fired to bring the ISS back to its initial height. The energy density of liquid hydrogen rocket fuel is 8.5×10^3 MJ m^{-3}.

Estimate the volume of fuel needed. [2]

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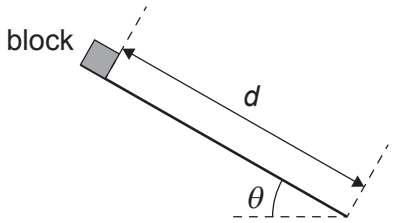
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Question 8 - working space

5. A block of mass *m* is released from rest and slides down a ramp of length *d* that makes an angle θ with the horizontal. A constant frictional force *F* acts on the block.



What is the kinetic energy of the block at the bottom of the ramp?

A. $mgd - Fd\cos\theta$

B. $mgd - Fd$

C. $mgd\sin\theta - Fd\cos\theta$

D. $mgd\sin\theta - Fd$

6. An electric motor of efficiency 75 % raises a mass of 120 kg at a constant speed of 0.50 $m\,s^{-1}$. What is the power input to the motor?

A. 20 W

B. 450 W

C. 600 W

D. 800 W

6. A pump has efficiency η when raising water from a well of depth *d*. The mass of water raised per second is *R*. Changes in kinetic energy of the water are considered negligible.

What is the input power to the pump required to raise the water?

A. $\frac{Rd}{\eta g}$

B. $\frac{\eta R}{gd}$

C. ηRgd

D. $\frac{Rdg}{\eta}$

Turn over

3. A net force of 8.0 N accelerates a 4.0 kg body from rest to a speed of 5.0 m s^{-1}.

What is the work done by the force?

A. 50 J

B. 40 J

C. 32 J

D. 20 J

6. An object is released from rest in a vacuum at a height H above the Earth's surface.

As the object falls it passes a point at a height of $0.75H$ above the surface.

What is $\frac{\text{kinetic energy of the object at a height of } 0.75H}{\text{gravitational potential energy of the object at a height of } H}$?

A. $\frac{1}{16}$

B. $\frac{1}{4}$

C. $\frac{9}{16}$

D. $\frac{3}{4}$

APOLLO

Rigid body mechanics

12 questions

7. A system of moment of inertia I rotates from rest about a given axis. The angular acceleration α of the system is constant.

What is the change in angular momentum when the system has made four complete rotations about the given axis?

A. $2I\sqrt{2\pi\alpha}$

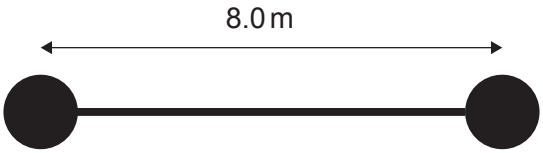
B. $4I\sqrt{\pi\alpha}$

C. $2I\sqrt{2\alpha}$

D. $4I\sqrt{\alpha}$

8. Two small spheres each of mass 10 kg are 8.0 m apart and connected by a rod of negligible mass.

This system rotates about an axis halfway along the rod and at right angles to it.



What is the moment of inertia of the system?

A. 160 kg m^2

B. 320 kg m^2

C. 640 kg m^2

D. 1280 kg m^2

6. A wheel, initially at rest, rolls without slipping down an incline for 4.0 s. The final angular velocity of the wheel is 5π rad s^{-1}.

How many revolutions did the wheel complete?

A. 5

B. 10

C. 15

D. 30

7. What is the unit of angular impulse?

A. $\mathrm{N\,s}$

B. $\mathrm{N\,m}$

C. $\mathrm{N\,m\,s^{-1}}$

D. $\mathrm{N\,m\,s}$

8. A car of total mass M is travelling with a constant speed v. Each of the four wheels of the car has a mass m and a radius R and rolls without slipping.

The moment of inertia of each wheel is $I = \frac{1}{2}mR^2$.

What is $\frac{\text{sum of the rotational kinetic energy of all four wheels}}{\text{translational kinetic energy of the car}}$?

A. $\frac{m}{2M}$

B. $\frac{m}{M}$

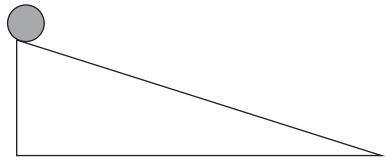
C. $\frac{2m}{M}$

D. $\frac{4m}{M}$

Turn over

7. A solid cylinder of mass m and radius r is released from rest on an inclined plane. The cylinder rolls without slipping.

The moment of inertia of the cylinder is $\frac{1}{2}mr^2$. The speed when it reaches the bottom of the inclined plane is v.



What is the vertical height from which the cylinder was released?

A. $\frac{v^2}{g}$

B. $\frac{3v^2}{4g}$

C. $\frac{v^2}{2g}$

D. $\frac{v^2}{4g}$

8. Two spheres, X and Y, are spinning with the same rotational kinetic energy. The moment of inertia of X is I_X and that of Y is I_Y.

What is $\frac{\text{angular momentum of X}}{\text{angular momentum of Y}}$?

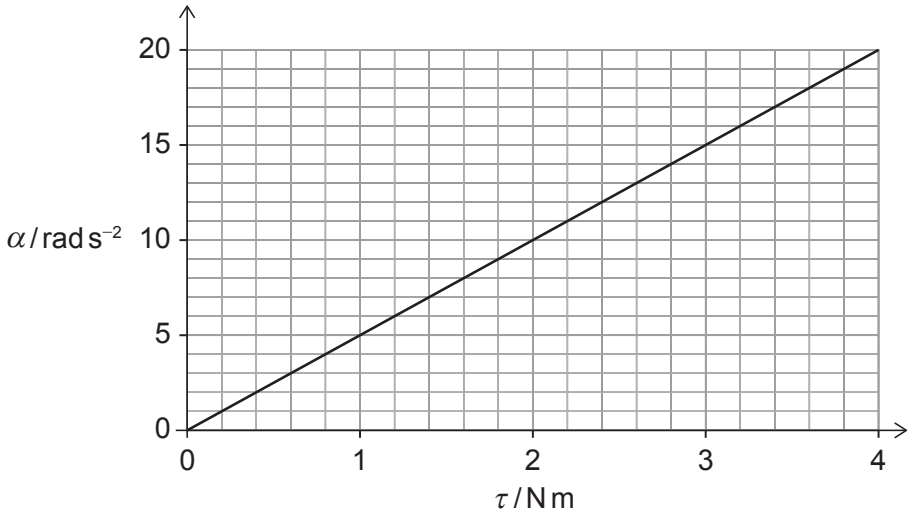
A. $\sqrt{\frac{I_X}{I_Y}}$

B. $\sqrt{\frac{I_Y}{I_X}}$

C. $\frac{I_X}{I_Y}$

D. $\frac{I_Y}{I_X}$

7. The graph shows how the angular acceleration α of a flywheel varies with torque τ applied to the flywheel.



What is the moment of inertia of the flywheel?

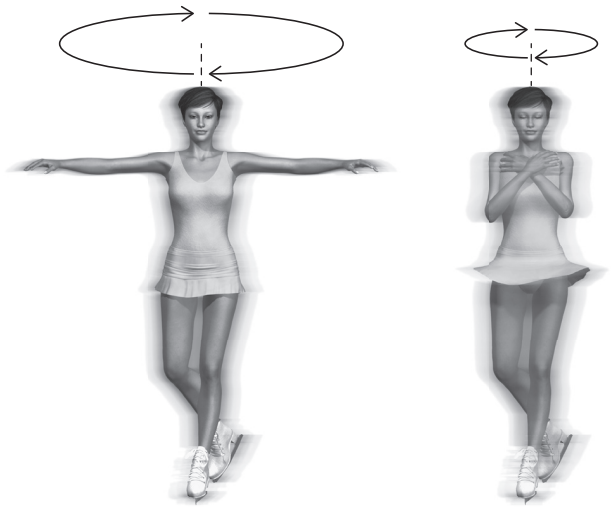
A. $0.20\,\text{kg}\,\text{m}^2$

B. $5.0\,\text{kg}\,\text{m}^2$

C. $40\,\text{kg}\,\text{m}^2$

D. $80\,\text{kg}\,\text{m}^2$

7. An ice skater is spinning with their arms extended in a fixed position at a constant angular velocity. The ice skater then quickly pulls their arms closer to their body. Frictional effects are negligible.



Three statements are made about the ice skater's motion.

I. The angular momentum of the ice skater remains constant.

II. The rotational kinetic energy of the ice skater remains constant.

III. The net torque acting on the ice skater is zero.

Which of the statements are correct?

A. I and II only

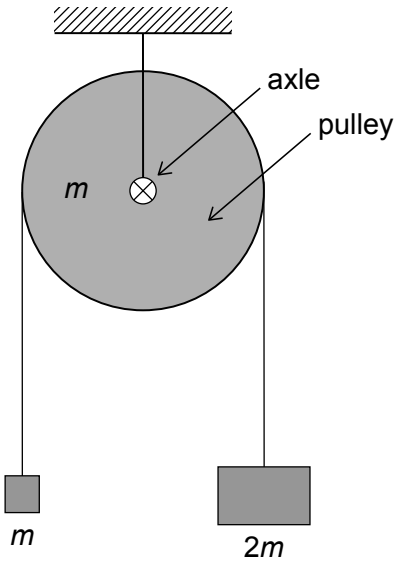
B. I and III only

C. II and III only

D. I, II and III

6. Two blocks of mass m and $2m$ are connected with a string that goes over a pulley of mass m.

diagram not to scale



When the blocks are released, the pulley turns about the axle as the blocks move. The string does not slip relative to the pulley. The radius of the pulley is r and its moment of inertia about the axle is $\frac{mr^2}{2}$.

(a) Show that the acceleration a of the blocks is given by $a = \frac{2g}{7}$. [3]

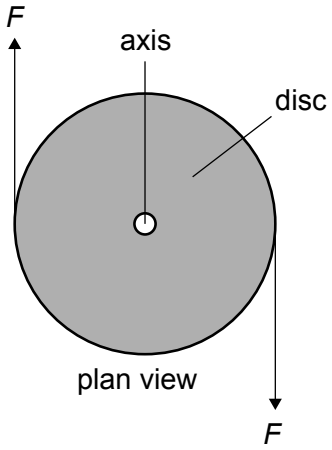
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(b) Suggest whether the angular momentum of the pulley–blocks system is conserved. [1]

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Question 6 - working space

4. A disc of mass *M* and radius *R* is on a horizontal frictionless table. Two equal and opposite forces, each of magnitude *F*, act on the disc. The moment of inertia of the disc about its axis is $\frac{1}{2}MR^2$.



What is the angular acceleration of the disc?

A. 0

B. $\frac{F}{MR}$

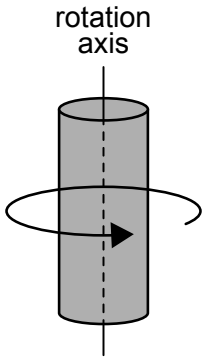
C. $\frac{2F}{MR}$

D. $\frac{4F}{MR}$

Turn over

7. A cylinder of mass *M* and radius *R* rotates at constant angular speed ω about an axis through its centre. The rotational kinetic energy of the cylinder is *K*.

The moment of inertia of the cylinder is $\frac{1}{2}MR^2$.



A second cylinder has mass 2*M*, radius 2*R* and rotates with angular speed 2ω.

What is the rotational kinetic energy of the second cylinder?

A. 8*K*

B. 16*K*

C. 32*K*

D. 64*K*

Turn over

APOLLO

Galilean and special relativity

10 questions

9. Observer X sees a spacecraft moving in the positive x-direction at a speed of 0.50*c*.

Observer Y sees the same spacecraft moving in the negative x-direction at a speed of 0.50*c*.

What is the speed of Y in the frame of reference of X?

A. 0

B. 0.80*c*

C. *c*

D. 1.3*c*

9. A pendulum has a period of 3.0 s as measured in its inertial frame of reference. An observer is moving with a speed of 0.80 *c* with respect to the pendulum's frame.

What is the period of the pendulum measured by the observer?

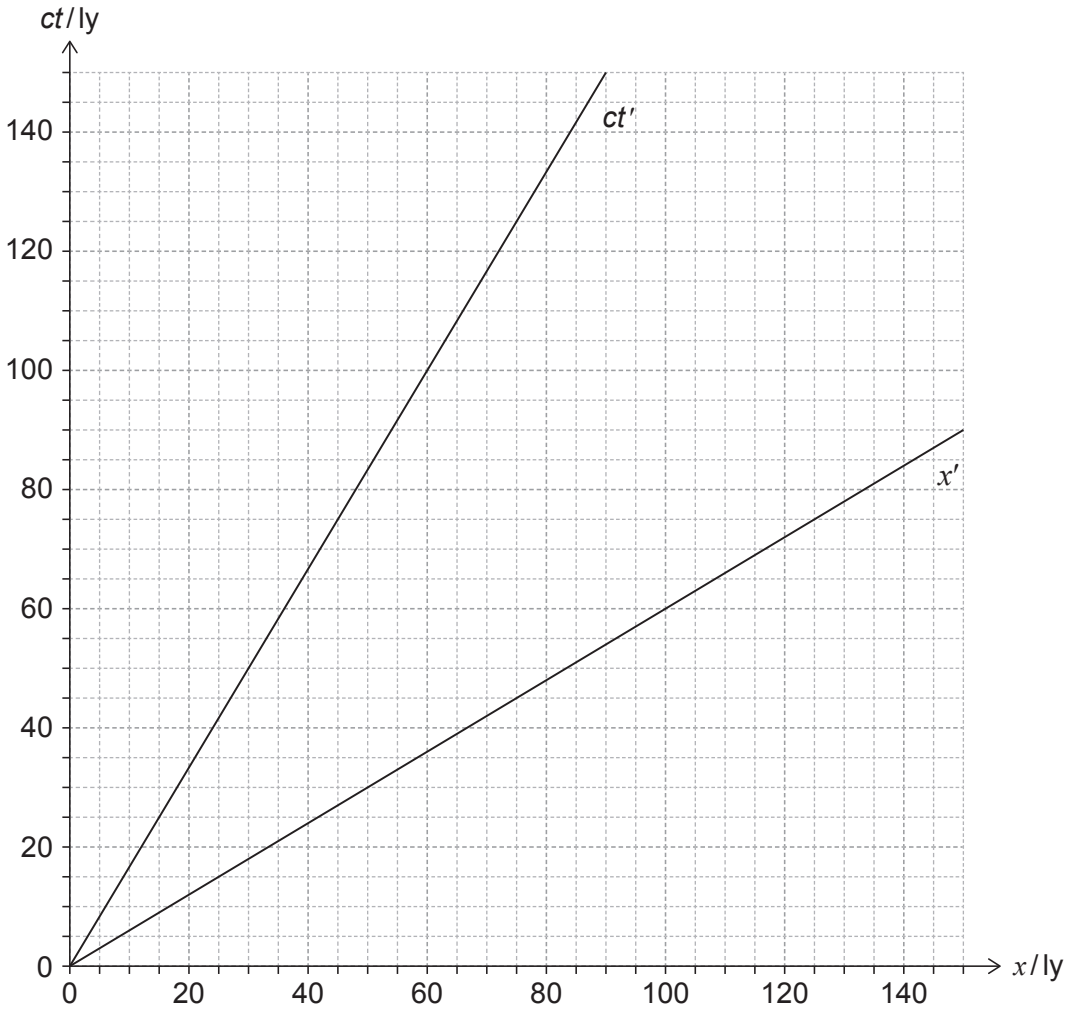
A. 8.3 s

B. 5.0 s

C. 1.8 s

D. 1.1 s

6. Spacecraft S leaves Earth with speed 0.60c on the way to a planet P. As measured by Earth, P is at a distance of 30 ly from Earth. The diagram shows the spacetime axes of Earth (x, ct) and of S (x', ct').



(This question continues on the following page)

(Question 6 continued)

(a) S arrives at P after 50 years according to Earth. Calculate the time at which S arrives at P according to S clocks. [2]

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(b) When S arrives at P, S sends a radio signal back to Earth.

(i) Draw, on the spacetime diagram, the world line of the signal from when it is emitted until it is received on Earth. [1]

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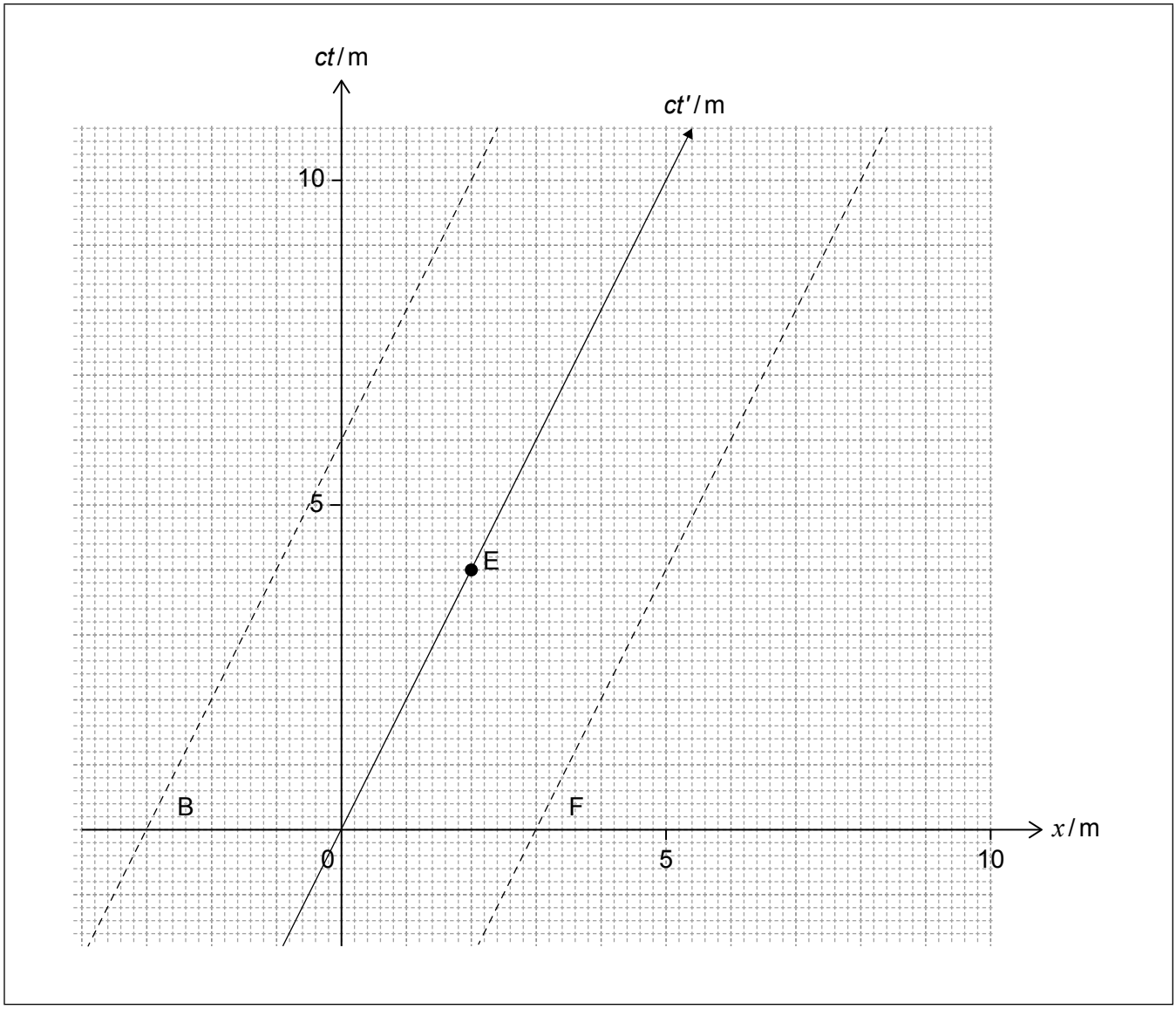
(ii) Determine, using the spacetime diagram or otherwise, the time of travel of the signal according to S. [3]

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Question 6 - working space

2. The spacetime diagram shows the x, *ct* axes for an observer on the ground. The *ct'* axis for a passenger on a train moving relative to the observer and world lines for the back (B) and front (F) of the moving train are also shown. The observer on the ground and the passenger are opposite each other at the origin of the spacetime diagram.

The train is travelling at 0.5*c*.



Event E is the lighting of a match by the passenger in the train, with coordinates $x = 2\,\text{m}$ and $ct = 4\,\text{m}$. The light from the match reaches two mirrors at the back and front of the train.

(a) Draw, on the graph, the x' axis for the passenger on the train. [1]

(b) Draw, on the graph, the path of the light emitted from the match to show the events where the light strikes both mirrors. Label the events T_B and T_F. [1]

(This question continues on the following page)

(Question 2 continued)

(c) Explain, with reference to T_B and T_F, which person concludes that the light reached both mirrors simultaneously. [2]

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(d) State the length of the train for the observer on the ground. [1]

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Question 2 - working space

8. A muon of proper lifetime t is produced in the high atmosphere and travels towards Earth at a relativistic speed v. What is the distance travelled by the muon in the reference frame of Earth?

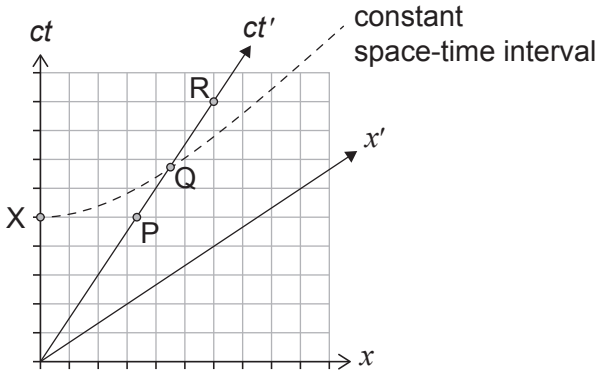
A. vt

B. $vt\left(1-\frac{v^2}{c^2}\right)$

C. $vt\sqrt{1-\frac{v^2}{c^2}}$

D. $\frac{vt}{\sqrt{1-\frac{v^2}{c^2}}}$

9. The space–time diagram shows coordinate axes of inertial reference frames S(x, ct) and S′(x', ct'). Event X occurs at $t = 1\,\text{s}$ according to the S reference frame. A line of constant space–time interval is drawn through X.

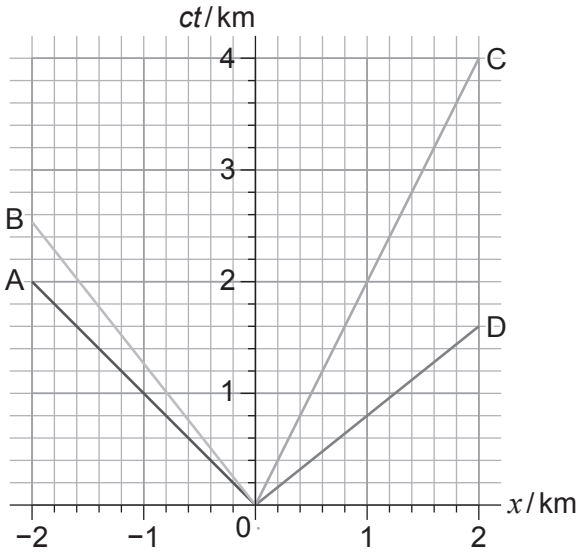


In the S′ reference frame, which event is simultaneous with X and which event has the time coordinate $t' = 1\,\text{s}$?

	Simultaneous with X in the S′frame	**$t' = 1\,\text{s}$ in the S′frame**
A.	P	R
B.	Q	R
C.	R	P
D.	R	Q

8. Rocket R travels away from an observer on Earth at a speed of 0.80*c*. A space–time diagram shows four world lines.

What is the correct world line of R in the reference frame of Earth?



9. The fixed distance between Earth and a star measured in Earth's reference frame is d_E. A spaceship travels from Earth to the star at a constant speed of $0.8c$ relative to Earth. The distance between Earth and the star as measured by the spaceship is d_s.

What is $\frac{d_s}{d_E}$?

A. $\frac{3}{5}$

B. $\frac{4}{5}$

C. $\frac{5}{4}$

D. $\frac{5}{3}$

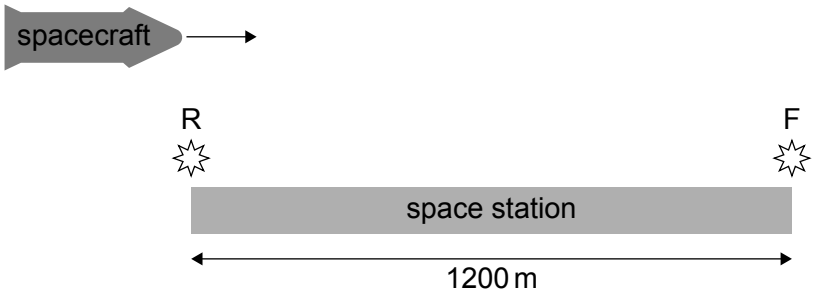
9. A spacecraft, moving with speed v relative to Earth, passes Earth on its way to a planet. As the spacecraft passes Earth, clocks on Earth and in the spacecraft show zero.

The planet is a distance D from Earth, according to an observer on Earth.

What are the readings on the Earth clock and on the spacecraft clock when the spacecraft arrives at the planet?

	Earth clock reading	Spacecraft clock reading
A.	$\frac{D}{v}$	$\frac{D}{v}\sqrt{1-\frac{v^2}{c^2}}$
B.	$\frac{D}{v}$	$\frac{D}{v\sqrt{1-\frac{v^2}{c^2}}}$
C.	$\frac{D}{v\sqrt{1-\frac{v^2}{c^2}}}$	$\frac{D}{v}$
D.	$\frac{D}{v}\sqrt{1-\frac{v^2}{c^2}}$	$\frac{D}{v}$

2. A spacecraft is flying past a space station at a relative speed of 0.80*c*. Beacons, R and F, at each end of the space station emit light pulses at the same time according to observers on the space station. The pulses are emitted 1200 m apart as measured by space station observers.



(a) Calculate γ for a speed of 0.80*c*. [1]

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(b) Calculate, for the reference frame of the spacecraft,

(i) the distance between the light pulses. [1]

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(ii) the time between the light pulses. [2]

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(c) Determine which light pulse happened first. [2]

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Question 2 - working space

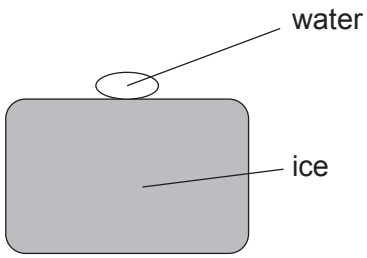
APOLLO

Thermal energy transfers

11 questions

10. A block of ice of mass M is at its melting point.

A smaller mass m of water at a temperature of T°C is placed on the top surface of the ice and remains there.



The specific latent heat of fusion of ice is L and the specific heat capacity of water is c.

What mass of ice melts?

A. $\frac{mcT}{L}$

B. $\frac{mLT}{c}$

C. $\frac{McT}{L}$

D. $\frac{MLT}{c}$

9. X and Y are two spherical black-body radiators. X has a radius R and emits half the total power of Y. The absolute temperature of X is double that of Y.

What is the radius of Y?

A. $2\sqrt{2}R$

B. $4R$

C. $4\sqrt{2}R$

D. $16R$

10. A liquid is heated at a constant rate in an open container. The temperature of the liquid rises by 0.50 °C per second until it boils. In a period of 10 minutes after reaching boiling point, half the mass of the liquid has vaporized.

What is $\frac{\text{specific heat capacity of the liquid}}{\text{specific latent heat of vaporization of the liquid}}$?

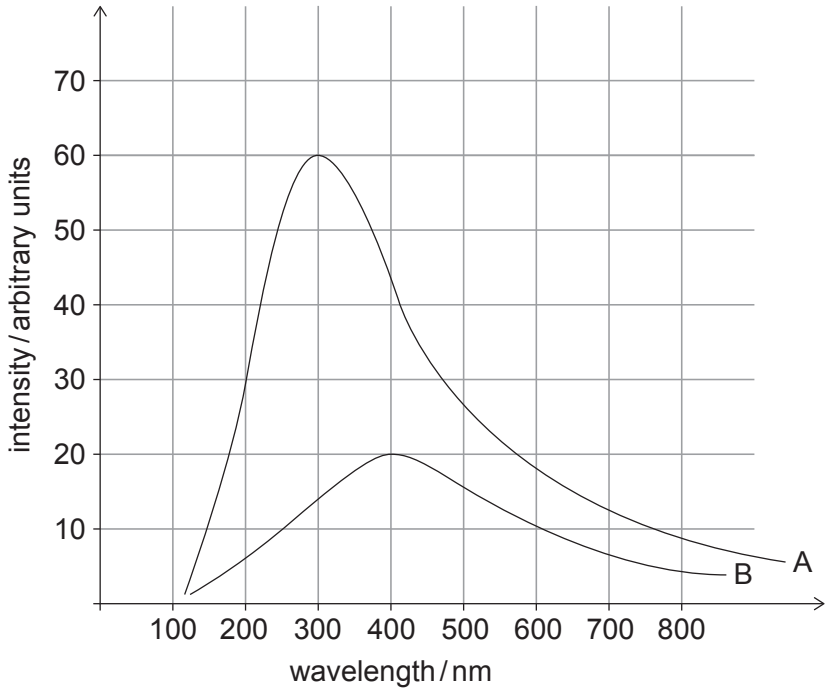
A. $\frac{1}{600}$

B. $\frac{1}{300}$

C. $\frac{1}{10}$

D. $\frac{1}{5}$

12. The black-body radiation curves for two objects A and B are shown.



What is $\frac{\text{temperature of A}}{\text{temperature of B}}$?

A. $\frac{1}{3}$

B. $\frac{3}{4}$

C. $\frac{4}{3}$

D. 3

2. (a) Describe the mechanism of heat transfer by conduction. [2]

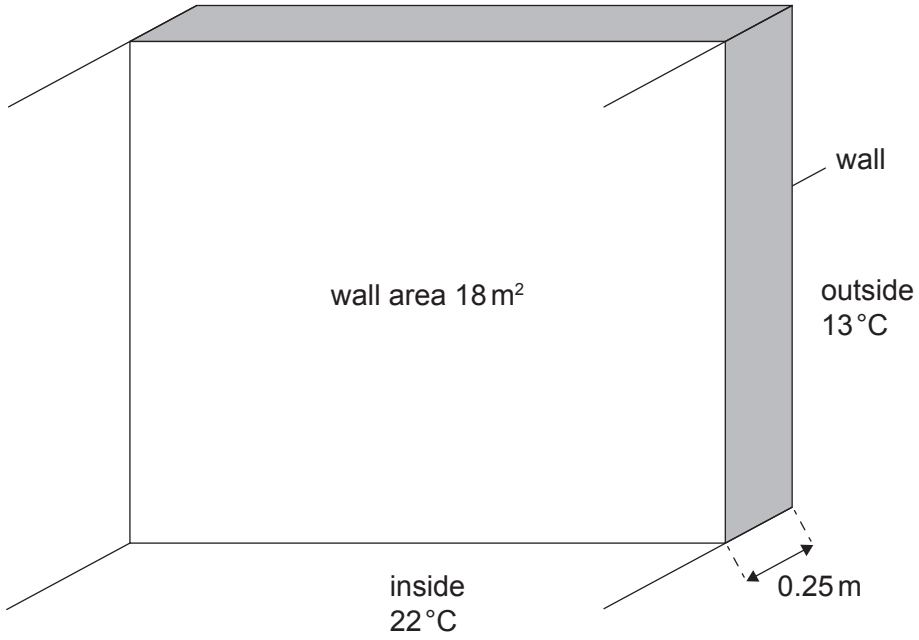
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The diagram shows a wall separating the inside of a room from the outside. The temperature of the room is kept constant by a heater.



The following data are available:

Thickness of wall = 0.25 m
Area of wall = 18 m²
Thermal conductivity of wall = 1.3 W m⁻¹ K⁻¹
Constant room temperature = 22 °C
Constant outside temperature = 13 °C

(This question continues on the following page)

(Question 2 continued)

(b) Estimate the rate at which thermal energy leaves the room through the wall giving the answer with an appropriate unit. [2]

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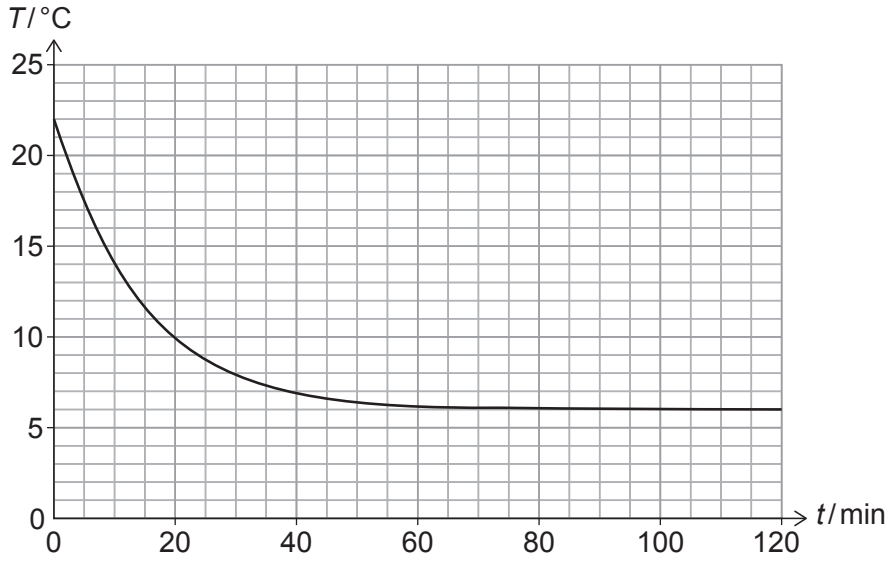
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(Question 2 continued)

(c) At night the outside temperature falls below 13 °C. The heater is turned off at time $t = 0$. The graph shows the variation with time t of the temperature T of the room.



(i) Outline why the magnitude of the gradient of the graph decreases. [1]

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(ii) The pressure and volume of the air in the room remain constant but the number of molecules has increased. Determine the percentage increase in the number of molecules of air in the room between $t = 0$ and $t = 120$ min. [3]

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(Question 2 continued)

(d) Discuss how the second law of thermodynamics applies to the situation of the room cooling down. [2]

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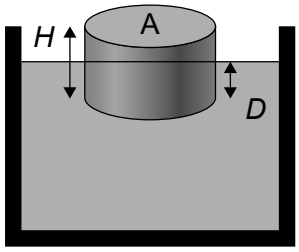
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Question 2 - working space

7. A cylindrical cork of height *H* and cross-sectional area A is floating stationary in water. Its depth below the water surface is *D*.

diagram not to scale



(a) (i) Draw and label the forces acting on the cork. [1]

(ii) Show that

$$\frac{D}{H}=\frac{\rho_{\mathrm{c}}}{\rho_{\mathrm{w}}}$$

where ρ_{c} is the density of the cork and ρ_{w} is the density of water. [2]

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(Question 7 continued)

The cork is displaced downward by a force. It is then released and it oscillates.

(b) Outline why the cork undergoes simple harmonic motion. [2]

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(Question 7 continued)

(c) (i) Explain why the density of most substances in a solid state is larger than its density in a liquid state. [2]

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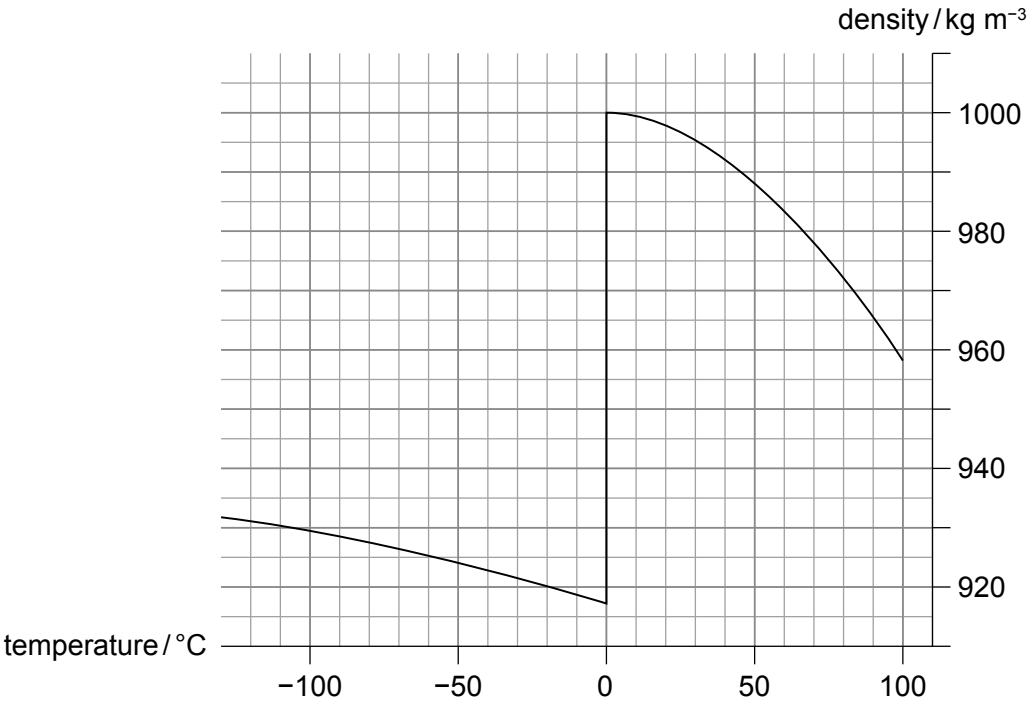
Water shows an anomaly with respect to what is stated in (c)(i).

Graph 1 shows the variation with temperature of the density of water between −100 °C and 100 °C. **Graph 2** shows the same graph enlarged for the range 0 to 10 °C.

(ii) Identify the temperature at which water has its maximum density. [1]

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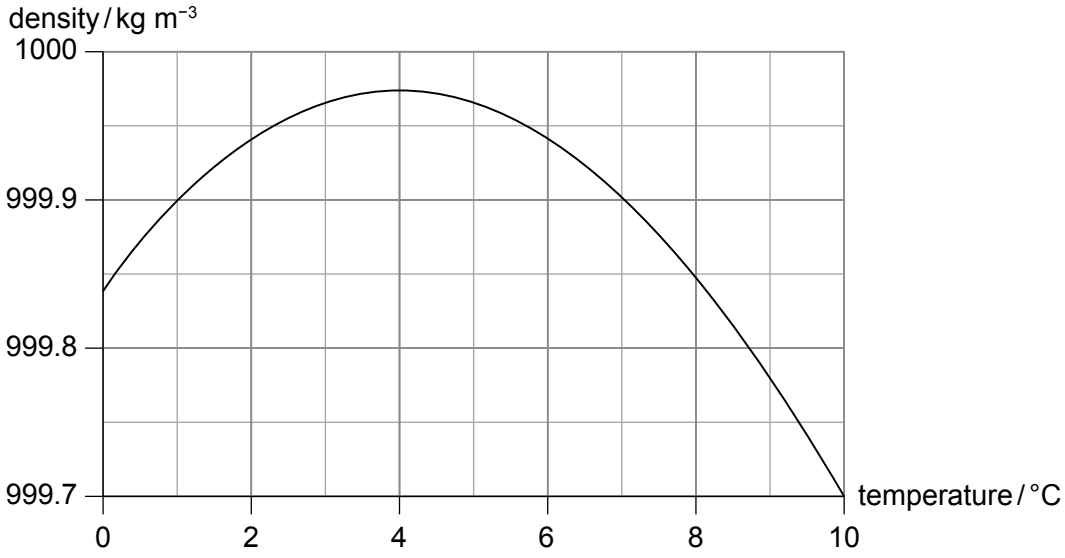
Graph 1



(This question continues on the following page)

(Question 7 continued)

Graph 2



(This question continues on page 23)

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Answers written on this page
will not be marked.

(Question 7 continued)

(d) An icebreaking ship is designed to withstand a collision with an iceberg, a large partially submerged body of ice freely floating in water. The designers model the shape of the iceberg as a cylinder with an approximate cross-sectional area of $4200\,\text{m}^2$ and height above sea level of $32\,\text{m}$.

The following data are available:

$$\rho_{\text{ice}} = 920\,\text{kg m}^{-3}$$
$$\rho_{\text{seawater}} = 1030\,\text{kg m}^{-3}$$

(i) Show that the mass of the iceberg is about $1.2 \times 10^9\,\text{kg}$. [2]

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The designers assume that the mass of the ship is about $\frac{1}{40}$ the mass of the iceberg and is moving at $12\,\text{m s}^{-1}$ when it collides with the iceberg. They stick together after the collision.

(ii) Calculate the speed of the ship after the collision. [2]

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(Question 7 continued)

Ice in a still lake will usually form in a single layer on the surface.

(e) On a winter day, the surface of a lake is frozen. The temperature of the air above the lake is –6.0 °C. The layer of ice frozen on the surface of the lake has a thickness of 1.9 cm.

(i) The thermal conductivity of ice is $2.3\,\text{W m}^{-1}\,\text{K}^{-1}$. Calculate the rate per unit area at which thermal energy leaves the lake by conduction through the ice layer. [2]

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(ii) The depth of water below the ice is 22 m and its average initial temperature is 2.0 °C. Estimate the minimum thermal energy per unit area that must be removed to freeze all the water in the lake. [3]

The following data are available:

$$\text{Specific heat capacity of water} = 4.2 \times 10^3\,\text{J kg}^{-1}\,\text{K}^{-1}$$
$$\text{Latent heat of fusion of water} = 3.3 \times 10^5\,\text{J kg}^{-1}$$
$$\rho_{\text{water}} = 1000\,\text{kg m}^{-3}$$

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(Question 7 continued)

Layers of ice on lakes do not grow thicker than a small percentage of the lake's depth even when the exterior temperature remains constant below the freezing point for some time.

(iii) Explain how the rate calculated in (e)(i) changes as the layer of ice grows thicker. [1]

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(iv) Discuss why the anomaly in the value of the density of water supports life in water on Earth. [2]

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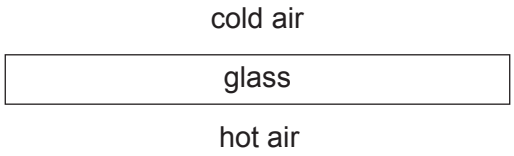
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Question 7 - working space

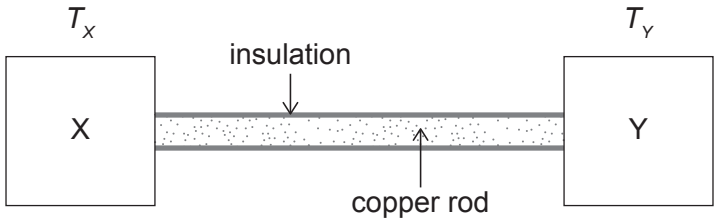
10. A layer of glass separates cold air from hot air. The temperature gradient across the glass is H, and the rate of thermal energy transfer through a unit surface area of the glass is P.



The thickness of the glass layer is doubled. What are the temperature gradient and the rate of thermal energy transfer through the glass after this change?

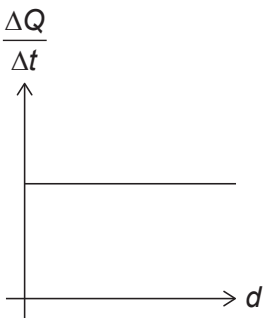
	Temperature gradient	Rate of thermal energy transfer
A.	$2H$	$2P$
B.	$2H$	$\frac{P}{2}$
C.	$\frac{H}{2}$	$2P$
D.	$\frac{H}{2}$	$\frac{P}{2}$

10. Insulated solid copper rods of different diameters and fixed length are placed in thermal contact with two objects X and Y, maintained at different temperatures T_X and T_Y respectively. The diagram shows the setup with one such rod.

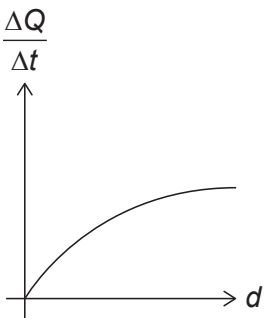


Which graph shows the variation with rod diameter d of the rate of thermal energy transfer $\frac{\Delta Q}{\Delta t}$ along the rod?

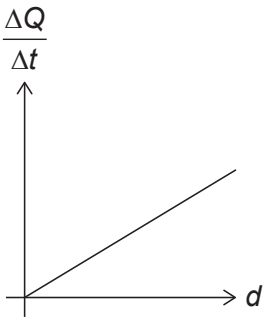
A.



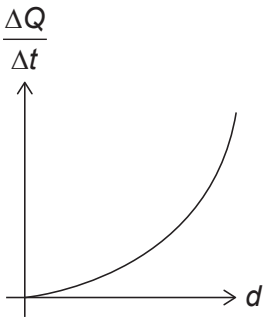
B.



C.



D.



11. 80 g of a liquid are heated with a constant power output of 100 W. All the power goes into the liquid. After 60 s, the rise in temperature is 50 K.

What is the specific heat capacity of the liquid in $J\,kg^{-1}\,K^{-1}$?

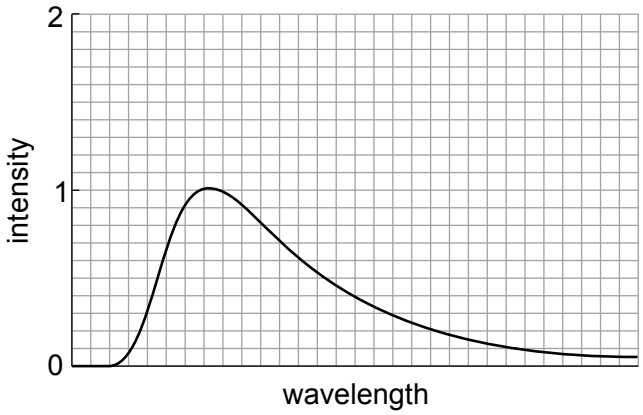
A. 120

B. 960

C. 1200

D. 1500

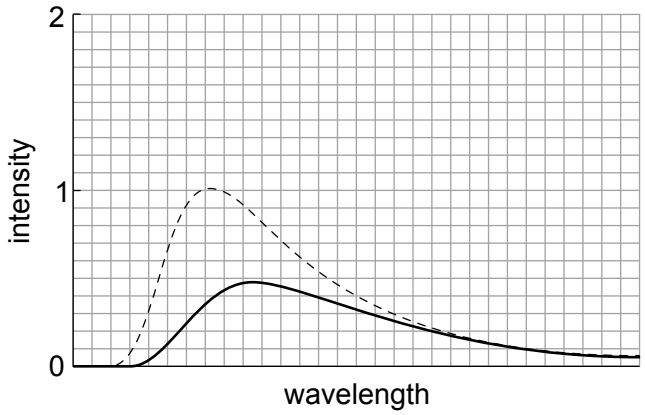
13. The black-body radiation curve of an object at 600 K is shown. The intensity units are arbitrary.



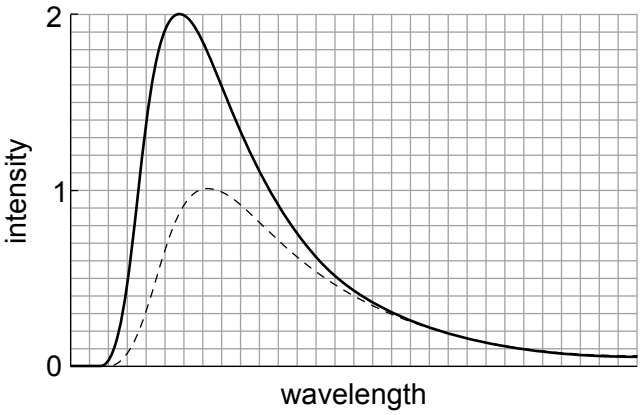
What is the radiation curve of the same object at 450 K?

The original curve is shown with a dashed line.

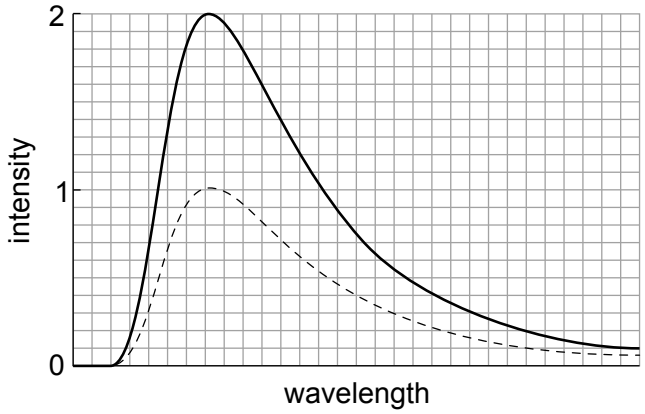
A.



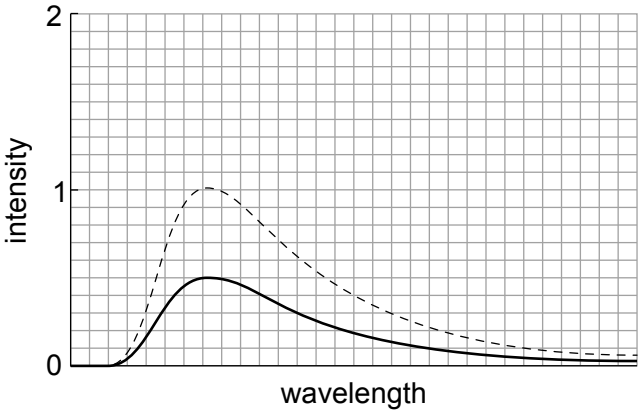
B.



C.



D.



8. Small pieces of solid paraffin with a total mass of 30 g at a temperature of 42 °C are mixed with 150 g of liquid paraffin at a temperature of 240 °C. The mixture is stirred until an equilibrium temperature is reached.

The following data for paraffin are available:

Specific heat capacity of solid paraffin $= 0.7\,\text{kJ}\,\text{kg}^{-1}\,\text{K}^{-1}$
Specific heat capacity of liquid paraffin $= 2.13\,\text{kJ}\,\text{kg}^{-1}\,\text{K}^{-1}$
Specific latent heat of fusion of paraffin $= 220\,\text{kJ}\,\text{kg}^{-1}$
Melting point of paraffin $= 47\,°\text{C}$

(a) Calculate the theoretical equilibrium temperature of the mixture. [3]

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(b) (i) When the experiment was carried out, the equilibrium temperature of the mixture was found to be different from the theoretical value.

Suggest the reason for this difference. [2]

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(ii) The mixture was held in a large metal container during the mixing.

Explain **one** change to the procedure that will reduce the difference in (b)(i). [1]

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Question 8 - working space

APOLLO

Greenhouse effect

6 questions

11. What is a primary cause of the enhanced greenhouse effect?

A. Melting of ice at Earth’s poles

B. Increases in volcanic activity

C. Deforestation of rainforests

D. Burning of fossil fuels

10. The albedo of the atmosphere above a small region on the Earth's surface is 0.25. The solar constant is S.

What is the incoming intensity of solar radiation incident on this region when the Sun is directly overhead?

A. $\frac{3S}{16}$

B. $\frac{S}{4}$

C. $\frac{3S}{4}$

D. S

13. The albedo of a planet with no atmosphere is 0.25. The reflected intensity is $240\,\mathrm{W\,m^{-2}}$.

What is the outgoing radiated intensity?

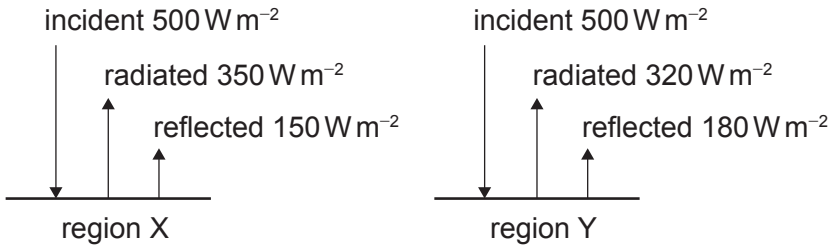
A. $180\,\mathrm{W\,m^{-2}}$

B. $300\,\mathrm{W\,m^{-2}}$

C. $720\,\mathrm{W\,m^{-2}}$

D. $960\,\mathrm{W\,m^{-2}}$

11. The diagram shows the incident, radiated and reflected intensities of the solar radiation for two regions X and Y on the surface of Earth. X and Y have the same surface temperature.



Which region has a greater albedo, and which region has a greater emissivity?

	Greater albedo	Greater emissivity
A.	X	X
B.	Y	X
C.	X	Y
D.	Y	Y

Turn over

12. Which process involving gas molecules in the Earth's atmosphere is the main cause of the greenhouse effect?

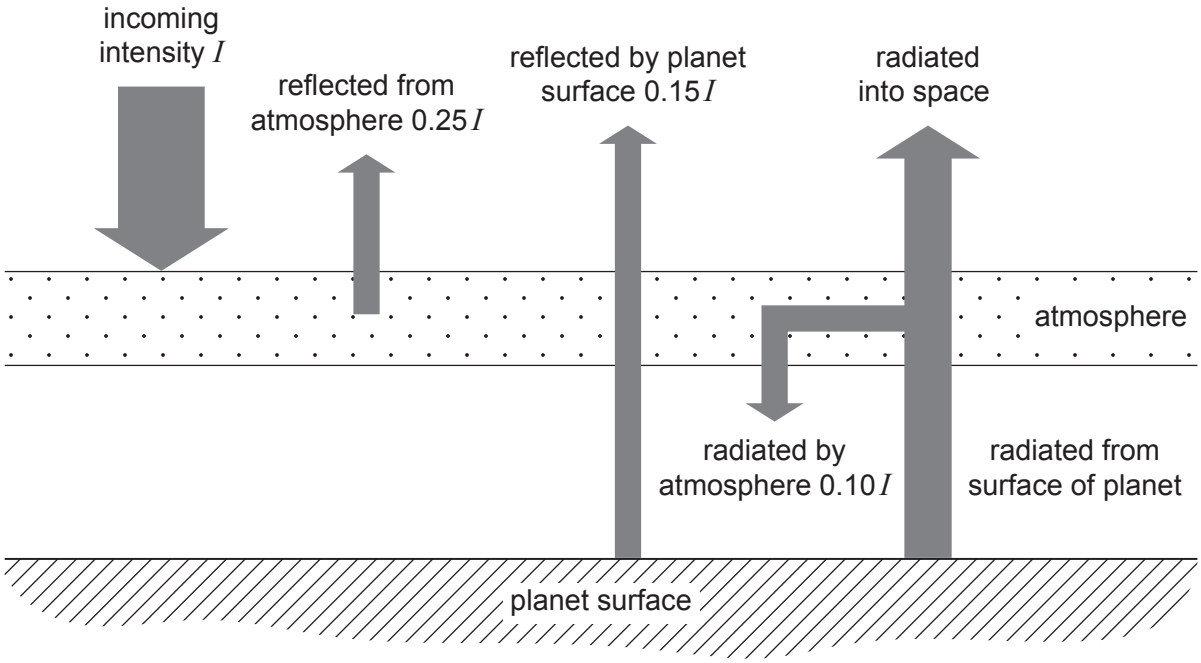
A. Reflection of incoming solar radiation

B. Absorption and re-radiation of incoming solar radiation

C. Reflection of outgoing infrared radiation

D. Absorption and re-radiation of outgoing infrared radiation

12. The energy balance model of a planet's climate is shown. The reflected and radiated intensities are given in terms of the incident incoming intensity I.



What is the radiated intensity from the surface of the planet?

A. $0.40\,I$

B. $0.50\,I$

C. $0.70\,I$

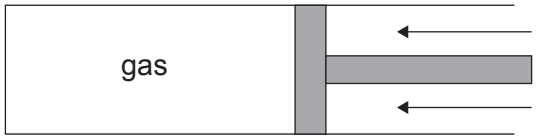
D. $1.10\,I$

APOLLO

Gas laws

6 questions

12. An ideal gas is held in a cylinder by a piston. The piston compresses the gas rapidly.



The average speed of the gas molecules increases because the gas molecules...

A. have a smaller volume available in which they can move.

B. receive thermal energy transferred from outside the cylinder.

C. receive energy from the piston as they collide with it.

D. make more collisions every second with each other.

11. A gas is held in a container. An identical container holds the same number of more massive molecules of another gas at the same temperature.

What is true about the density and pressure in both containers?

	Density in both containers	Pressure in both containers
A.	same	same
B.	same	different
C.	different	same
D.	different	different

31. Gases in the atmosphere are compounds of ${}^{12}_{6}C$, ${}^{1}_{1}H$, ${}^{16}_{8}O$ and ${}^{14}_{7}N$.

Four of these gases are CO_2, N_2O, CH_4 and H_2O. A pure sample of each gas is produced. Each sample has the same volume, pressure, and temperature.

Which sample has the smallest mass?

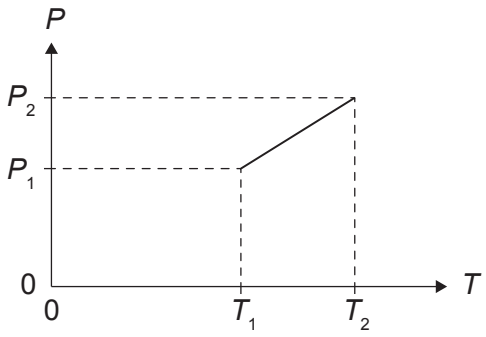
A. CH_4

B. N_2O

C. CO_2

D. H_2O

13. A sample of n moles of an ideal gas is kept at a constant volume. The graph shows how the pressure P of the gas varies with absolute temperature T.



What is the volume of the gas?

A. $nR\dfrac{T_2 - T_1}{P_2 - P_1}$

B. $nR\dfrac{P_2 - P_1}{T_2 - T_1}$

C. $nR\left(\dfrac{T_2}{P_2} - \dfrac{T_1}{P_1}\right)$

D. $nR\left(\dfrac{P_2}{T_2} - \dfrac{P_1}{T_1}\right)$

13. A rigid vessel of volume V contains N molecules of an ideal monatomic gas. The average kinetic energy of the molecules is E_k. What is the pressure in the vessel?

A. $\frac{2N}{3VE_k}$

B. $\frac{2NE_k}{3V}$

C. $\frac{3N}{2VE_k}$

D. $\frac{3NE_k}{2V}$

17. Two containers, X and Y, are filled with an ideal gas at the same pressure.

The volume of X is four times the volume of Y. The temperature of X is 327 °C and the temperature of Y is 27 °C.

What is $\frac{\text{amount of substance in X}}{\text{amount of substance in Y}}$?

A. $\frac{1}{8}$

B. $\frac{1}{2}$

C. 2

D. 8

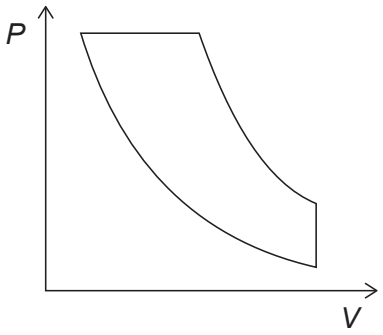
APOLLO

Thermodynamics

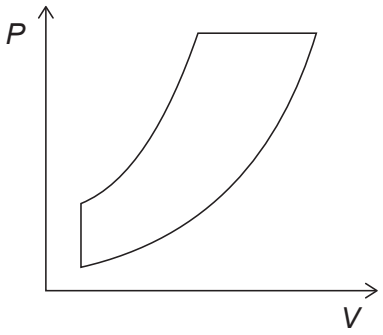
15 questions

13. Which pressure–volume (P–V) diagram represents a Carnot cycle?

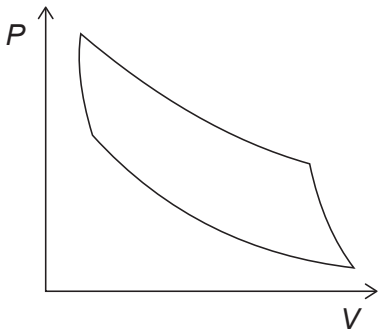
A.



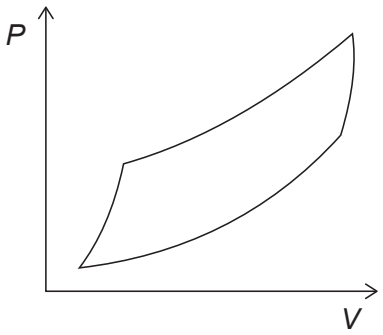
B.



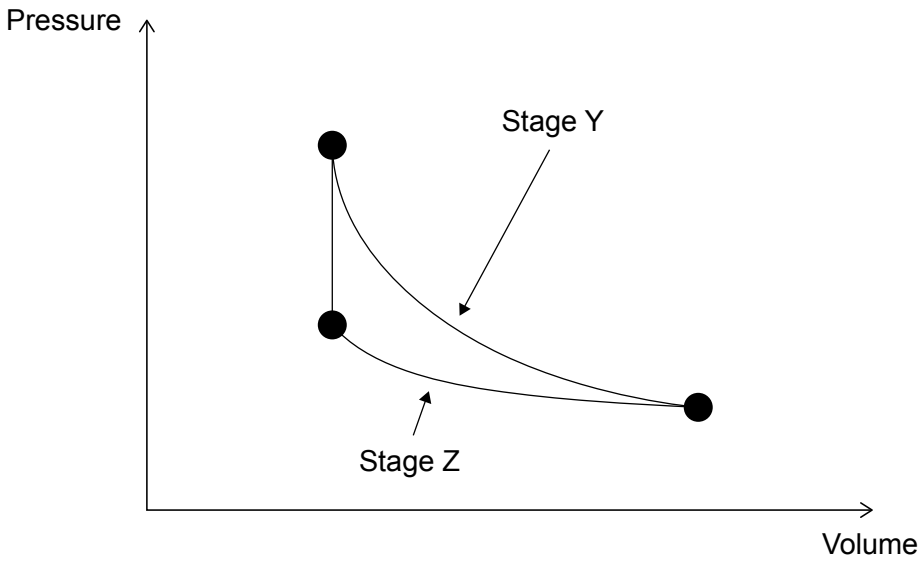
C.



D.



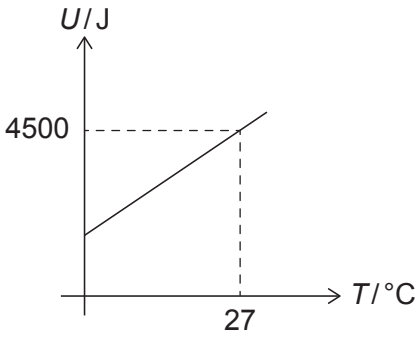
12. A cyclic process for an ideal gas is shown. The cycle has three stages: isovolumetric, adiabatic, and isothermal. Work is done on the gas during the isothermal stage.



Which stage is isothermal and what is the direction of the cyclic process?

	Stage	Direction
A.	Y	Anti-clockwise
B.	Z	Anti-clockwise
C.	Y	Clockwise
D.	Z	Clockwise

14. The graph shows the variation of the internal energy U with temperature T for a sample of an ideal monatomic gas. R is the gas constant.



How many moles of the gas are in the sample?

A. $\frac{500}{3R}$

B. $\frac{15}{R}$

C. $\frac{1000}{9R}$

D. $\frac{10}{R}$

15. 75 J of thermal energy is transferred to an ideal monatomic gas at a constant pressure of 1.0×10^5 Pa. The volume of the gas increases from 2.7×10^{-3} m^3 to 3.0×10^{-3} m^3.

What is the change in the internal energy of the gas?

A. 45 J

B. 105 J

C. −45 J

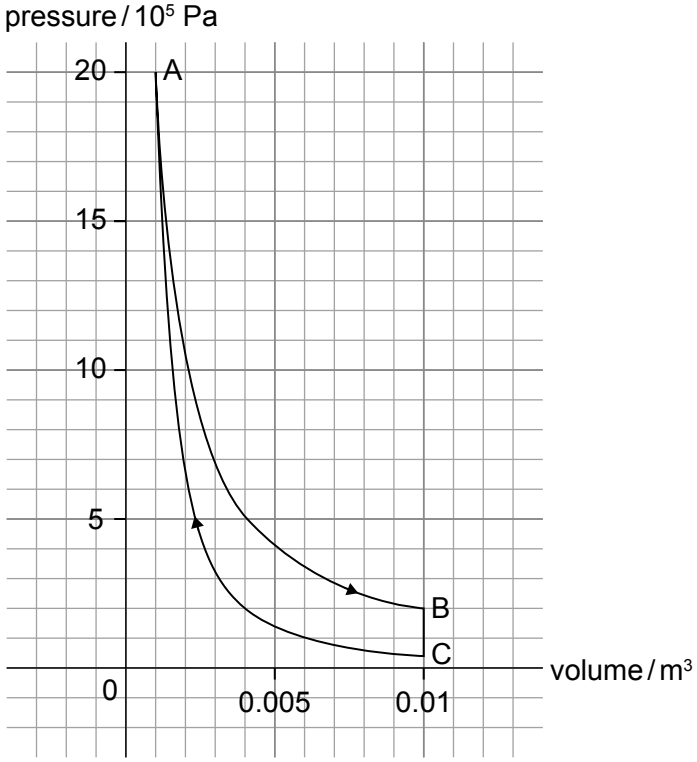
D. −105 J

16. A gas is compressed at constant temperature.

What are the changes in entropy of the gas and its surroundings during the compression?

	Entropy of the gas	Entropy of surroundings
A.	Increases	Increases
B.	Increases	Decreases
C.	Decreases	Increases
D.	Decreases	Decreases

3. The pressure–volume diagram shows a 3-stage cyclic process of 0.20 moles of an ideal gas in a closed container. A–B is an isothermal process. C–A is an adiabatic process.



The following data are available:

$$\text{Pressure at A} = 2.0 \times 10^6\,\text{Pa}$$
$$\text{Volume at A} = 1.0 \times 10^{-3}\,\text{m}^3$$
$$\text{Pressure at B} = 2.0 \times 10^5\,\text{Pa}$$
$$\text{Volume at B} = 1.0 \times 10^{-2}\,\text{m}^3$$

(a) Show that the temperature at C is about 260 K. [2]

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(Question 3 continued)

(b) Determine the work done by the gas in C–A. [2]

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(c) Outline why this cycle can be used for a heat engine. [1]

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Question 3 - working space

14. Two containers are filled with monatomic gas of equal mass at the same temperature. One container holds helium and the other neon.

The mass of a neon atom is five times the mass of a helium atom.

What is $\frac{\text{internal energy of the helium gas}}{\text{internal energy of the neon gas}}$?

A. $\frac{1}{5}$

B. 1

C. $\sqrt{5}$

D. 5

15. A thermal energy of 7.0 J is removed from an ideal gas, and a work of 2.0 J is done by the gas. What is the change in the internal energy of the gas?

A. −9.0 J

B. −5.0 J

C. +5.0 J

D. +9.0 J

14. A substance changes from a liquid into a solid without a change in temperature.

What is true about the internal energy of the substance and the total intermolecular potential energy of the substance when this phase change occurs?

	Internal energy of the substance	Total intermolecular potential energy of the substance
A.	decrease	decrease
B.	no change	decrease
C.	decrease	no change
D.	no change	no change

15. The entropy of a system is S, and the number of possible microstates is Ω. What is the number of possible microstates for a system of entropy $\frac{S}{2}$?

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

B. $\frac{\sqrt{\Omega}}{2}$

C. $\sqrt{\Omega}$

D. Ω^2

16. The Carnot efficiency of a heat engine is 0.4 when the cold reservoir temperature is T_c. The hot reservoir is held at a constant temperature. What is the Carnot efficiency when the cold reservoir temperature is $\frac{T_c}{2}$?

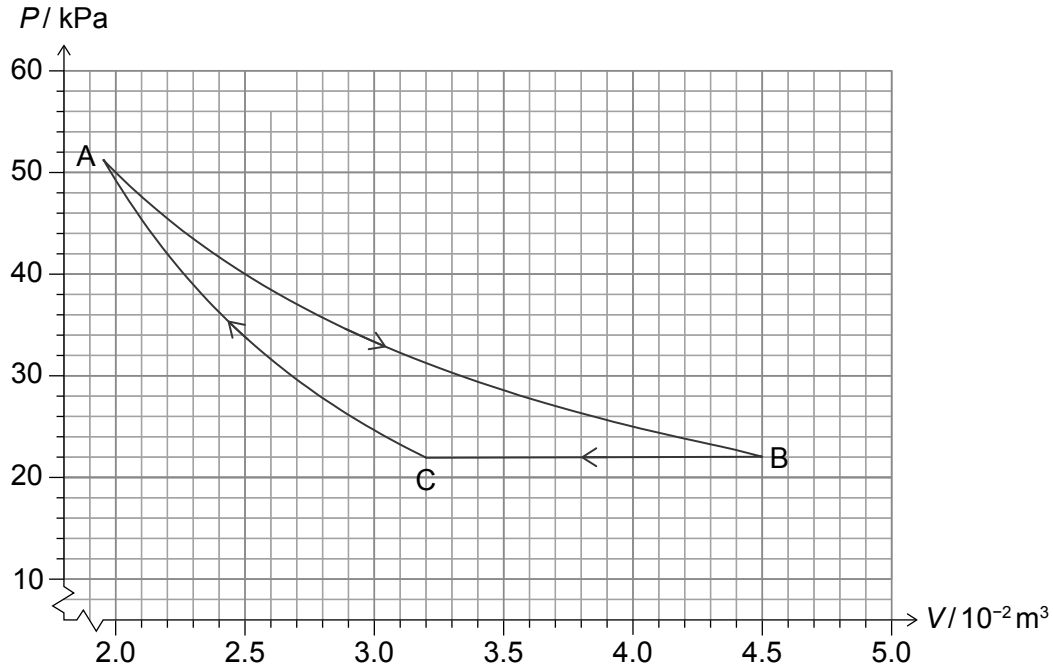
A. 0.2

B. 0.3

C. 0.7

D. 0.8

5. The graph shows the cycle of a heat engine operating with an ideal monatomic gas. It consists of three stages: an isothermal A → B, an isobaric B → C and an adiabatic C → A. The temperature at A is 560 K.



(a) Show that the thermal energy transferred from the gas along B → C is about 700 J. [3]

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. . . . . .

(b) The work done along A → B is 840 J. Calculate the efficiency of the engine. [3]

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Question 5 - working space

10. The internal energy of a real gas is

A. zero.

B. equal to the intermolecular potential energy of the particles.

C. equal to the total kinetic energy of the particles.

D. equal to the sum of the intermolecular potential energy and the total kinetic energy of the particles.

11. A gas undergoes one cycle of a cyclic process.

The net change in internal energy of the gas is

A. zero.

B. positive.

C. negative.

D. determined by the initial temperature of the gas.

12. A working refrigerator with the door open is placed in a sealed room.

The entropy of the room

A. is zero.

B. decreases.

C. remains unchanged.

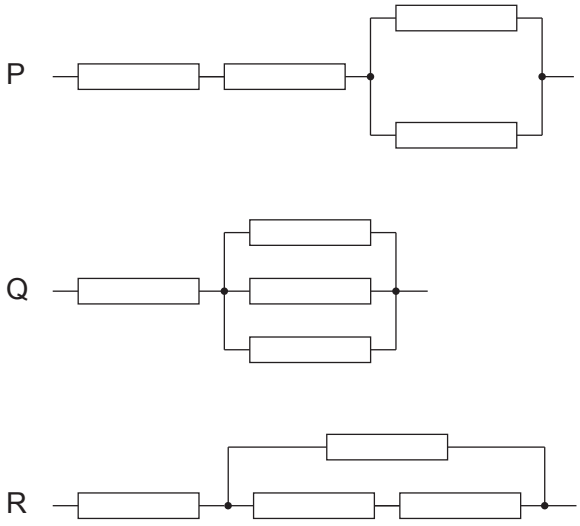
D. increases.

APOLLO

Current and circuits

11 questions

14. Three combinations of resistors are shown. The resistors are identical.



What is the total resistance of each combination of resistors in order of **increasing** resistance?

A. P Q R

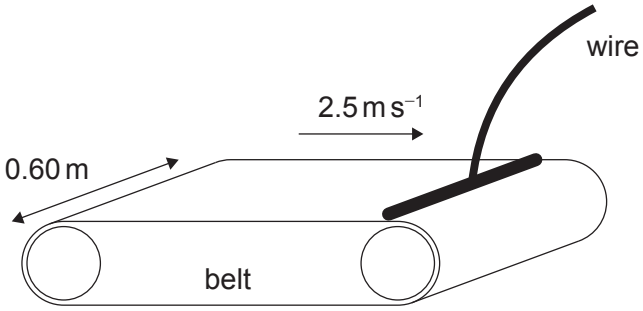
B. Q P R

C. P R Q

D. Q R P

15. A continuous belt of width 0.60 m travels at a constant speed of 2.5 m s^{-1}. The belt has a uniform distribution of charge of 5.0 mC m^{-2} on its surface.

As the belt passes a point all the charge is removed and is carried as a current in a wire.



What is the current in the wire?

A. 1.2 mA

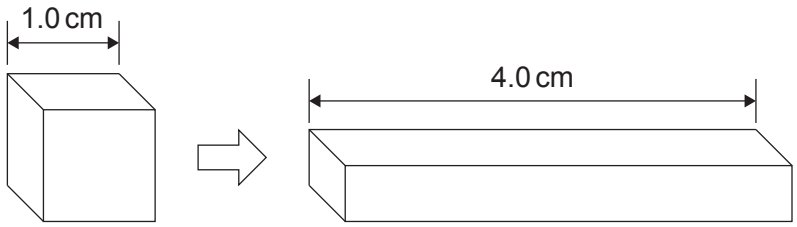
B. 7.5 mA

C. 19 mA

D. 21 mA

16. A cube of side 1.0 cm has a resistance between opposite sides of 50 Ω.

The material is reshaped into a block of length 4.0 cm and constant square cross-section.



What is the resistance of the block between its square ends?

A. 3.1 Ω

B. 50 Ω

C. 800 Ω

D. 3200 Ω

13. A wire of length L is used in an electric heater. When the potential difference across the wire is 200 V, the power transferred in the wire is 500 W. A second wire is made from the same metal and has the same cross-sectional area. When a potential difference of 400 V is applied across the second wire, the power transferred is 2000 W.

What is the length of the second wire?

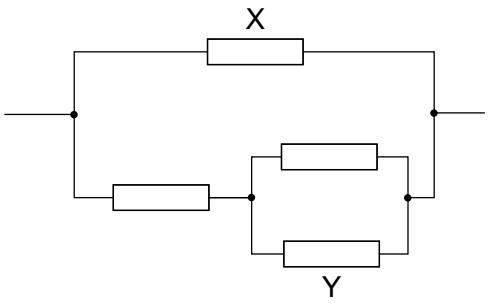
A. $\frac{L}{4}$

B. $\frac{L}{2}$

C. L

D. $2L$

14. Four identical resistors are connected as shown.



What is $\frac{\text{current in X}}{\text{current in Y}}$?

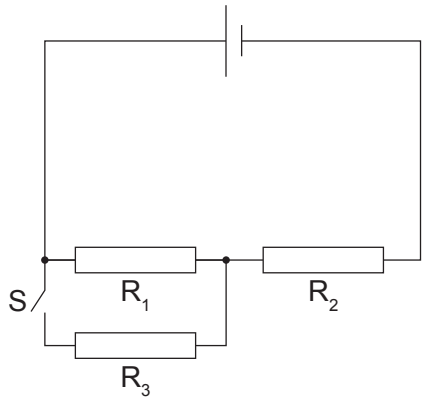
A. $\frac{1}{2}$

B. $\frac{2}{3}$

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

D. 3

17. Three identical resistors, R_1, R_2 and R_3, each of resistance $2\,\Omega$, are connected to a cell of negligible internal resistance as shown. When switch S is open, the power dissipated by R_1 is 18 W.



What is the power dissipated by R_1 when S is closed?

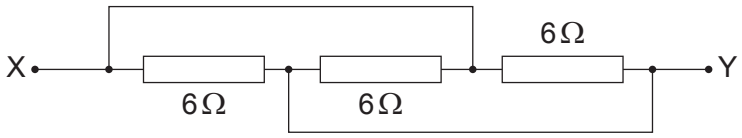
A. 8 W

B. 16 W

C. 18 W

D. 36 W

18. Three identical resistors of $6\,\Omega$ are arranged as shown.



What is the resistance between X and Y?

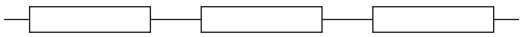
A. $2\,\Omega$

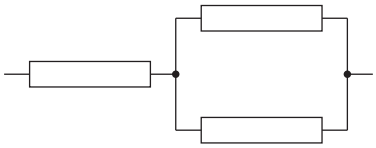
B. $4\,\Omega$

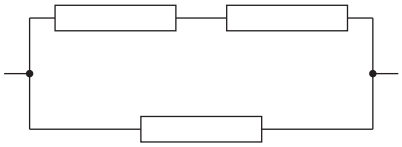
C. $9\,\Omega$

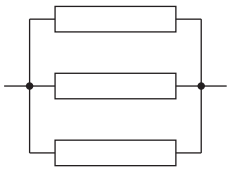
D. $18\,\Omega$

16. Three identical resistors are arranged in four different networks. The same potential difference is applied across each network. Which network dissipates the greatest electrical power?

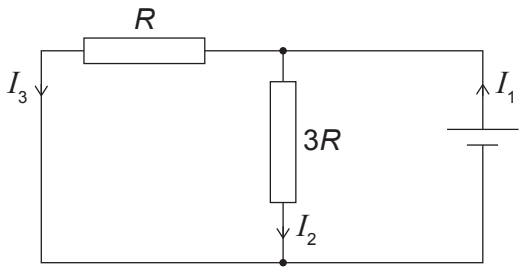
A. 

B. 

C. 

D. 

17. In the circuit shown, the cell has negligible internal resistance.



Which equation is correct?

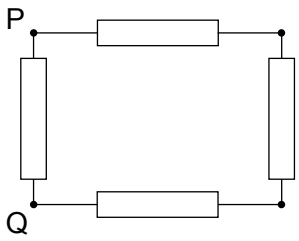
A. $I_1 = 4(I_2 + I_3)$

B. $I_1 = 4I_2$

C. $I_3 = 4I_2$

D. $I_3 = \frac{4I_1}{3}$

15. Four identical resistors, each of resistance R, are connected as shown.



What is the effective resistance between P and Q?

A. $\frac{3R}{4}$

B. R

C. $\frac{4R}{3}$

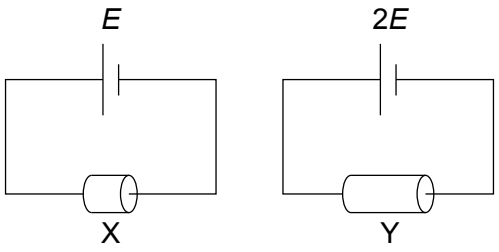
D. $4R$

16. Conductor X is connected to a cell of emf *E*. A power of 16 W is dissipated in X.

Conductor Y is made from the same material with the same diameter as X but is twice as long. A cell of emf 2*E* is connected to Y.

Both cells have negligible internal resistance.

What power is dissipated in Y?



A. 8.0 W

B. 16 W

C. 32 W

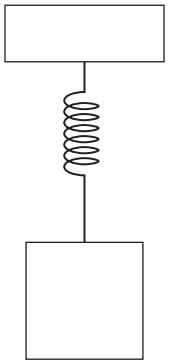
D. 64 W

APOLLO

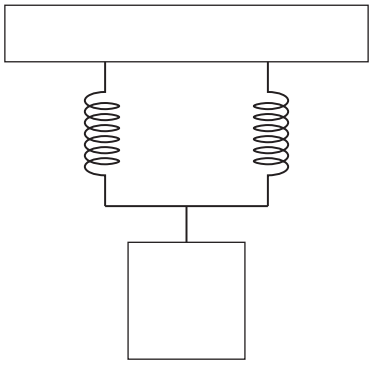
Simple harmonic motion

12 questions

17. A mass–spring system oscillates with time period T_1 .



Another identical spring is connected in parallel with the first spring as shown. The mass is unchanged.



The time period of the oscillation for the two-spring system is T_2.

What is $\frac{T_2}{T_1}$?

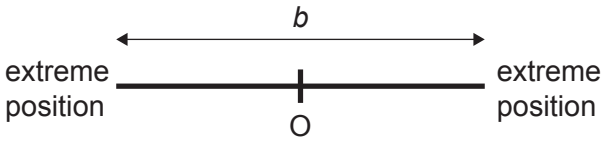
A. $\frac{1}{2}$

B. $\frac{1}{\sqrt{2}}$

C. $\sqrt{2}$

D. 2

19. An object performs simple harmonic motion with frequency f. The distance between the extreme positions at which the object is at rest is *b*.



What is the speed of the object when it is halfway between its equilibrium position O and its extreme position?

A. $\frac{1}{4}\pi f b$

B. $\frac{1}{2}\pi f b$

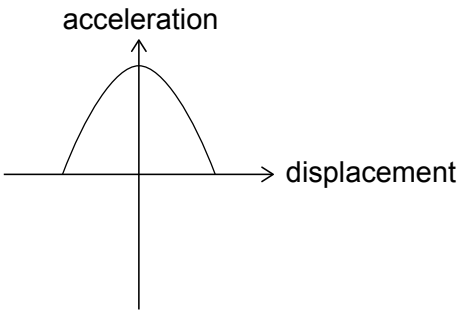
C. $\frac{\sqrt{3}}{4}\pi f b$

D. $\frac{\sqrt{3}}{2}\pi f b$

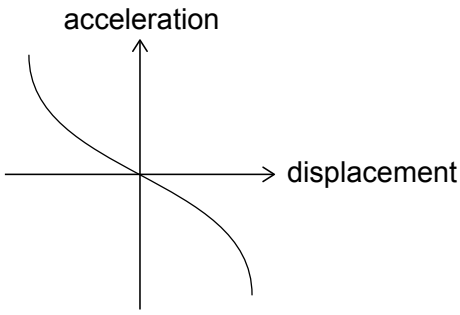
15. A mass–spring system is oscillating with simple harmonic motion.

Which graph represents the variation of acceleration with displacement?

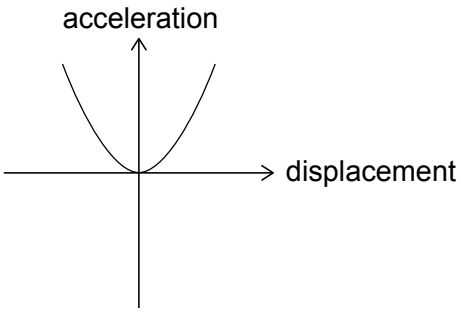
A.



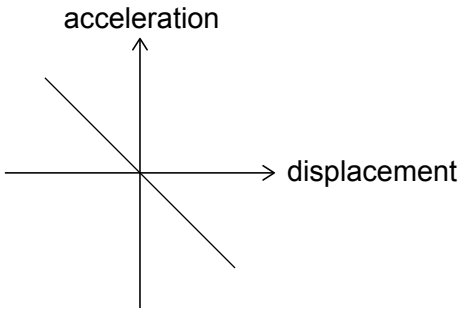
B.



C.



D.



16. A mass–spring system oscillates in simple harmonic motion with maximum elastic potential energy E. The mass is tripled and the amplitude is doubled.

What is the new maximum elastic potential energy of the system?

A. $\frac{4}{3}E$

B. $4E$

C. $6E$

D. $12E$

20. For a lightly damped oscillation…

A. the amplitude goes to zero within one period of oscillation.

B. the oscillation frequency does not change with time.

C. energy is transferred from the oscillation as quickly as possible.

D. the oscillation frequency equals the undamped oscillation frequency.

19. A simple pendulum oscillates with period T on Earth. The mass of the pendulum is doubled and oscillates on the Moon where the acceleration due to gravity is $\frac{1}{6}$ that of Earth. The length of the pendulum stays the same.

What is the period of the pendulum on the Moon?

A. $\sqrt{12}\,T$

B. $\sqrt{6}\,T$

C. $\sqrt{3}\,T$

D. $\sqrt{2}\,T$

20. A body of mass 2.0 kg undergoes simple harmonic motion with a maximum displacement of 0.5 m. The period of oscillation of the body is $\frac{\pi}{4}$ s.

What is the total energy of the body?

A. 2 J

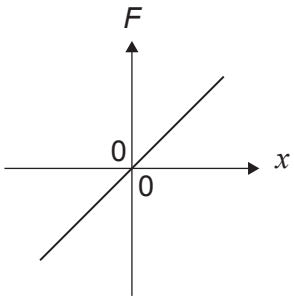
B. 8 J

C. 16 J

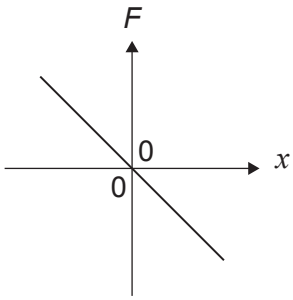
D. 32 J

17. A force *F* acts on a particle. The displacement of the particle is x. Which variation of *F* with x results in simple harmonic motion?

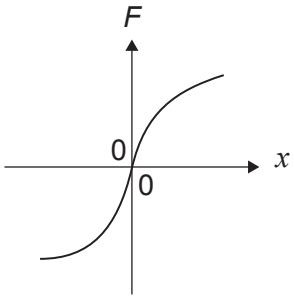
A.



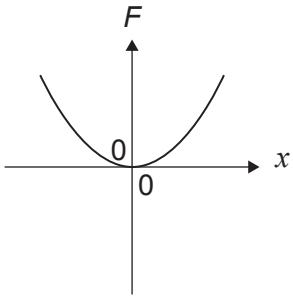
B.



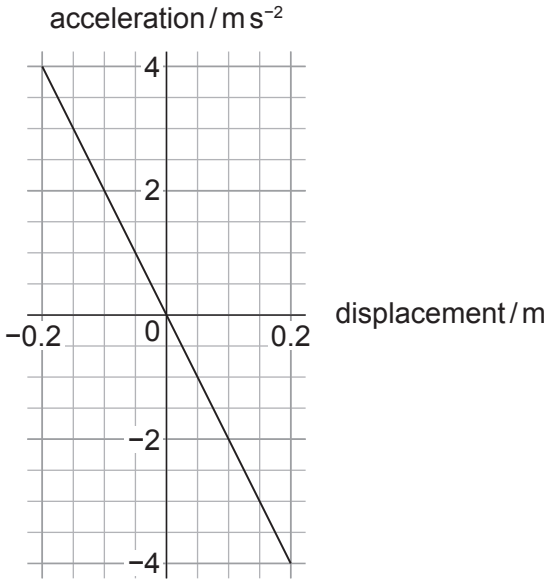
C.



D.



18. An object undergoes simple harmonic motion with frequency f. The graph shows the variation of its acceleration with displacement.



What is the value of f^2 in s^{-2}?

A. $\frac{5}{\pi^2}$

B. $\frac{5}{\pi}$

C. $\frac{100}{\pi^2}$

D. $\frac{100}{\pi}$

19. A mass oscillating vertically on a spring undergoes simple harmonic motion with amplitude X, total energy E and maximum speed v_{max}.

What is correct about the elastic potential energy E_H and speed v when the displacement is $\frac{X}{2}$?

A.	$E_H < \frac{E}{2}$	$v > \frac{v_{max}}{2}$
B.	$E_H < \frac{E}{2}$	$v < \frac{v_{max}}{2}$
C.	$E_H > \frac{E}{2}$	$v > \frac{v_{max}}{2}$
D.	$E_H > \frac{E}{2}$	$v < \frac{v_{max}}{2}$

19. A particle undergoes simple harmonic motion of period T. At time $t = 0$ the particle is at its equilibrium position.

What is t when the particle is at its greatest distance from the equilibrium position?

A. $\frac{T}{8}$

B. $\frac{T}{2}$

C. $\frac{3T}{4}$

D. T

21. A mass of 0.25 kg hangs from a spring of spring constant $4.0\,\text{N}\,\text{m}^{-1}$.

What is the natural frequency of oscillation for this system?

A. 0.50 Hz

B. 0.64 Hz

C. 1.6 Hz

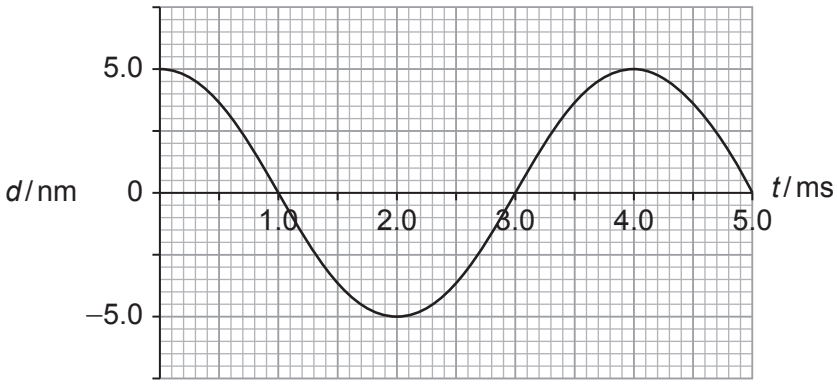
D. 2.0 Hz

APOLLO

Wave model

6 questions

18. A wave is travelling through a medium. The variation with time t of the displacement d of a particle in the medium is shown.

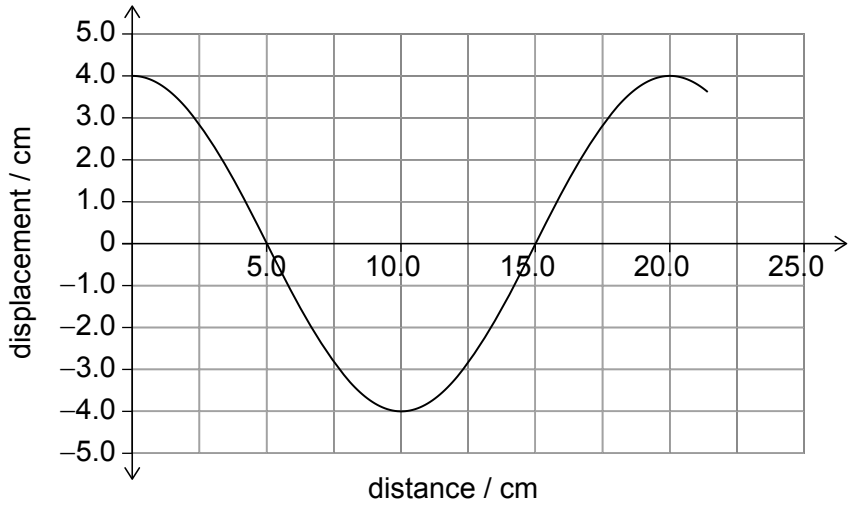


What is the frequency and the amplitude of the wave?

	Frequency / Hz	Amplitude / nm
A.	4.0×10^{-3}	5.0
B.	250	5.0
C.	4.0×10^{-3}	10.0
D.	250	10.0

Turn over

17. A transverse wave of period 20 ms travels through a medium. The graph shows the variation of particle displacement with distance for the wave.



What is the average speed of the particle motion and the direction of particle motion relative to the direction of the wave travel during one cycle?

	Average speed of particle / m s^{-1}	**Direction of particle motion**
A.	8	parallel
B.	8	perpendicular
C.	10	parallel
D.	10	perpendicular

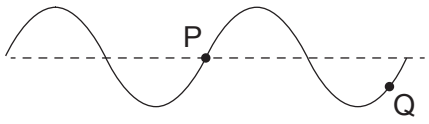
Turn over

18. An ultraviolet wave is travelling in a vacuum.

What is the frequency and the nature of the wave?

	Wave frequency / Hz	Nature of the wave
A.	10^{15}	transverse
B.	10^{15}	longitudinal
C.	10^{-7}	transverse
D.	10^{-7}	longitudinal

21. The diagram below shows a snapshot of a transverse wave on a rope. Points P and Q are two points on the rope at a position shown in the diagram. The subsequent motion of P is upwards.

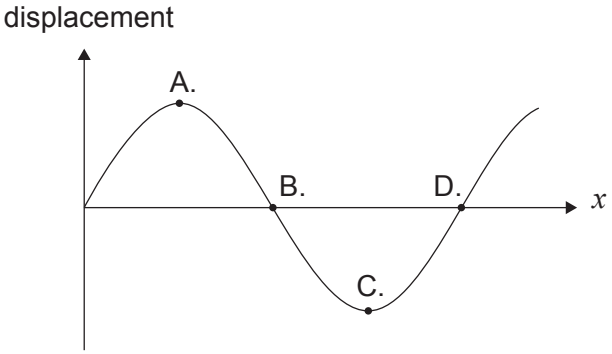


What is the direction of motion of Q and the direction of travel of the wave?

	Direction of motion of Q	Direction of travel of the wave
A.	Upwards	Left to right
B.	Downwards	Left to right
C.	Upwards	Right to left
D.	Downwards	Right to left

18. The graph shows how the displacement of a wave varies with the position x along the wave. The wave travels towards positive x.

At the instant shown, which point along the wave has the maximum positive velocity?



18. An electromagnetic wave has a wavelength that is about the size of the diameter of an atom.

What region of the electromagnetic spectrum does the wave belong to?

A. Infrared

B. Visible light

C. Ultraviolet

D. X-ray

APOLLO

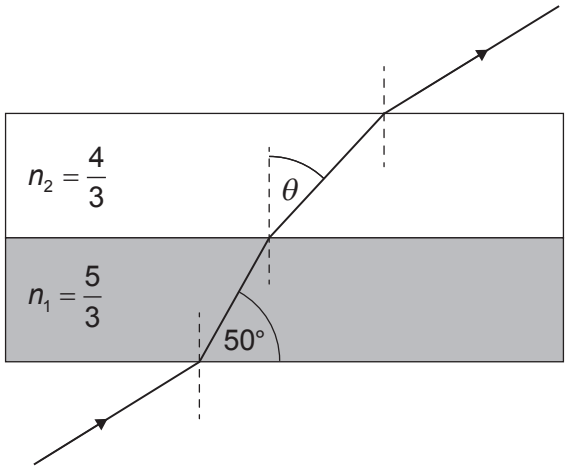
Wave phenomena

18 questions

20. Light passes through two parallel layers as shown.

The refractive indices for light travelling between air and the media are shown in the diagram as n_1 and n_2.

diagram not to scale



What is θ?

A. 31°

B. 38°

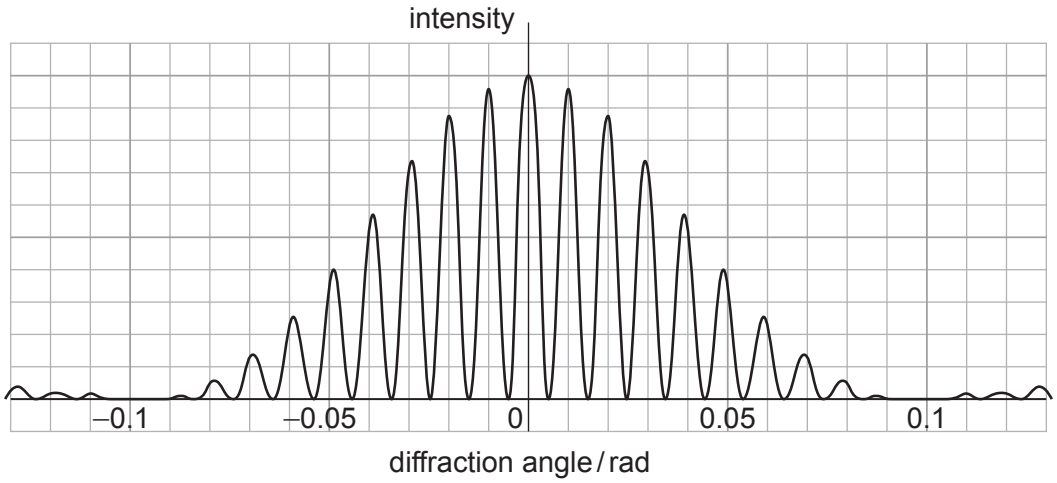
C. 53°

D. 73°

Turn over

21. Light of wavelength λ is incident on two parallel slits of width b that are separated by distance d.

The graph of intensity against diffraction angle is shown.



What are $\frac{\lambda}{d}$ and $\frac{\lambda}{b}$?

	$\frac{\lambda}{d}$	$\frac{\lambda}{b}$
A.	0.1	0.1
B.	0.1	0.01
C.	0.01	0.1
D.	0.01	0.01

23. Light of wavelength 5.8×10^{-7} m is normally incident on a diffraction grating that has 400 000 lines m^{-1}.

How many maxima can be observed with this diffraction grating?

A. 4

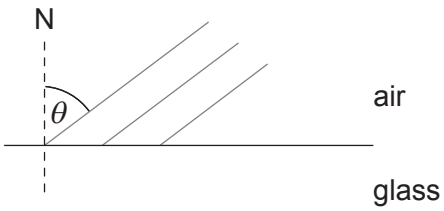
B. 5

C. 8

D. 9

22. The diagram shows wavefronts of light incident on an air–glass boundary.

The angle between the incident wavefront and the normal, N, is θ.



Which of the following gives the correct expression for the refractive index of the glass, where r is the angle of refraction?

A. $\frac{\sin\theta}{\sin r}$

B. $\frac{\sin(90-\theta)}{\sin r}$

C. $\frac{\sin r}{\sin\theta}$

D. $\frac{\sin r}{\sin(90-\theta)}$

23. S_1 and S_2 are two coherent sound sources with no phase difference. The wavelength of both waves is 0.20 m. P is a point 6.0 m away from S_1 and 6.5 m away from S_2 respectively. At P the amplitude of the wave from S_1 is x_0 and from S_2 is $2x_0$.

What is the resultant amplitude at P?

A. 0

B. x_0

C. $2x_0$

D. $3x_0$

24. A parallel beam of monochromatic light of wavelength λ passes through a rectangular slit of width b and is incident on a screen at a distance x from the slit.

What is the width of the central maximum of the diffraction pattern on the screen?

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

B. $\frac{2\lambda}{b}$

C. $\frac{\lambda x}{b}$

D. $\frac{2\lambda x}{b}$

2. A group of students is investigating refraction in a semi-circular glass block.

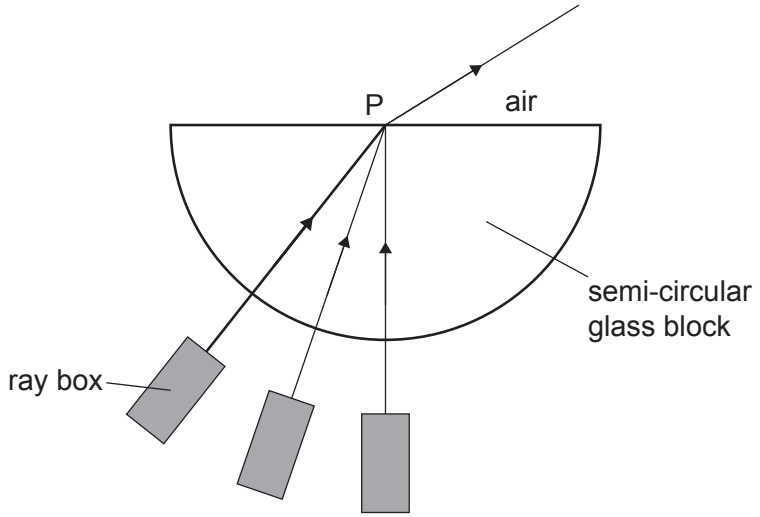
Light from a ray box enters the curved side of the block. The light passes through the block and leaves, refracted, at P.

(a) Outline how the students can ensure that the light is not deflected at the curved surface. [1]

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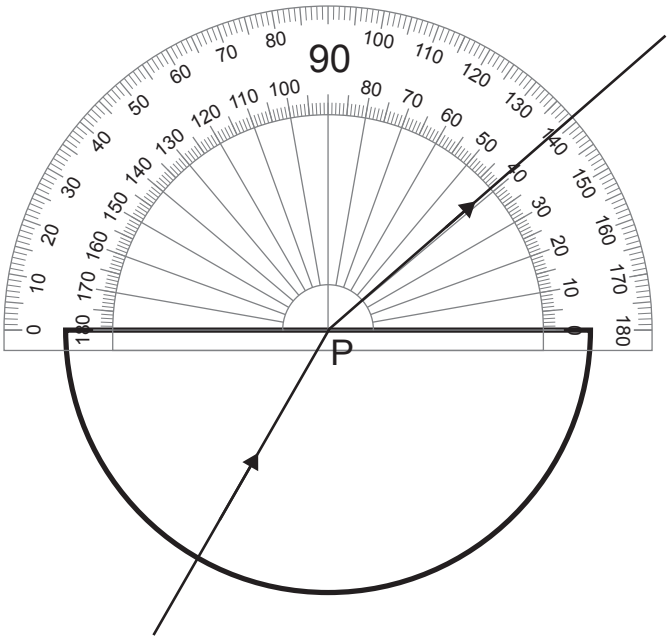
The students vary the position of the ray box to obtain data to determine the refractive index of the glass. They use a protractor to collect values for the angles of incidence θ_i and refraction θ_r at P and record them on a table.



(This question continues on the following page)

(Question 2 continued)

(b) (i) One of their measurements is shown. State θ_r for this measurement. [1]



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(ii) Complete the table. [1]

θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
10	15	0.174	0.259
20	31	0.342	0.515
25	39	0.423	0.629
30	49	0.500	
35	60	0.574	0.866
40	75	0.643	0.966

(This question continues on page 7)

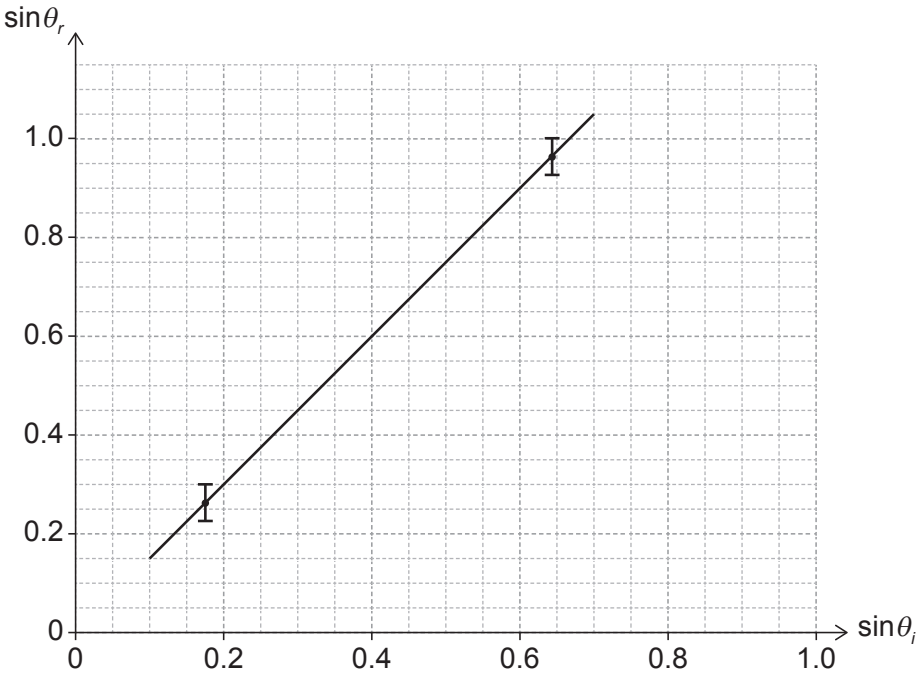
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(Question 2 continued)

They plot a graph of the variation with the sine of θ_i of the sine of θ_r.

They add uncertainty bars for $\sin\theta_r$ for the first and last data point and draw the best-fit line.



(c) (i) Determine the gradient of the students' best-fit line. [2]

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(ii) Draw on the students' graph the line of maximum gradient. [1]

(iii) Determine the value of the refractive index of the glass with its absolute uncertainty. [2]

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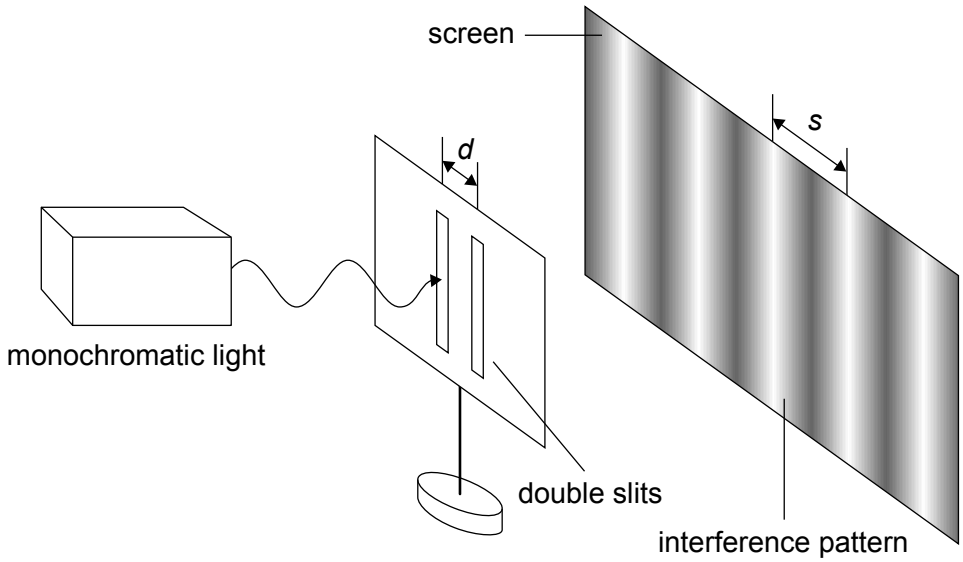
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Question 2 - working space

2. Students set up a double slit experiment to determine the wavelength λ of monochromatic light. A light source is directed at a double slit with **variable** separation *d*. An interference pattern is formed on a screen at a fixed distance from the slits. The separation of the fringes is *s*.

At close range the pattern is shown as a set of constructive interference fringes.



(a) Students use a ruler with millimetre intervals to measure *s*. Describe a method to determine *s* such that its absolute uncertainty is reduced. [2]

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(b) Discuss the effect on the fractional uncertainty in *s* when using a smaller value of *d*. [2]

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(This question continues on the following page)

(Question 2 continued)

(c) (i) To determine λ students plot a graph with s on the vertical axis. State the variable that must be plotted on the horizontal axis to obtain a line of best fit that is straight. [1]

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(ii) The calculator value obtained from the graph gives $\lambda = 611.089\,\text{nm}$ with a percentage uncertainty of $\pm 5\,\%$. Deduce how this value should be recorded in a conclusion, including the absolute uncertainty, to the appropriate number of significant digits. [2]

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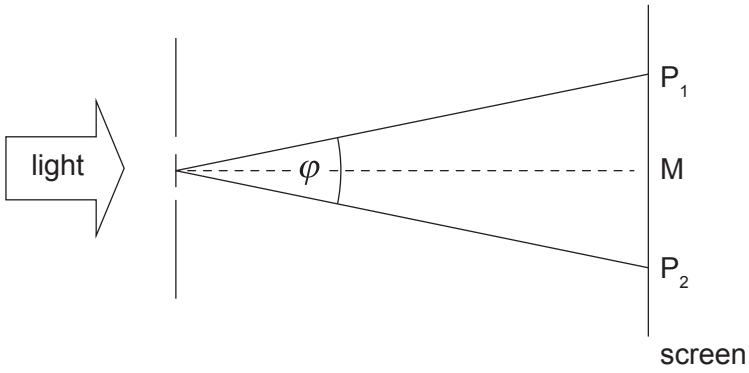
Question 2 - working space

4. Two sources of light produce an interference pattern on a screen.

(a) Explain why the two sources need to be coherent for the interference pattern to be observed. [2]

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(b) Light of wavelength 720 nm is incident on two narrow slits that are separated by 0.12 mm. An interference pattern is observed on a screen. P_1 and P_2 are the points of destructive interference closest to the central maximum M.



(i) Calculate, in radians, the angular separation φ of P_1 and P_2. [2]

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(ii) Suggest how energy conservation is consistent with the fact that the energy at P_1 and P_2 is zero. [1]

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(This question continues on the following page)

(Question 4 continued)

A beam of light containing all wavelengths in the range [550 nm, 650 nm] is incident normally on a diffraction grating. The grating has 580 lines per mm. A diffraction pattern is observed on a screen as shown.



(c) Outline why the interference at M is constructive. [1]

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(d) Determine the largest order of the diffraction pattern in which all the wavelengths in the incident beam are present. [3]

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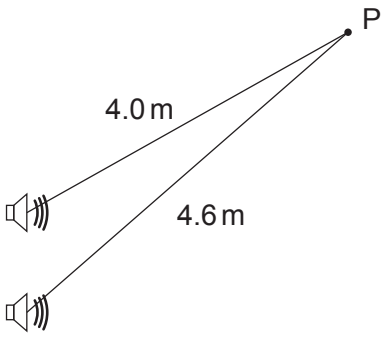
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Question 4 - working space

19. Two loudspeakers are driven in phase and emit sound of the same frequency. A minimum intensity of sound is detected at point P.

P is 4.0 m from one loudspeaker and 4.6 m from the other.



What is a possible wavelength of the sound?

A. 20 cm

B. 30 cm

C. 40 cm

D. 60 cm

20. Monochromatic light of wavelength λ is incident normally on a diffraction grating. The adjacent lines of the diffraction grating are separated by a distance of 2.8λ. How many diffraction maxima are present in the transmitted light?

A. 2

B. 3

C. 5

D. 7

20. A sound wave in air is directed towards a water boundary, and part of it is refracted.

Three statements are made about the refracted wave compared to the incident wave.

I. The wavelength is different.

II. The amplitude is different.

III. The frequency is different.

Which of the statements are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

21. The critical angle for light passing from a medium into air is 30°.

What is the approximate value for the speed of light in the medium?

A. $0.5 \times 10^8 \, \text{m s}^{-1}$

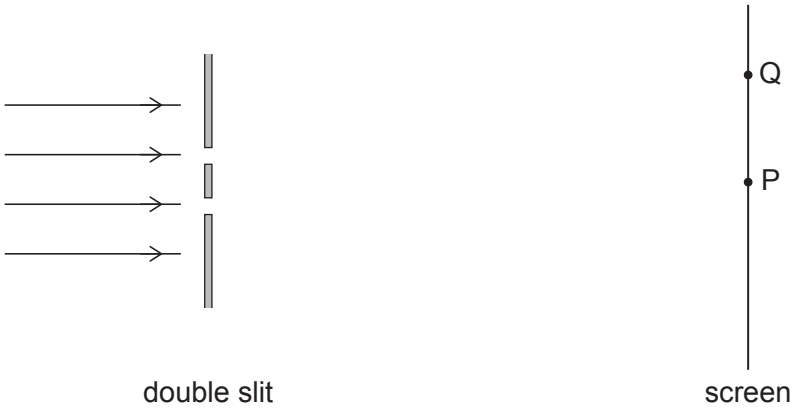
B. $1.5 \times 10^8 \, \text{m s}^{-1}$

C. $2.0 \times 10^8 \, \text{m s}^{-1}$

D. $2.6 \times 10^8 \, \text{m s}^{-1}$

22. In a double-slit experiment using coherent light of wavelength λ, the central bright fringe is observed on a screen at point P. A point of destructive interference occurs at point Q. Only one point of constructive interference is observed between P and Q.

diagram not to scale



What is the path difference at Q?

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

B. λ

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

D. 2λ

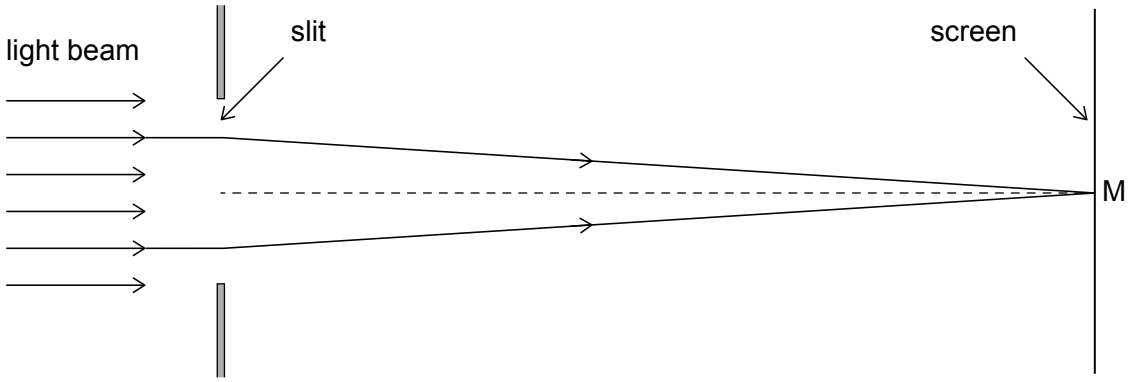
23. Monochromatic coherent light is directed normally at a diffraction grating with N slits per unit length. Nine maxima in intensity are produced on a screen far away.

What change will occur to the angle between successive maxima and the number of observable maxima when the number of slits per unit length is $2N$?

	Angle between successive maxima	**Number of observable maxima**
A.	increase	decrease
B.	increase	increase
C.	decrease	decrease
D.	decrease	increase

7. A monochromatic light beam is incident on a single slit. M is the point on a screen far from the slit, directly across from the mid-point of the slit. The diagram shows two of the incident rays that reach M after they have diffracted at the slit. These rays are symmetrical with respect to the dotted line.

diagram not to scale



(a) Outline, by considering pairs of rays arriving at M such as the ones shown, why a maximum in intensity will be observed at M. [2]

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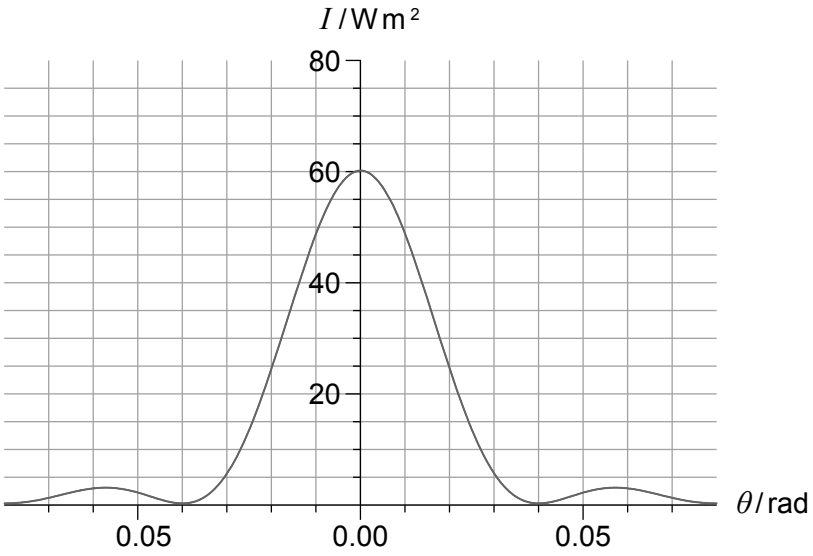
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(Question 7 continued)

(b) The graph shows the variation with diffraction angle θ of the intensity I on the screen.



The slit width is 1.3×10^{-5} m. Calculate the wavelength of the light. [2]

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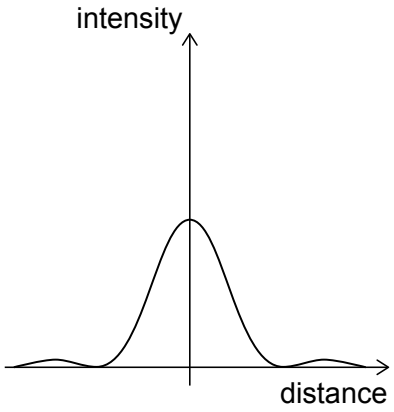
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Question 7 - working space

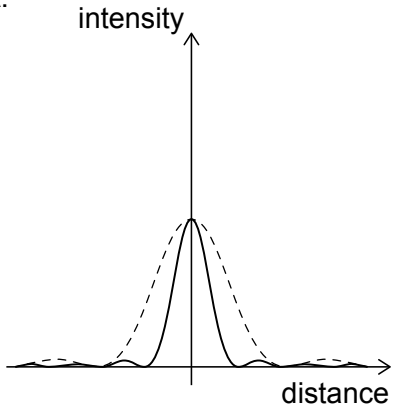
22. Light from a monochromatic source is incident on a single slit and the resulting diffraction pattern is viewed on a screen. The graph shows the variation of intensity with distance on the screen.



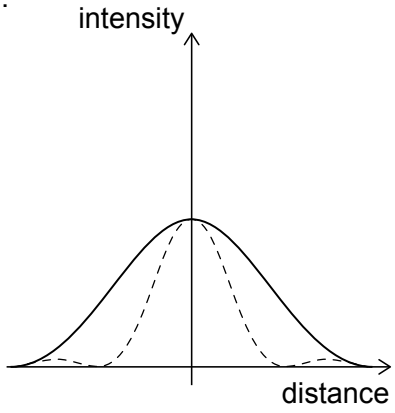
The intensity of the source remains the same. The width of the slit is increased.

Which graph correctly shows the variation of intensity after the change? The original curve is shown with a dashed line.

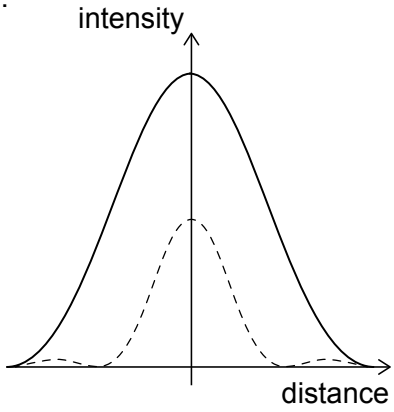
A.



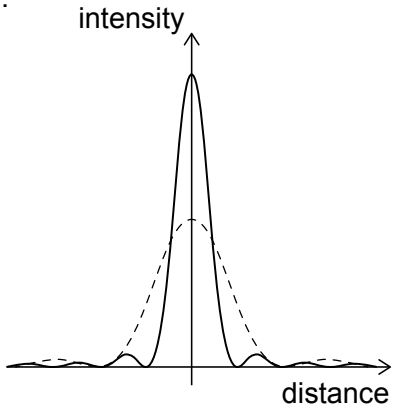
B.



C.



D.



Turn over

23. Monochromatic light is incident on a diffraction grating. The diffraction pattern from the diffraction grating is then formed on a screen.

Only the central maximum and the first-order maxima can be observed on the screen.

What change will allow the second-order maxima to be observed on the screen?

A. Decrease the distance between the diffraction grating and the source of light

B. Increase the distance between the diffraction grating and the screen

C. Increase the wavelength of the monochromatic light

D. Reduce the number of lines per unit length of the diffraction grating

APOLLO

Standing waves and resonance

9 questions

22. A pipe of length L is closed at one end.

What is the wavelength of the fifth-harmonic standing wave in this pipe?

A. $\frac{8L}{5}$

B. $\frac{5L}{4}$

C. $\frac{4L}{5}$

D. $\frac{5L}{8}$

19. A fifth-harmonic standing wave is formed in a pipe of length 25 cm that is closed at both ends.

What two points along the pipe have a phase difference of π ?

A. 2 cm and 7 cm

B. 4 cm and 21 cm

C. 7 cm and 9 cm

D. 11 cm and 14 cm

25. The frequency of the first harmonic for a pipe open at both ends is f. The length of the pipe is 0.4 m. A second pipe, open at one end and closed at the other, produces a first harmonic of the same frequency f.

What is the length of the second pipe?

A. 0.1 m

B. 0.2 m

C. 0.4 m

D. 0.8 m

Turn over

21. A standing sound wave is formed in a pipe of length L that is open at both ends. The standing wave has two nodes. What is the wavelength of the standing wave?

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

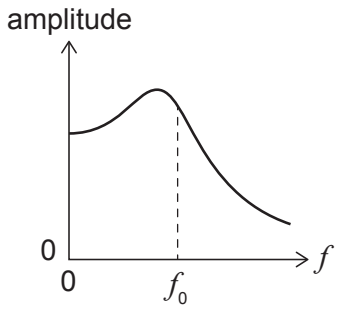
B. $\frac{2L}{3}$

C. L

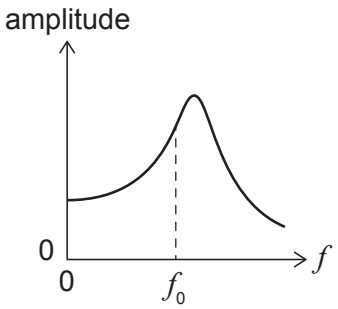
D. $2L$

22. A heavily damped oscillator of natural frequency f_0 is driven by a periodic force of frequency f. Which graph shows how the amplitude of the oscillations varies with f?

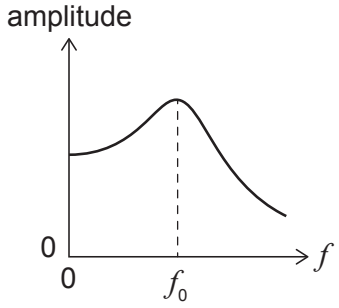
A.



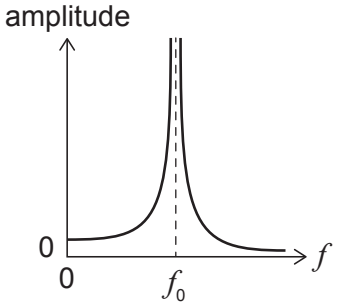
B.



C.



D.



24. A string that is fixed at both ends oscillates in the second harmonic with frequency 100 Hz. What other harmonic frequencies, in Hz, can this string oscillate at?

A. 25 and 50

B. 25 and 75

C. 50 and 150

D. 75 and 150

9. (a) A copper rod has mass 0.400 kg. The density of solid copper is $8.94 \times 10^3\,\text{kg m}^{-3}$. The molar mass (the mass of a mole) of copper is $63.5\,\text{g mol}^{-1}$.

Estimate

(i) the mass of a copper atom; [2]

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(ii) the volume corresponding to each atom, given by $\frac{\text{volume of copper}}{\text{number of copper atoms}}$; [2]

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(iii) the average separation of two neighbouring copper atoms, assuming that the volume corresponding to each atom is a cube. [1]

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(b) The specific latent heat of fusion of copper is $206\,\text{kJ kg}^{-1}$. Calculate the energy needed to completely melt 0.400 kg of solid copper at its melting point. [1]

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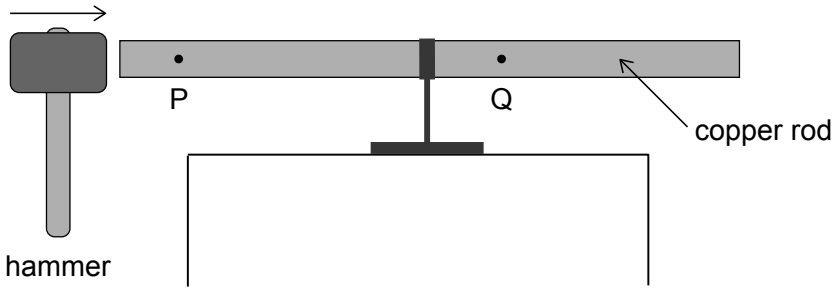
(Question 9 continued)

(c) Copper atoms in the solid and liquid phase coexist at the melting point. Comparing equal numbers of atoms in the solid and liquid phase at the melting point, state and explain which atoms have the greater internal energy. [3]

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(d) A copper rod is suspended at its centre, as shown. P and Q are the equilibrium positions of two copper atoms in the rod. When a hammer taps the left-hand end of the rod, the first harmonic sound standing wave is formed in the rod. The longitudinal standing wave in this rod is identical to a standing wave in a pipe with both ends open.

diagram not to scale



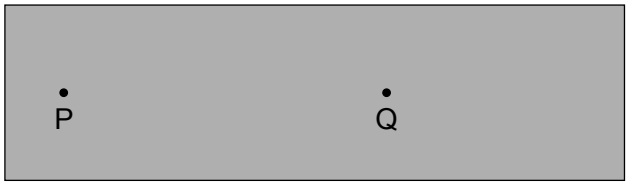
(i) Explain, by reference to the principle of superposition, why a standing wave is set up in the pipe. [2]

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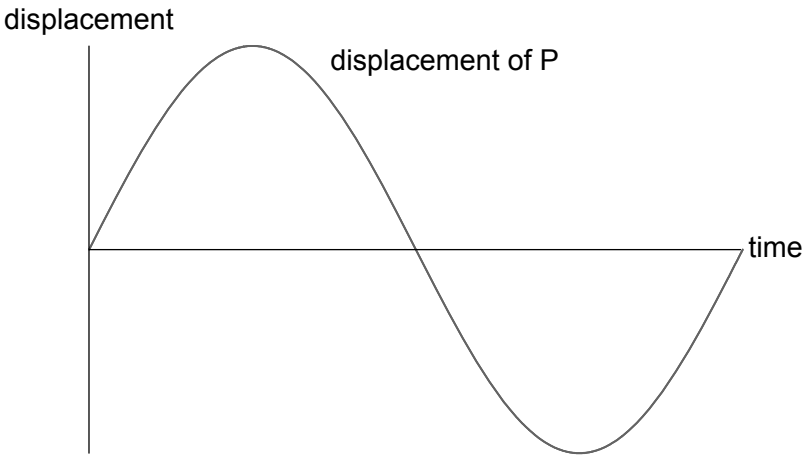
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(Question 9 continued)

(ii) Draw, on the diagram, the standing wave in the rod. The width of the rod is shown larger to help with your drawing. [1]



(iii) The graph shows the variation with time of the displacement of the atom at P. Draw, on the same axes, the variation with time of the displacement of the atom at Q. [2]

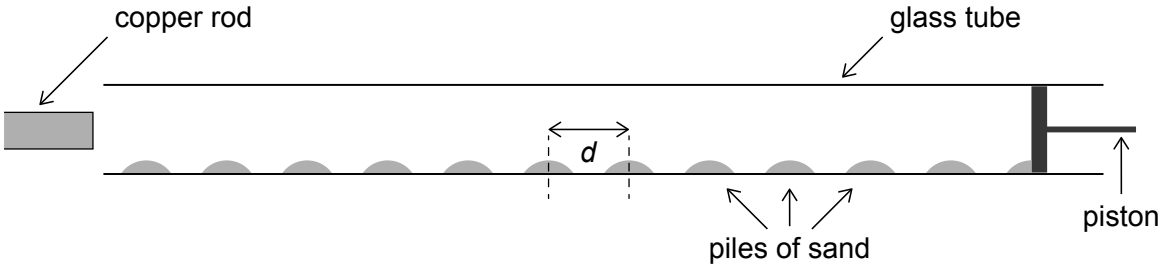


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(Question 9 continued)

(e) The copper rod is brought close to a glass tube that contains light sand. When the left-hand end of the rod is tapped with a hammer and the length of the tube is adjusted by moving the piston, a standing wave is established in the tube. Sand collects in piles as shown. The distance between the centres of two consecutive piles of sand is d.

diagram not to scale



(i) Outline why the sand collects in piles. [2]

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(ii) The following data are available:

$d = 1.8\,\text{cm}$
speed of sound in air $= 330\,\text{m s}^{-1}$
length of copper rod $= 34\,\text{cm}$

Determine the speed of sound in copper. [4]

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Turn over

Question 9 - working space

20. Diagram 1 shows the variation with position of the displacement of a standing wave formed on a string.

Diagram 2 shows the variation with position of the displacement of a travelling wave moving to the right along a string.

Diagram 1

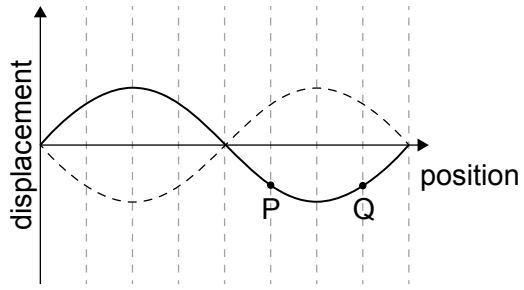
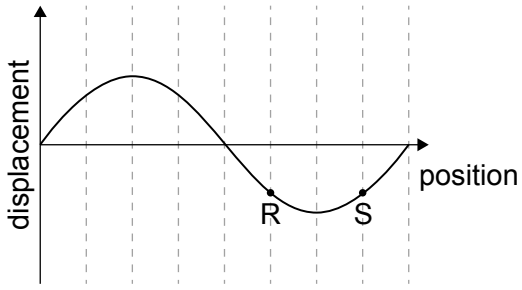


Diagram 2



Points P, Q, R and S are points on the string.

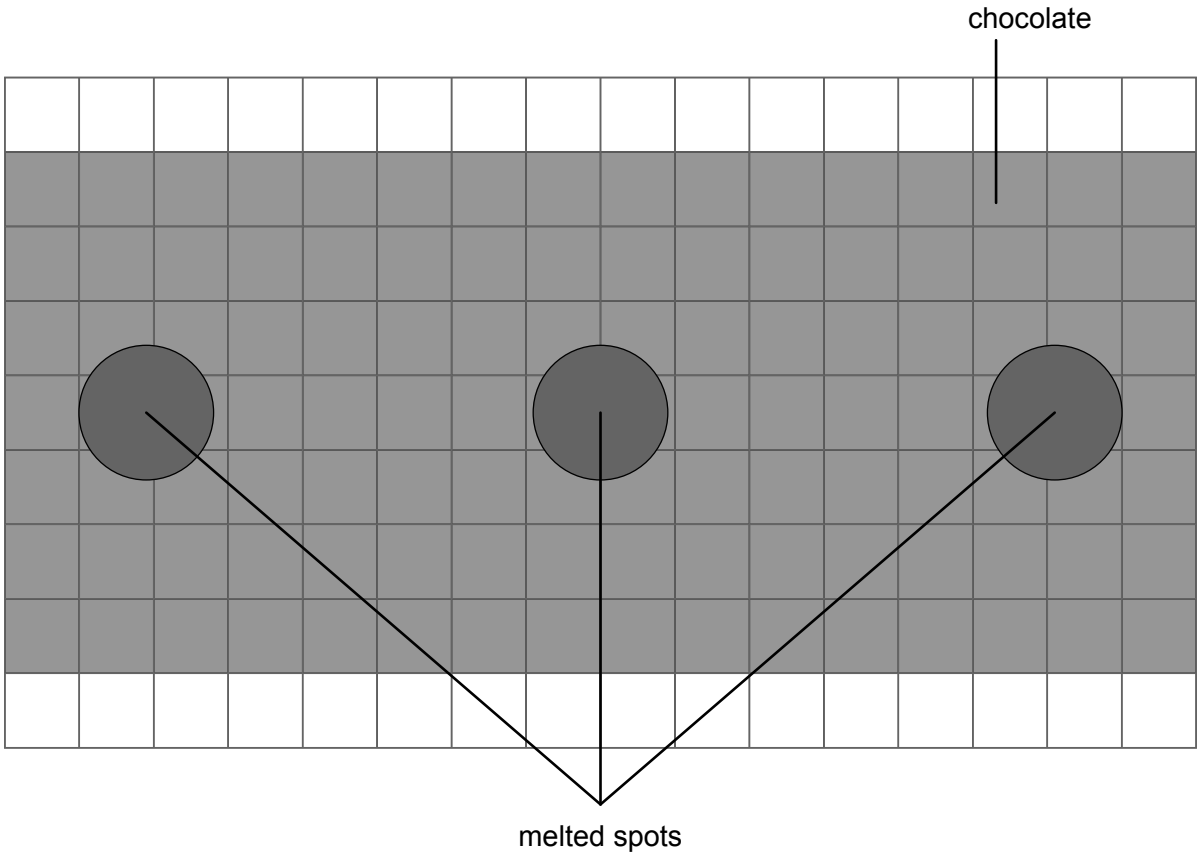
What is the phase difference between P and Q and the phase difference between R and S?

	Phase difference between P and Q	**Phase difference between R and S**
A.	0	0
B.	$\frac{\pi}{2}$	0
C.	0	$\frac{\pi}{2}$
D.	$\frac{\pi}{2}$	$\frac{\pi}{2}$

3. In a microwave oven electromagnetic waves are emitted so that a standing wave pattern is established inside the oven.

A flat piece of chocolate is placed inside the oven and the microwaves are switched on. The chocolate is stationary.

Melted spots form on the surface of the chocolate. The diagram shows the pattern of melting on the chocolate. Each square has a length of 1 cm.



(a) Outline how this standing wave pattern of melted spots is formed. [2]

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(This question continues on the following page)

(Question 3 continued)

(b) Determine, taking appropriate measurements from the diagram, the frequency of the electromagnetic waves in the oven. [3]

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Question 3 - working space

APOLLO

Doppler effect

3 questions

4. (a) Identify **two** differences between sound waves in air and light waves. [2]

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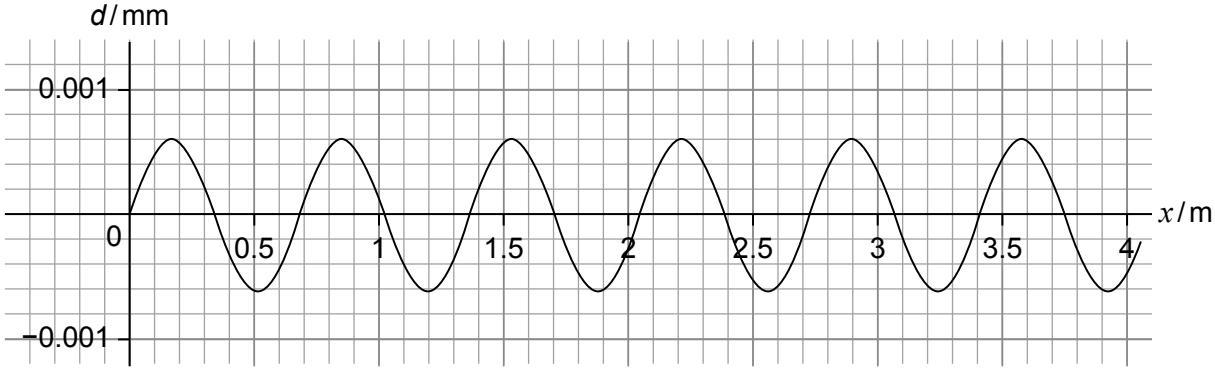
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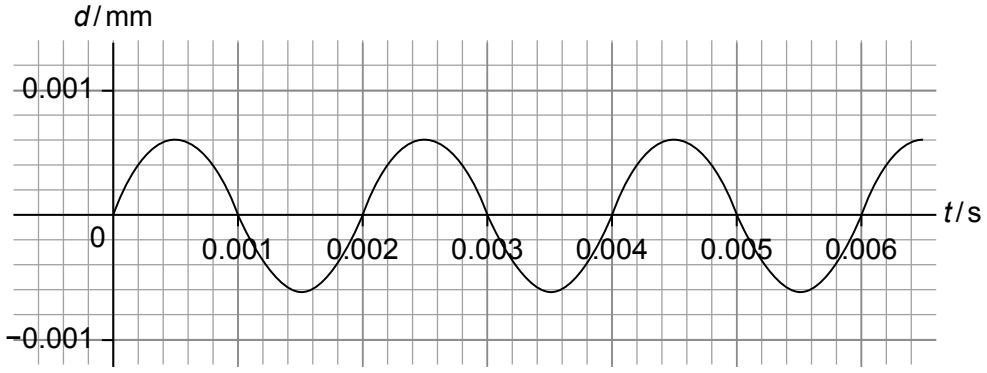
Graph 1 shows the variation of particle displacement *d* with position x for a travelling sound wave.

Graph 1



Graph 2 shows the variation of particle displacement *d* with time *t* for the same travelling sound wave.

Graph 2



(This question continues on the following page)

(Question 4 continued)

(b) (i) State the wavelength and the period of the sound wave. [2]

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(ii) Calculate the speed of the sound wave. [1]

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(Question 4 continued)

The Doppler effect applies to both sound and light waves.

(c) (i) Explain the Doppler effect. [2]

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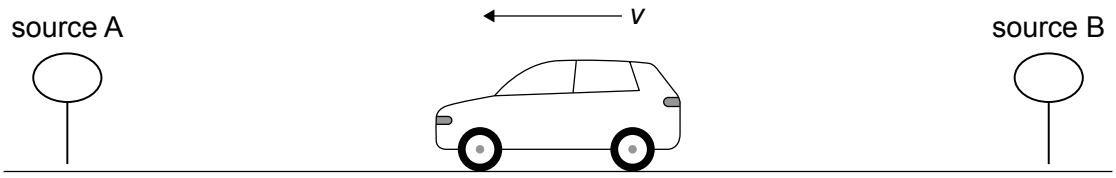
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(ii) A car is moving at constant velocity v between two sources of sound as shown in the diagram. The sources emit sound at 440 Hz and at 540 Hz. The driver hears both sounds at the same frequency. The speed of sound is 340 m s^{-1}.

diagram not to scale



Determine v. [2]

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(Question 4 continued)

(iii) The spectrum of light received from a galaxy shows a peak at a wavelength of 659.0 nm. The peak corresponds to an atomic transition in the hydrogen atom that emits a wavelength of 656.1 nm when observed in a laboratory on Earth.

Calculate the velocity of the galaxy with respect to Earth. [2]

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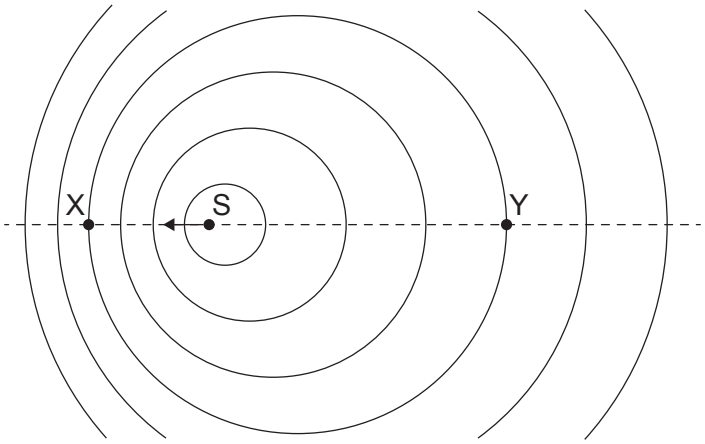
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will not be marked.

Question 4 - working space

23. A source S of a sound wave is moving at a constant velocity along a line joining stationary observers X and Y. The diagram shows consecutive wavefronts of the sound.



Consider the following statements:

I. More wavefronts pass X in a unit time than Y.

II. The speed of the wavefronts is greater at X than at Y.

III. The wavelength of the sound at X is less than the wavelength at Y.

Which statements are correct?

A. I and II only

B. I and III only

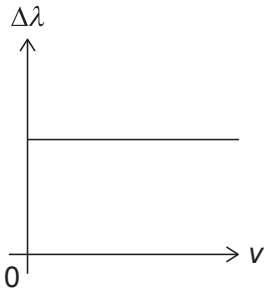
C. II and III only

D. I, II and III

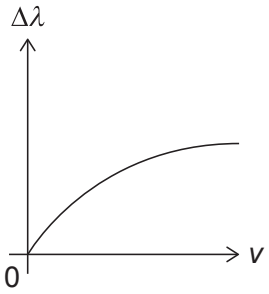
25. A source moving with speed *v* away from a stationary observer emits light of wavelength λ. The wavelength received by the observer is $\lambda + \Delta\lambda$. The speed *v* is much less than the speed of light.

Which graph gives the variation of $\Delta\lambda$ with *v*?

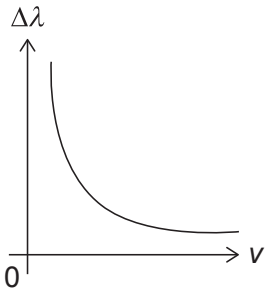
A.



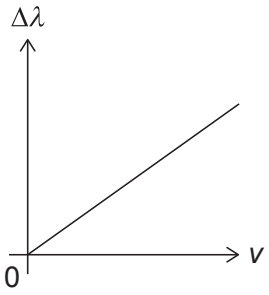
B.



C.



D.



APOLLO

Gravitational fields

16 questions

24. A planet P has a diameter one-third that of the Earth. The mass of Earth is 18 times that of P.

The gravitational field strength at the surface of the Earth is g.

What is the gravitational field strength at the surface of P?

A. $\frac{g}{6}$

B. $\frac{g}{2}$

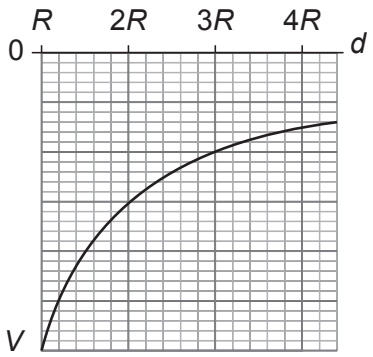
C. $2g$

D. $6g$

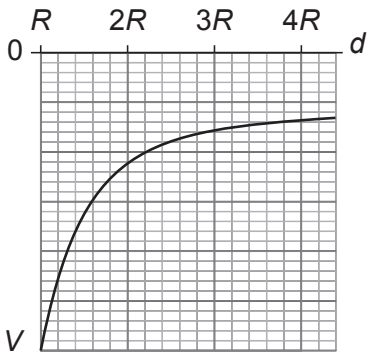
25. Which graph shows the variation of gravitational potential V with distance d from the surface of the Earth?

R is the radius of the Earth.

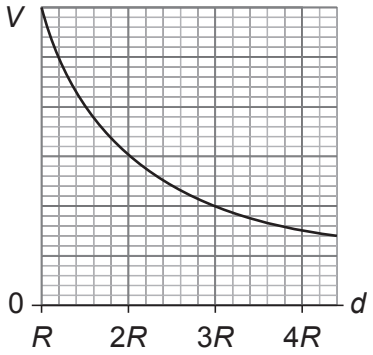
A.



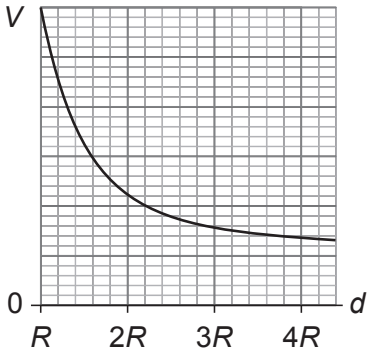
B.



C.



D.



21. A planet of mass m is in a circular orbit of radius R around a star. The orbital speed of the planet is v. A second planet of mass $2m$ is in a circular orbit of radius $1.5R$ around the same star.

What is the orbital speed of the second planet?

A. $\sqrt{\frac{2}{3}}v$

B. $\sqrt{2}v$

C. $\sqrt{3}v$

D. $2v$

26. The relationship between the period of a planet's orbit T and the distance to the Sun R can be expressed as $T^n \propto R^m$ where n and m are constants.

What is a possible pair of values for n and m?

	n	**m**
A.	1.0	3.0
B.	1.0	1.5
C.	2.0	1.5
D.	2.0	1.0

27. Point X is at a distance d from the centre of Earth. d is larger than the radius of Earth. The gravitational field strength at X is g_X. Point Y is at a distance $3d$ from the centre of Earth.

What is the difference in the magnitude of gravitational field strengths between X and Y?

A. $\frac{8g_X}{9}$

B. $\frac{3g_X}{4}$

C. $\frac{g_X}{4}$

D. $\frac{g_X}{9}$

28. The work done per unit mass to move a body from infinity to a point P in a gravitational field is the

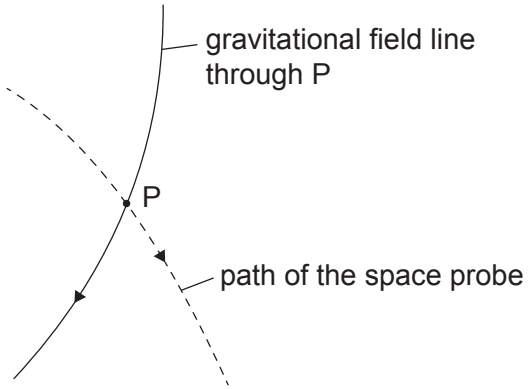
A. gravitational field strength at P.

B. gravitational force at P.

C. gravitational potential energy at P.

D. gravitational potential at P.

24. A space probe moves in a gravitational field. No other forces than the gravitational force act on the probe. At one instant, the probe is at point P. The diagram shows the path of the probe and the gravitational field line through P.



What is the direction of the acceleration of the probe at P?

A. Tangent to the path of the probe

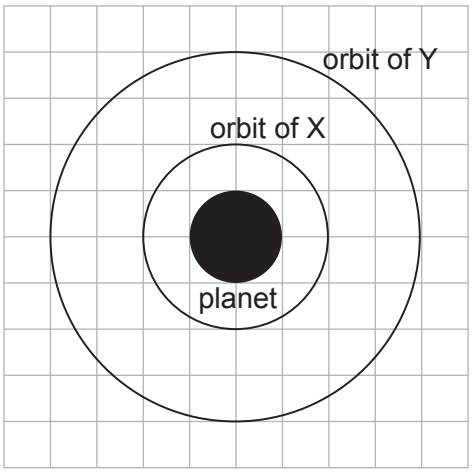
B. Perpendicular to the path of the probe

C. Tangent to the gravitational field line through P

D. Perpendicular to the gravitational field line through P

Turn over

25. Two satellites X and Y with the same mass orbit a planet. The scaled diagram shows the orbits of the satellites.



What is $\frac{\text{kinetic energy of X}}{\text{kinetic energy of Y}}$?

A. 2

B. 3

C. 4

D. 9

26. Which is a statement of one of Kepler's laws of orbital motion?

A. The square of the planet's orbital period is proportional to the cube of the length of the semi-major axis of its orbit.

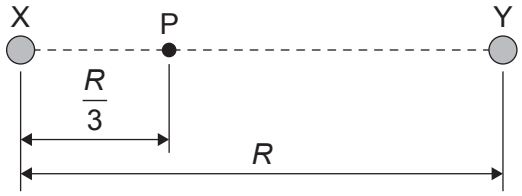
B. A line segment joining a planet and the Sun sweeps out equal arc lengths during equal intervals of time.

C. A planet's orbital period is proportional to the cube of the length of the semi-major axis of its orbit.

D. The orbit of a planet is an ellipse with the Sun positioned at the centre.

Turn over

27. Isolated planets X and Y have masses M_X and M_Y respectively and are separated by a distance R. A point P is located at a distance $\frac{R}{3}$ from planet X, as shown. The gravitational field strength at P is zero.



What is $\frac{M_Y}{M_X}$?

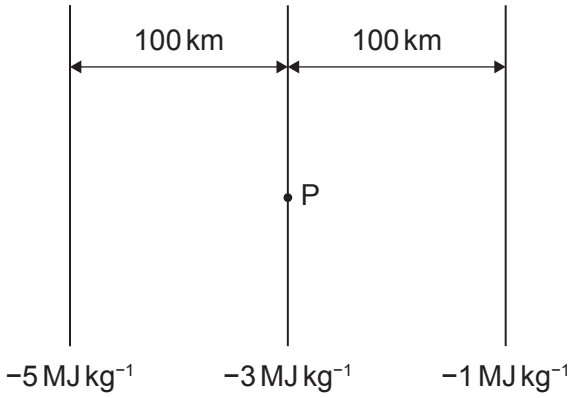
A. 2

B. 3

C. 4

D. 9

28. A point mass of 5 kg is placed at point P located on one of three gravitational equipotential lines, each separated by a distance of 100 km, as shown.



What is the initial acceleration of the point mass?

A. $4\,m\,s^{-2}$ to the left

B. $4\,m\,s^{-2}$ to the right

C. $20\,m\,s^{-2}$ to the left

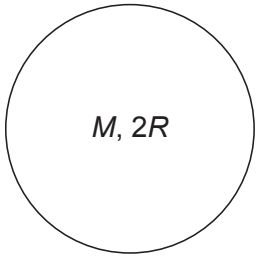
D. $20\,m\,s^{-2}$ to the right

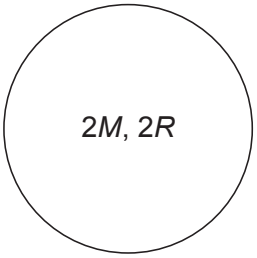
29. Four planets have masses M or $2M$ and radii R or $2R$ as shown.

Which planet has the largest escape speed?

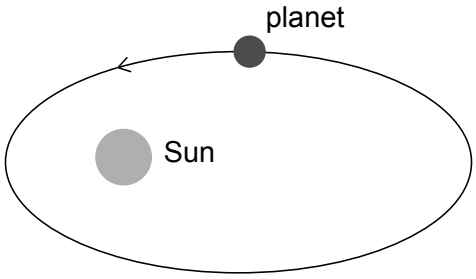
A. 

B. 

C. 

D. 

25. A planet orbits the Sun in an elliptical orbit moving in the direction shown.



At the position shown, which quantity is decreasing for the planet?

A. Acceleration

B. Angular momentum

C. Kinetic energy

D. Gravitational potential energy

28. Planets X and Y orbit the same star.

The average distance between planet X and the star is five times greater than the average distance between planet Y and the star.

What is $\frac{\text{orbital period of planet X}}{\text{orbital period of planet Y}}$?

A. $\sqrt[3]{5}$

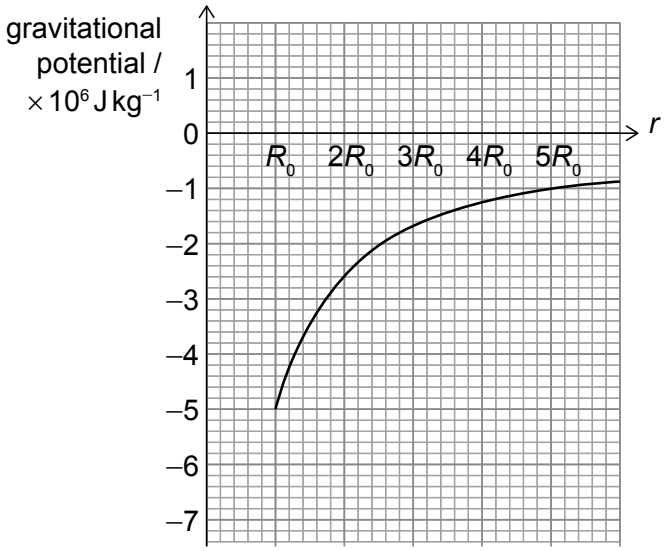
B. $\sqrt{5}$

C. $\sqrt[3]{5^2}$

D. $\sqrt{5^3}$

30. A spherical planet has a radius R_0.

The graph shows the variation of the gravitational potential due to the planet with distance r from the centre of the planet.



What is the escape speed from the surface of the planet?

A. $1.6 \times 10^3\,\mathrm{m\,s^{-1}}$

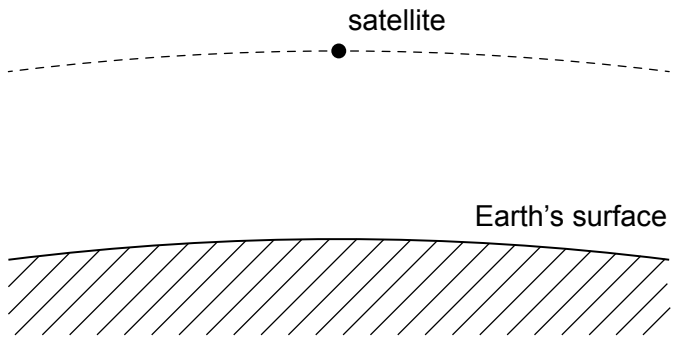
B. $2.2 \times 10^3\,\mathrm{m\,s^{-1}}$

C. $3.2 \times 10^3\,\mathrm{m\,s^{-1}}$

D. $4.5 \times 10^3\,\mathrm{m\,s^{-1}}$

Turn over

4. A satellite moves around Earth in a circular orbit.



(a) Draw an arrow on the diagram to represent the direction of the acceleration of the satellite. [1]

(b) The following data are given:

Mass of Earth, $M = 5.97 \times 10^{24}\,\text{kg}$
Radius of Earth, $R = 6.37 \times 10^{6}\,\text{m}$
Orbital period of the satellite, $T = 5.62 \times 10^{3}\,\text{s}$

(i) Kepler's Third Law of orbital motion states that $T^2 = kr^3$ where k is a constant and r is the orbital radius of the satellite.
Show that $k = \frac{4\pi^2}{GM}$. [1]

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(ii) Determine the height of the satellite above the Earth's surface. [2]

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(Question 4 continued)

(c) The atmosphere exerts a small viscous drag force on the satellite.

Outline how the total energy, kinetic energy, and gravitational potential energy change for the satellite during one orbit around Earth. [3]

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Question 4 - working space

APOLLO

Electric and magnetic fields

23 questions

26. The unit of $\mu_0 \times \varepsilon_0$ expressed in fundamental SI units is...

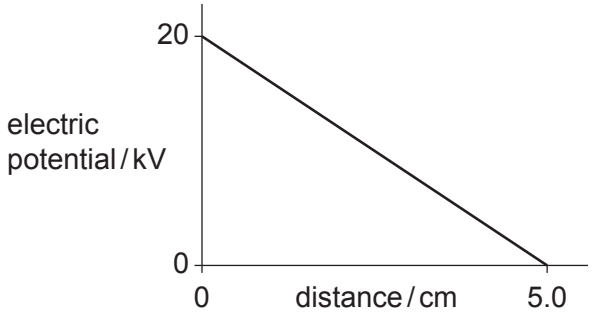
A. $m^{-2}s^2$.

B. $TCN^{-1}m^{-1}s$.

C. m^2s^{-2}.

D. $TC^2A^{-1}N^{-1}m^{-1}$.

27. Two parallel conducting plates are separated by 5.0 cm. The variation of electric potential with distance between the plates is shown.



What is the magnitude of the electric field strength between the plates?

A. $4.0\,\mathrm{N\,C^{-1}}$

B. $1.0 \times 10^{3}\,\mathrm{N\,C^{-1}}$

C. $1.0 \times 10^{5}\,\mathrm{N\,C^{-1}}$

D. $4.0 \times 10^{5}\,\mathrm{N\,C^{-1}}$

28. Charge is moving in a wire that is at right angles to a uniform magnetic field.

The length of the wire is 0.32 m.

When the current in the wire is increased by 5.0 A, the force acting on the wire increases by 4.0 mN.

What is the strength of the magnetic field?

A. 2.5 mT

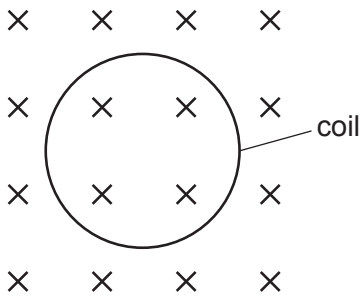
B. 25 mT

C. 40 T

D. 40 kT

29. Negative charge carriers travel counter-clockwise in a circular coil that lies in the plane of the page.

The coil is in a uniform magnetic field directed into the page.



What is the magnetic effect on the coil?

A. The coil will rotate clockwise in the plane of the paper.

B. The coil will rotate counter-clockwise in the plane of the paper.

C. The diameter of the coil will tend to increase.

D. The diameter of the coil will tend to decrease.

30. Who was the first scientist to show that electric charge is quantized?

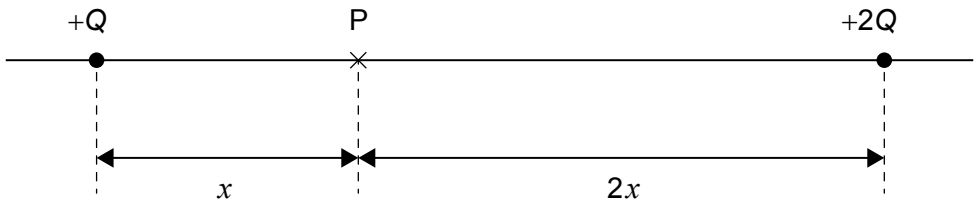
A. Coulomb

B. Millikan

C. Planck

D. Rutherford

22. A charge $+Q$ and a charge $+2Q$ are a distance $3x$ apart. Point P is on the line joining the charges, at a distance x from one of the charges as shown.



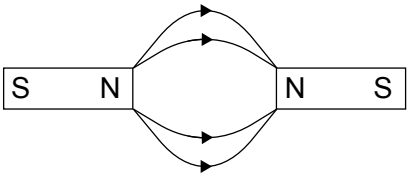
What is the electric field strength *E* at P?

	Magnitude of *E*	Direction of *E*
A.	$\frac{kQ}{2x^2}$	left
B.	$\frac{kQ}{2x^2}$	right
C.	$\frac{kQ}{x^2}$	left
D.	$\frac{kQ}{x^2}$	right

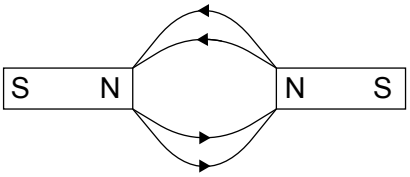
23. Two bar magnets are held in place with the north poles facing each other.

Which diagram shows four correct magnetic field lines?

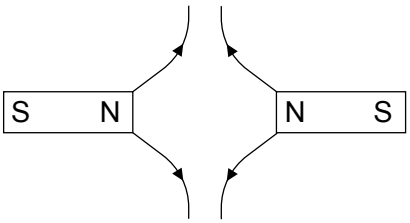
A.



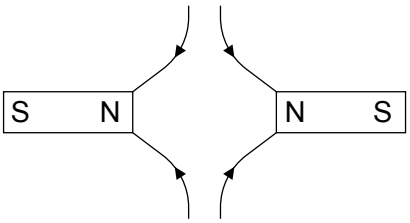
B.



C.



D.



24. A pair of parallel conducting plates are separated by 50 cm. The electric potential of one plate is +200 V and the electric potential of the other plate is +450 V. A proton travels from the +200 V plate to the +450 V plate.

What is the electric field strength between the plates and the change in the kinetic energy of the proton?

	Magnitude / N C^{-1}	Change in kinetic energy
A.	500	positive
B.	500	negative
C.	900	positive
D.	900	negative

27. Two parallel wires X and Y carry the same current. There is a repulsive force per unit length F on each wire. The direction of the current in each wire is reversed. The current in X is doubled and the current in Y stays the same. The separation of X and Y is also doubled.

What is the magnitude and direction of the force per unit length on each wire?

	Magnitude	Direction
A.	F	repulsive
B.	F	attractive
C.	$\frac{F}{2}$	repulsive
D.	$\frac{F}{2}$	attractive

29. In a Millikan's experiment, an oil drop is stationary between two parallel plates. A second oil drop of the same density, between the same plates, has twice the charge and twice the radius of the first oil drop.

The second oil drop will initially

A. be stationary.

B. move with constant velocity downwards.

C. accelerate upwards.

D. accelerate downwards.

30. Two isolated point charges, X of charge $+Q$ and Y of charge $+2Q$, are separated by a distance $3d$. P is a point d from X and $2d$ from Y respectively.



What is the net electric field strength at P?

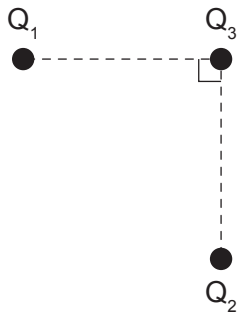
A. 0

B. $\frac{kQ}{2d^2}$

C. $\frac{3kQ}{4d^2}$

D. $\frac{3kQ}{2d^2}$

31. Two isolated positive point charges Q_1 and Q_2 are equidistant from a third charge Q_3 as shown. The force on Q_3 due to Q_1 is F. The force on Q_3 due to Q_2 is $2F$.



What is the resultant force on Q_3?

A. F

B. $\sqrt{3}F$

C. $\sqrt{5}F$

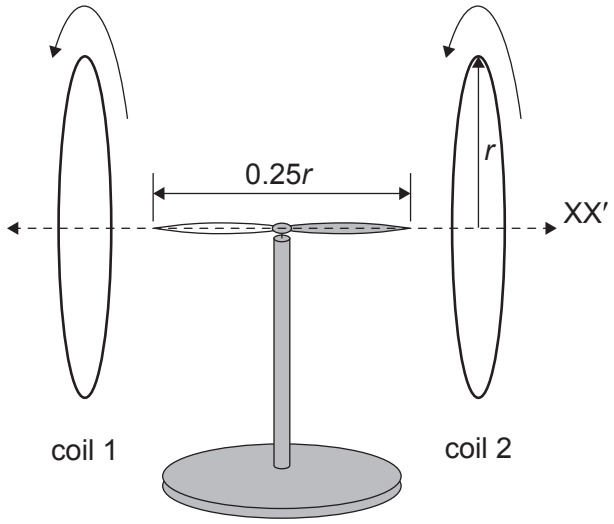
D. $3F$

3. A group of students wants to determine the horizontal component B_H of the Earth's magnetic field.

They place a magnet (in the form of a magnetic needle) midway between two coils.

When there is no current through the coils, the magnet aligns itself in the north-south direction. When there is an identical current established in the coils, the magnetic field produced deflects the magnet.

diagram not to scale



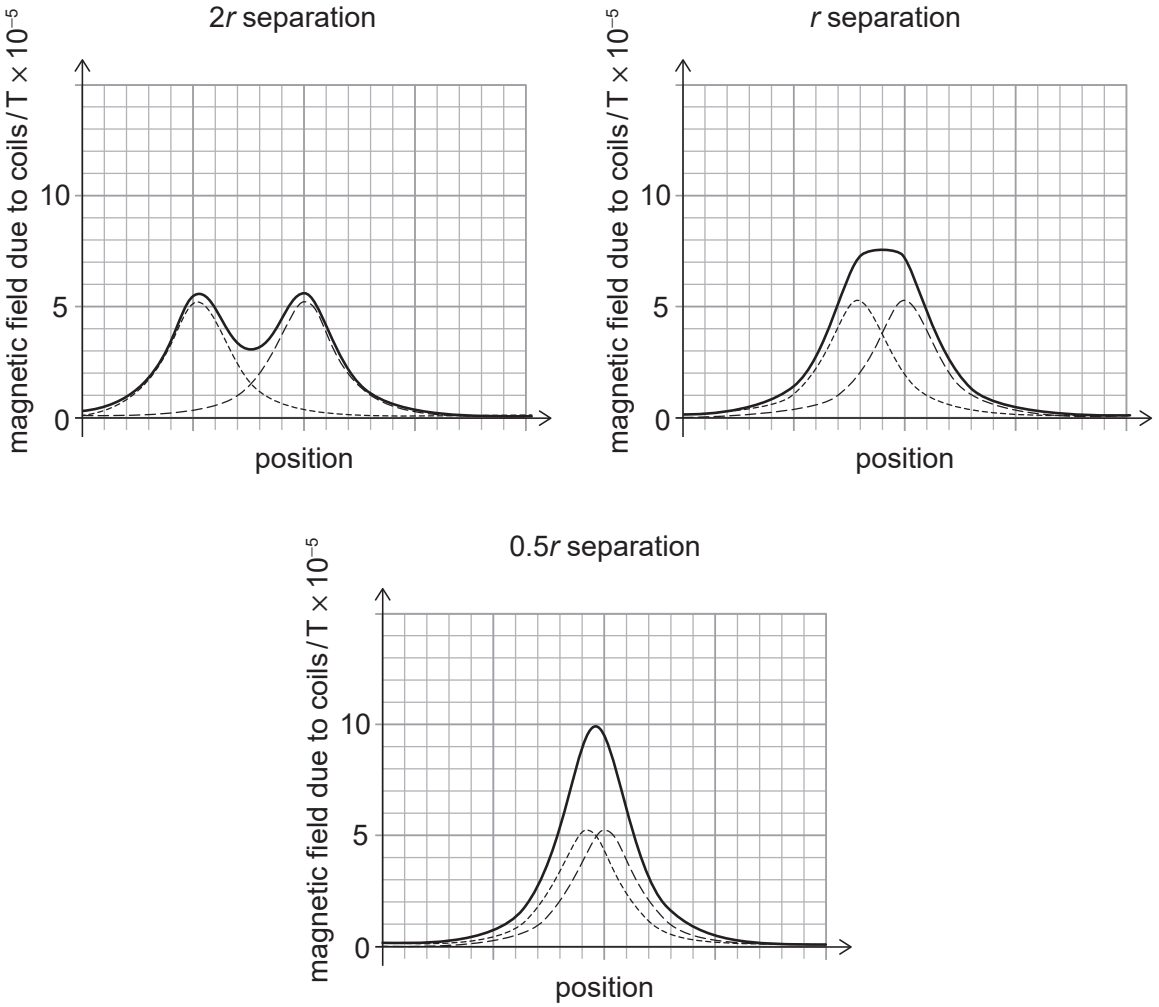
Each coil has a radius r. The length of the magnet is $0.25r$.

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(Question 3 continued)

The students have to decide on the horizontal separation of the two coils. Their choices are separations of 2*r*, *r* and 0.5*r*.

The variation with distance of the magnetic field strength due to each coil and the resultant magnetic field strength for both coils are shown for each of these separations. The dotted line represents the magnetic field from each coil, while the solid line shows the resultant magnetic field.



(a) State and explain which coil separation the students should choose for this experiment. [2]

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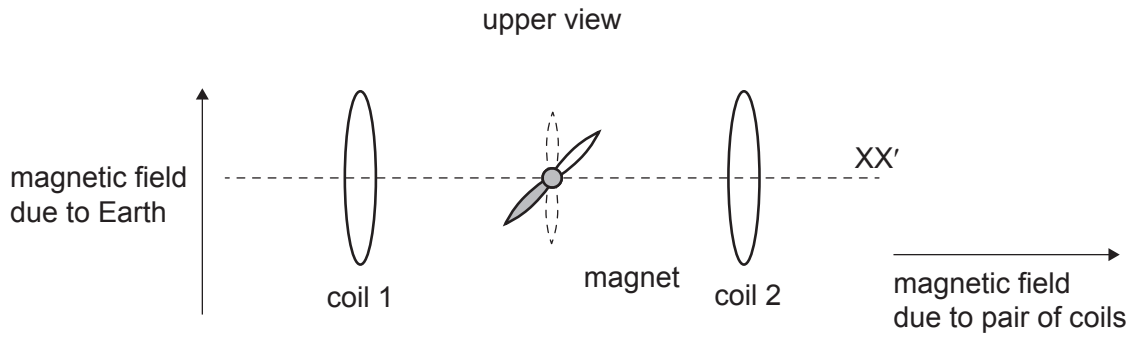
(Question 3 continued)

(b) Explain why the students place axis XX′ of the coils in the east-west direction. [2]

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(c) The deflection of the magnet is shown.

diagram not to scale



The magnet comes to rest when it makes an angle of 24° to XX′.

Determine, using the graphs, B_H. [2]

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Question 3 - working space

26. Two point charges, $+Q$ and $-Q$, are at a distance d from each other.

What is the magnitude of the electric field strength midway between the charges?

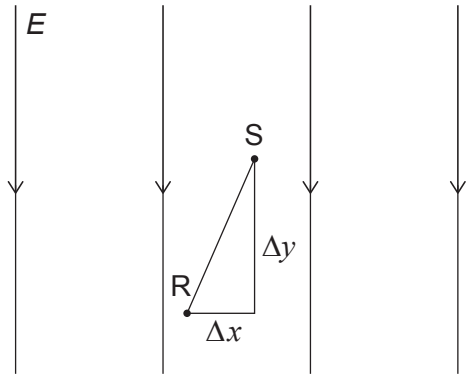
A. Zero

B. $\frac{2kQ}{d^2}$

C. $\frac{4kQ}{d^2}$

D. $\frac{8kQ}{d^2}$

27. Two points R and S are in a uniform electric field of strength E, directed vertically downwards. The horizontal distance from R to S is Δx, and the vertical distance from R to S is Δy.



The electric potential at R is zero. What is the electric potential at S?

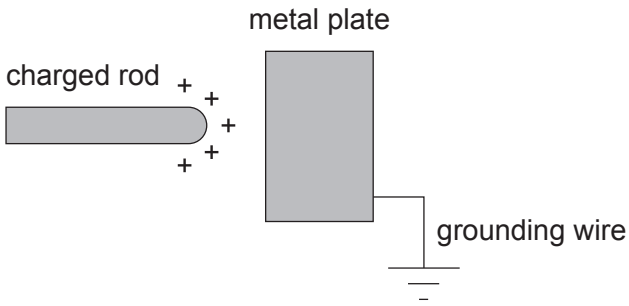
A. $E\sqrt{\Delta x^2 + \Delta y^2}$

B. $E\Delta y$

C. $-E\sqrt{\Delta x^2 + \Delta y^2}$

D. $-E\Delta y$

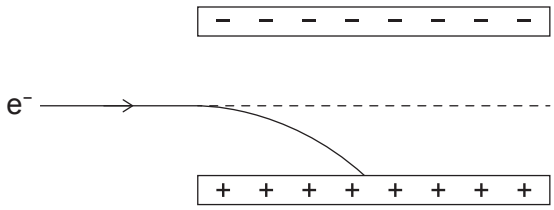
30. A positively charged rod is near a metal plate that is grounded as shown.



The grounding wire and then the rod are removed. What is correct about the overall charge on the plate before and after grounding is removed?

	Charge on plate before grounding is removed	Charge on plate after grounding is removed
A.	neutral	neutral
B.	neutral	negative
C.	negative	neutral
D.	negative	negative

31. An electron with speed v enters the region between two charged parallel plates midway between the plates, as shown. The potential difference between the plates is V.



What is the speed of the electron on impact with the plate?

A. $\sqrt{v^2 + \frac{eV}{2m_e}}$

B. $\sqrt{v^2 + \left(\frac{eV}{2m_e}\right)^2}$

C. $\sqrt{v^2 + \frac{eV}{m_e}}$

D. $\sqrt{v^2 + \left(\frac{eV}{m_e}\right)^2}$

24. A solid metallic sphere is positively charged and isolated from all other charges.

The electric potential due to the sphere

A. is constant inside the sphere.

B. is constant outside the sphere.

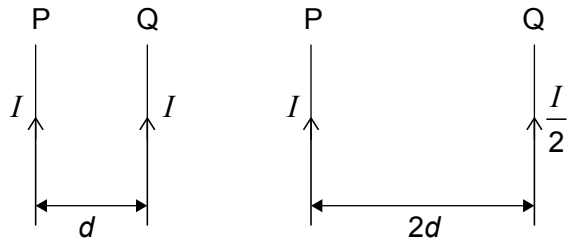
C. is smallest at the surface of the sphere.

D. increases with distance from the sphere.

26. Two long parallel wires P and Q are a distance *d* apart. They each carry a current.

A magnetic force per unit length *F* acts on P due to Q.

The distance between the wires is increased to 2*d* and the current in Q is decreased to $\frac{I}{2}$.



What is the magnetic force per unit length that acts on P due to Q after the changes?

A. $\frac{F}{8}$

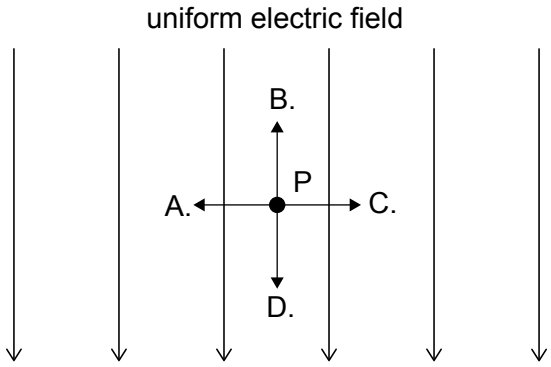
B. $\frac{F}{4}$

C. $\frac{F}{2}$

D. F

27. P is a point in a uniform electric field.

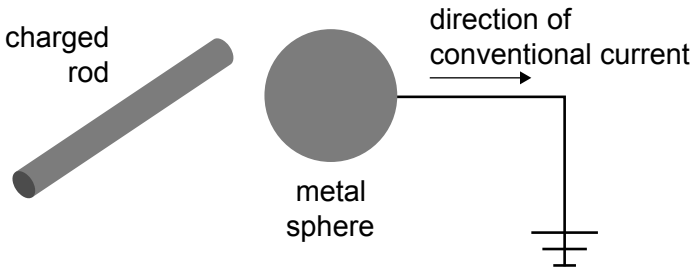
What is the direction in which the electric potential increases at P?



Turn over

31. A charged rod is brought near an initially neutral metal sphere without touching it.

When the sphere is grounded (earthed), there is an electric current for a short time from the sphere to the ground.

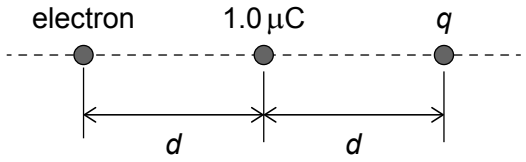


The ground connection is then removed.

What are the charge on the rod and the charge induced on the sphere when the connection is removed?

	Charge on the rod	Charge induced on the sphere
A.	negative	negative
B.	negative	positive
C.	positive	negative
D.	positive	positive

32. A positive point charge of magnitude 1.0 μC and a point charge *q* are separated by a distance *d*.



An electron is placed at a distance *d* from the +1.0 μC charge. The electric force on the electron is zero.

What is *q*?

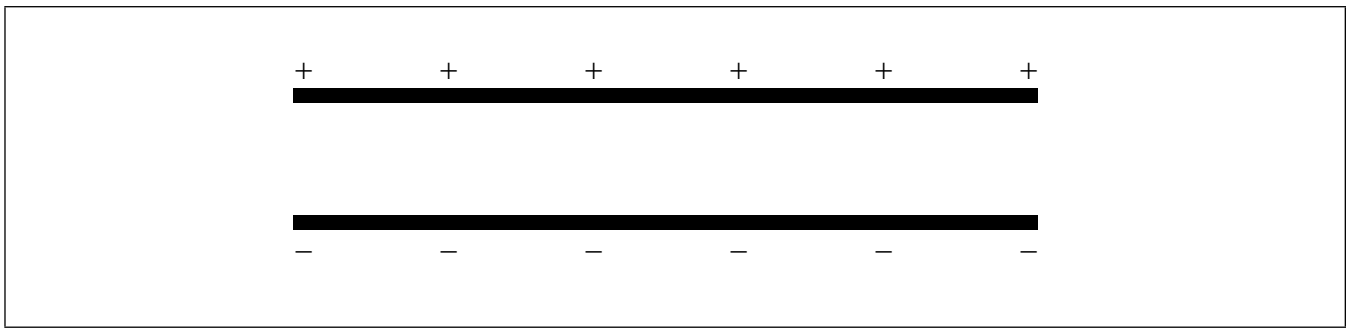
A. −4.0 μC

B. −2.0 μC

C. 2.0 μC

D. 4.0 μC

9. The diagram shows two parallel conducting plates that are oppositely charged.



(a) (i) Draw the electric field lines due to the charged plates. [2]

(ii) The potential difference between the plates is 960 V and the distance between them is 8.0 mm. Calculate the electric field strength *E* between the plates. [2]

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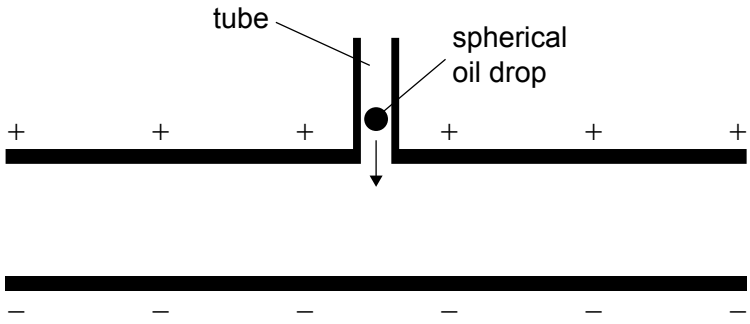
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(Question 9 continued)

In an experiment, an oil drop is introduced into the space between the plates through a small hole in the upper plate. The oil drop moves through air in a tube before falling between the plates.



(b) Explain why the oil drop becomes charged as it falls through the tube. [1]

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(This question continues on the following page)

(Question 9 continued)

(c) The oil drop is observed to be stationary in the space between the plates. Buoyancy is one of the forces acting on the drop.

The density of oil is 730 times greater than that of air.

(i) Show that the buoyancy force is much smaller than the weight. [3]

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(ii) Draw the forces acting on the oil drop, ignoring the buoyancy force. [2]



oil drop

(This question continues on the following page)

(Question 9 continued)

(iii) Show that the electric charge on the oil drop is given by

$$q = \frac{\rho_o g V}{E}$$

where ρ_o is the density of oil and V is the volume of the oil drop. [2]

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(iv) State the sign of the charge on the oil drop. [1]

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(This question continues on page 21)

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will not be marked.

(Question 9 continued)

(d) The electric field is turned off. The oil drop falls vertically reaching a constant speed v.

(i) Outline why, for this drop, $\rho_o gV = 6\pi\eta rv$ where η is the viscosity of air and r is the radius of the oil drop. [2]

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(ii) Show that the charge on the oil drop is about 4.8×10^{-19} C.

The following data for the oil drop are available:

$r = 1.36\,\mu m$
$\eta = 1.60 \times 10^{-5}\,Pa\,s$
$v = 0.140\,mm\,s^{-1}$ [3]

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(iii) The oil drop splits into two parts of equal mass. Both are charged. Deduce the net charge on each part. [2]

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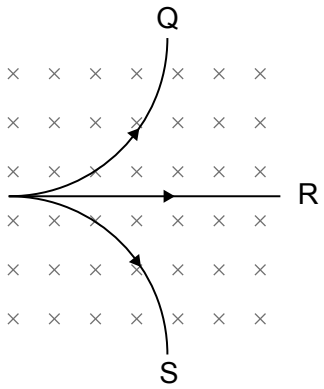
Question 9 - working space

APOLLO

Motion in electromagnetic fields

8 questions

25. The diagram shows possible paths Q, R, and S of particles moving into a region of uniform magnetic field. The field is directed into the plane of the page.

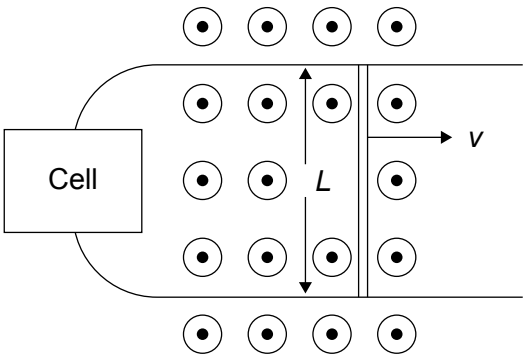


What particles are shown by each path?

	Q	R	S
A.	proton	neutron	electron
B.	neutron	electron	alpha particle
C.	electron	neutron	alpha particle
D.	proton	electron	neutron

Turn over

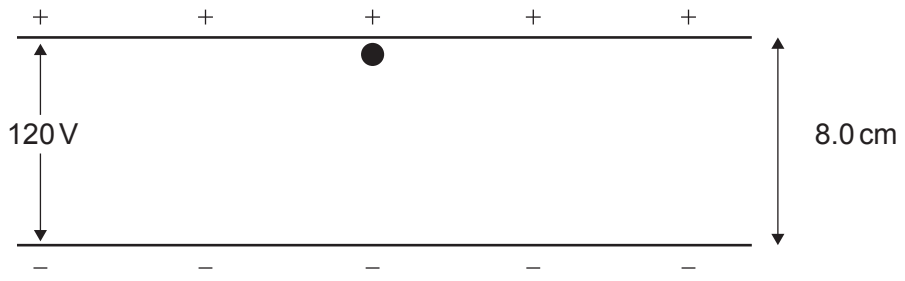
26. A circuit is created with a cell, two parallel conducting wires and a moveable metal rod of length *L*. When a uniform magnetic field *B* is directed out of the page through the circuit, the metal rod moves to the right with velocity *v*. The initial current in the circuit is I.



What is the direction of the current through the circuit and the initial force on the metal rod?

	Direction of I	**Initial force on the metal rod**
A.	anti-clockwise	$BIL\sin(90°)$
B.	clockwise	$BIL\sin(90°)$
C.	anti-clockwise	$BIL\sin(0°)$
D.	clockwise	$BIL\sin(0°)$

3. Two oppositely charged parallel plates are a distance 8.0 cm apart. The potential difference between the plates is 120 V. An alpha particle is placed on the positively charged plate and released from rest. Gravity is ignored.



(a) Calculate the electric field between the plates. [1]

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(b) (i) Show that the acceleration of the alpha particle is about $7 \times 10^{10}\,\text{m s}^{-2}$. [2]

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(ii) Calculate the time taken for the alpha particle to reach the negative plate. [2]

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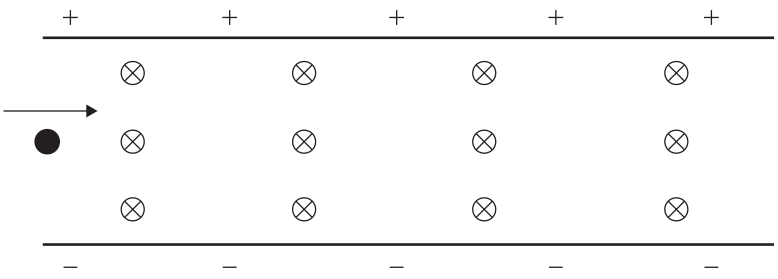
(iii) State, in eV, the kinetic energy of the alpha particle when it arrives at the negative plate. [1]

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(This question continues on the following page)

(Question 3 continued)

(c) A magnetic field directed into the plane of the page is now established between the plates. An alpha particle enters the region between the plates with a horizontal speed of $5.0 \times 10^5\,\text{m s}^{-1}$. The particle is not deflected.



Calculate the magnitude of the magnetic field. [2]

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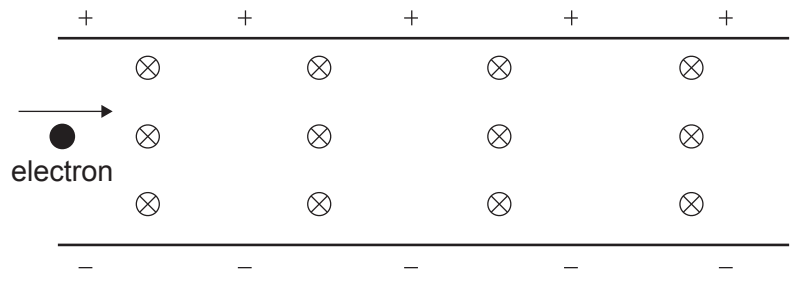
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(d) The alpha particle in (c) is replaced by an electron. The electron enters the region between the plates with the same velocity as the alpha particle.

Draw, on the diagram, the path of the electron. [1]

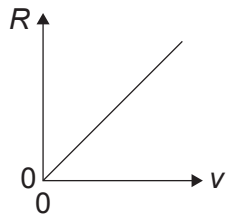


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Question 3 - working space

28. An electron moves with speed v in a region of a uniform magnetic field of strength B. The path of the electron is a circle of radius R. The graph shows how R varies with v.



What is the gradient of the graph?

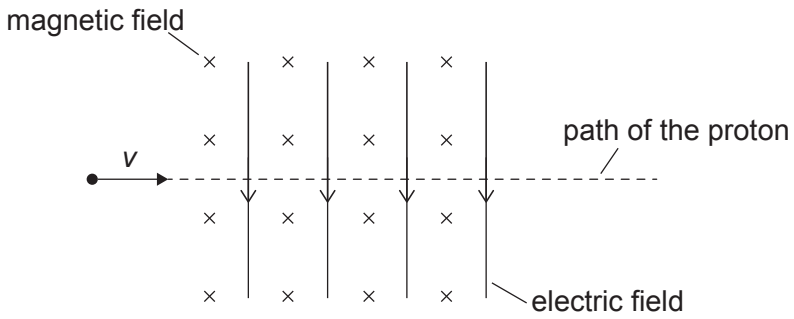
A. $\frac{m_e B}{e}$

B. $\frac{eB}{m_e}$

C. $\frac{m_e}{eB}$

D. $\frac{e}{m_e B}$

29. A proton enters a region where electric and magnetic fields are perpendicular to each other. The initial velocity v of the proton is perpendicular to both fields. The path of the proton is not deflected in the fields.



The proton is replaced by an alpha particle that is also not deflected by the fields. What is the velocity of the alpha particle?

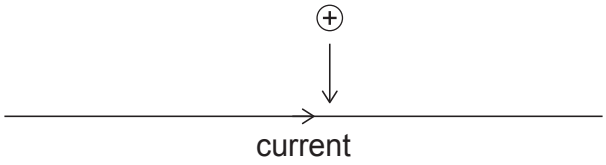
A. $\frac{v}{2}$

B. v

C. $2v$

D. $4v$

32. A positively charged particle is moving towards a current-carrying wire as shown.



What is the direction of the magnetic force acting on the charged particle?

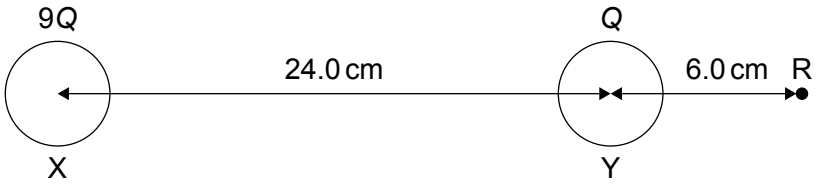
A. To the right

B. To the left

C. Into the page

D. Out of the page

3. (a) Two identical conducting spheres X and Y that carry positive charges are separated by a centre-to-centre distance of 24.0 cm in a vacuum. The charge on X is $9Q$ and the charge on Y is Q. Point R is 6.0 cm from the centre of Y, as shown.



The resultant electric field at R is 32.6 MN C^{-1}. Determine Q, giving an appropriate unit. [2]

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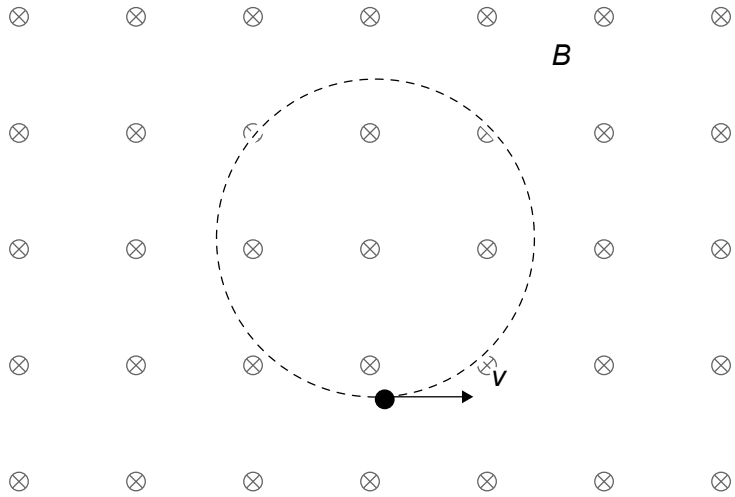
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(Question 3 continued)

(b) A particle of mass m and positive charge q moves on a circular path with speed v in a vacuum. A uniform magnetic field B is directed into the plane of the page.



(i) Show that the radius R of the circular path is given by $R = \frac{mv}{qB}$. [1]

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(ii) Suggest why the speed of the particle stays constant, even though a force acts on the particle. [1]

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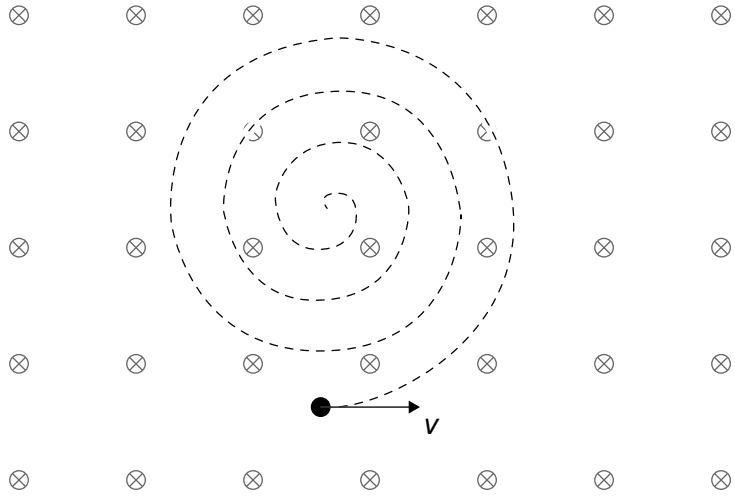
(This question continues on page 11)

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(Question 3 continued)

(c) The particle in (b), now moving in a region of magnetic field **in air**, follows the path shown.



Explain the shape of this path. [2]

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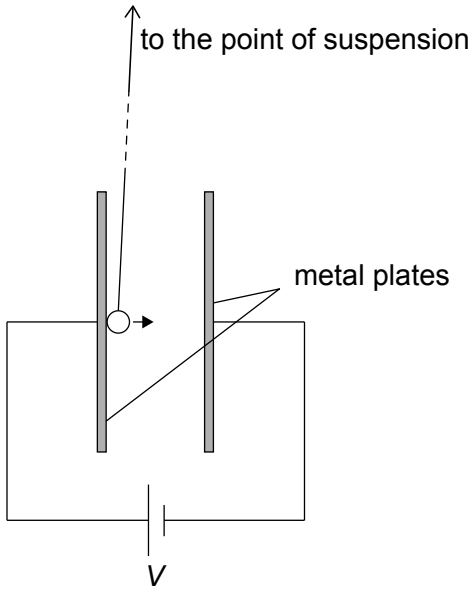
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Question 3 - working space

1. A group of students investigate the motion of a conducting ball suspended from a long string. The ball is between two vertical metal plates that have an electric potential difference V between them. The ball is touched to one plate so that it becomes electrically charged and is repelled from the plate. For a given potential difference, the ball bounces between the plates with a constant period.

diagram not to scale



(a) The students vary V and measure the time T for the ball to move **once** from one plate to the other. The table shows some of the data.

V / kV	T / s ± 0.1 s
3.00	1.4
5.00	0.8
7.00	0.6

(i) V is provided by two identical power supplies connected in series. The potential difference of each of the power supplies is known with an uncertainty of 0.01 kV.

State the uncertainty in the potential difference V. [1]

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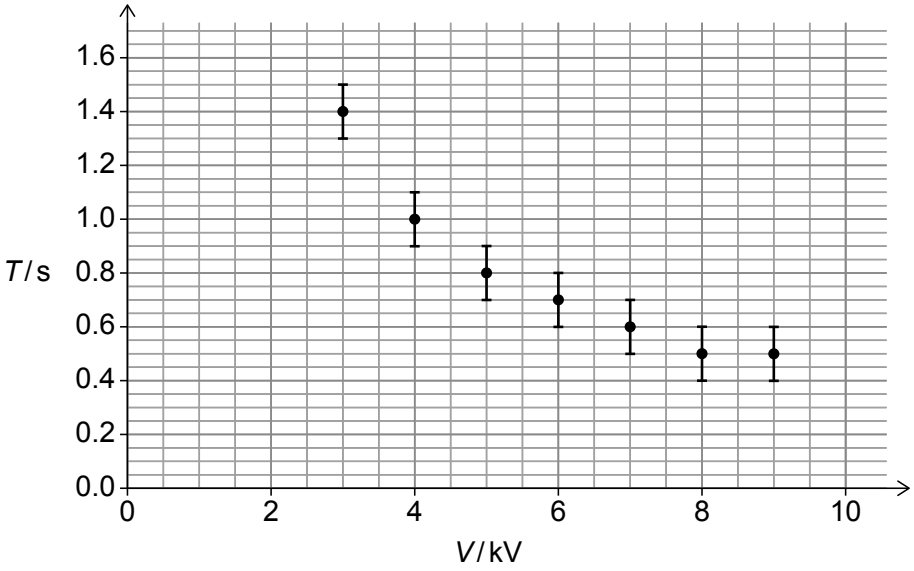
(Question 1 continued)

(ii) T is measured with an electronic stopwatch that measures to the nearest 0.1 s.

Describe how an uncertainty in T of less than 0.1 s can be achieved using this stopwatch. [2]

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The graph shows the variation of T with V. The uncertainty in V is not plotted.



(iii) Outline why it is unlikely that the relationship between T and V is linear. [1]

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(iv) Calculate the largest fractional uncertainty in T for these data. [2]

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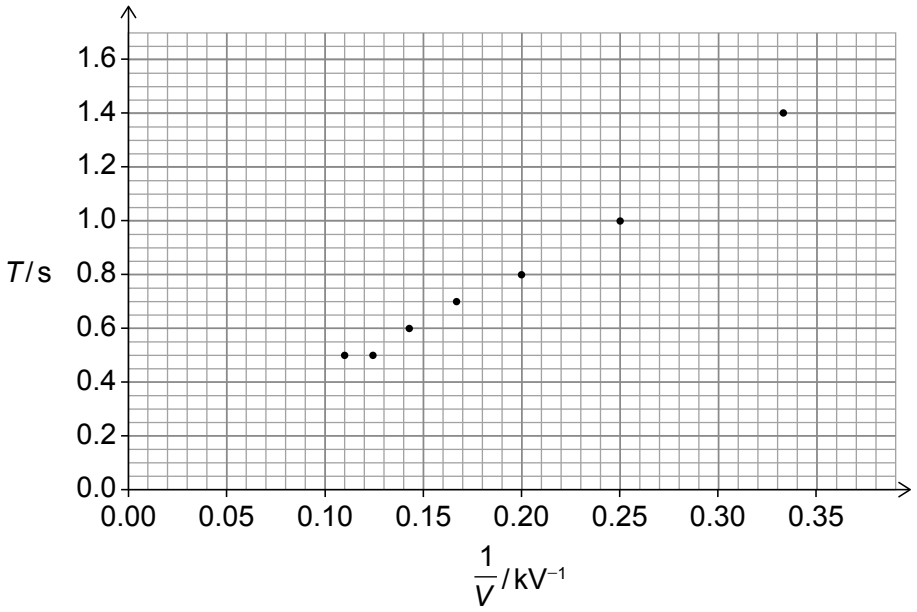
(Question 1 continued)

(b) The students suggest the following theoretical relationship between T and V:

$$T = \frac{A}{V}$$

where A is a constant.

To verify the relationship, the variation of T with $\frac{1}{V}$ is plotted.



(i) Determine A by drawing the line of best fit. [3]

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(Question 1 continued)

(ii) State the units of *A*. [1]

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(iii) The theoretical relationship assumes that the ball is only affected by the electric force.

Suggest why, in order to test the relationship, the length of the string should be much greater than the distance between the plates. [2]

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Question 1 - working space

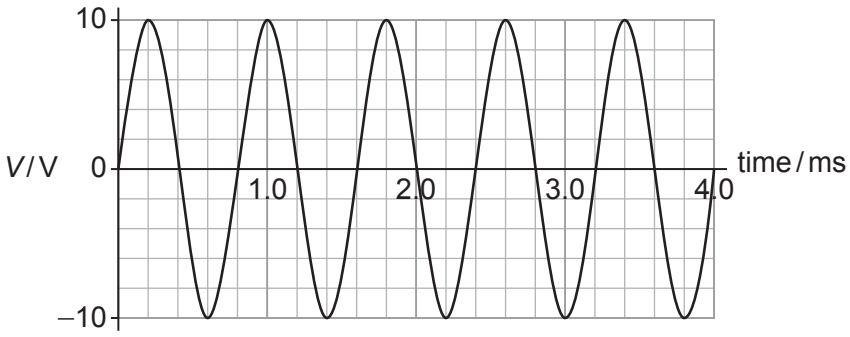
APOLLO

Induction

10 questions

31. A coil of wire rotates at a constant angular speed ω in a uniform magnetic field.

The variation with time of the emf in the coil is shown.



The angular speed is changed to $\frac{3\omega}{4}$.

What is the amplitude of the emf and the time period for the variation of the emf in the coil after the change?

	Amplitude of emf / V	Time period / ms
A.	13	0.60
B.	13	1.1
C.	7.5	0.60
D.	7.5	1.1

28. A horizontal conducting ring is perpendicular to a uniform vertical magnetic field. When the ring is rotated through 180° about the horizontal axis, an average emf of 2.0 μV is induced in the ring. The area enclosed by the ring is 4.0 cm^2 and the rotation takes 2.0 s.

What is the magnetic field?

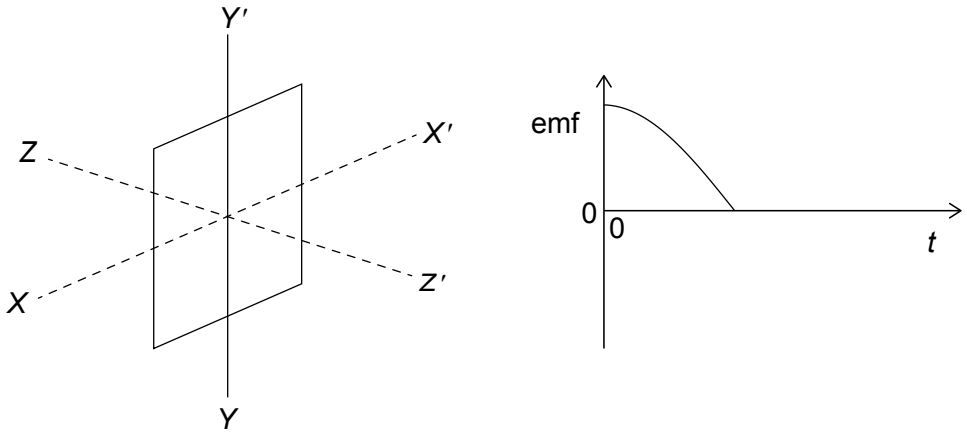
A. 2.5 mT

B. 5.0 mT

C. 10.0 mT

D. 20.0 mT

29. A rectangular coil rotates at a constant angular velocity. At the instant shown, the plane of the coil is at right angles to the line ZZ'. A uniform magnetic field acts in the direction YY'. The variation of emf with time t is shown.



What coil rotation about the axis specified produces this graph?

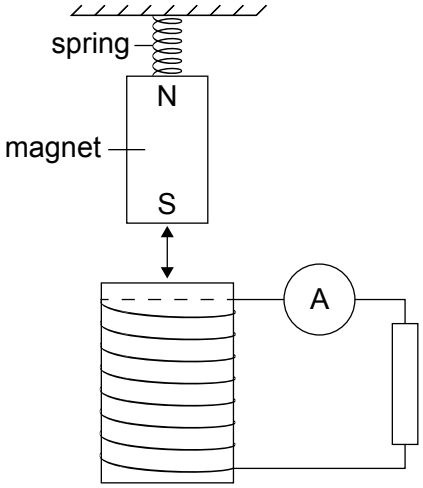
A. Through $\frac{\pi}{2}$ about XX'

B. Through π about XX'

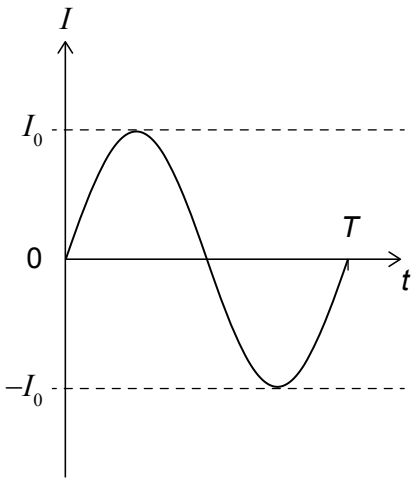
C. Through $\frac{\pi}{2}$ about YY'

D. Through π about YY'

30. A magnet attached to a spring oscillates above a coil as shown. The period of the oscillation is *T*.



The graph shows the variation with time *t* of the current I in the coil.



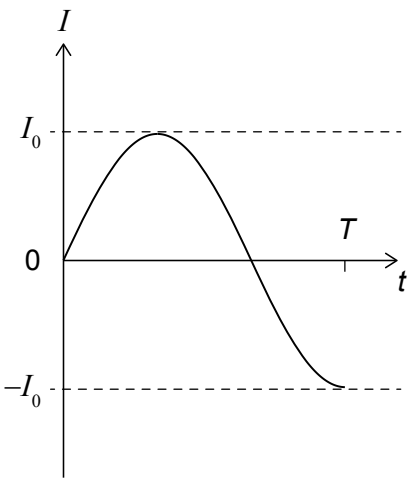
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(Question 30 continued)

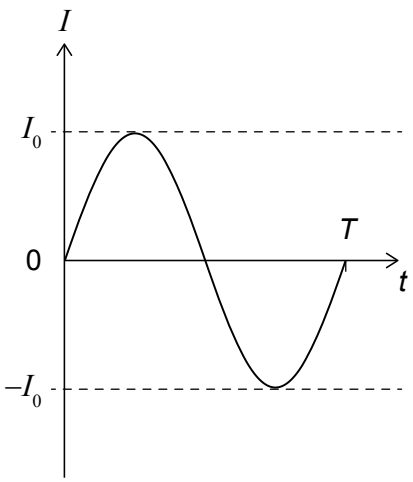
The amplitude of the magnet's oscillation is now decreased.

What is the new variation of I with t?

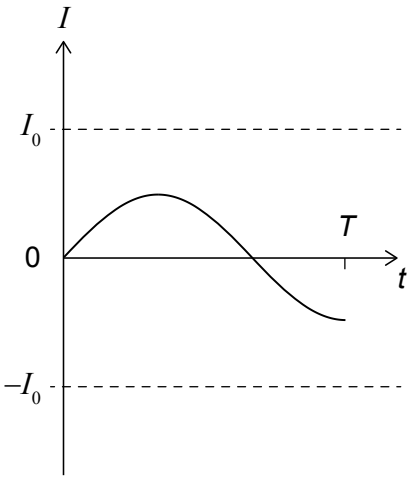
A.



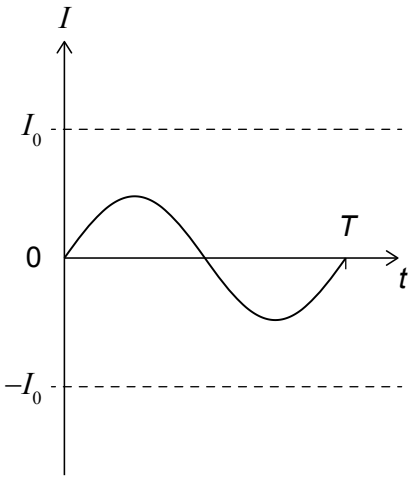
B.



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D.

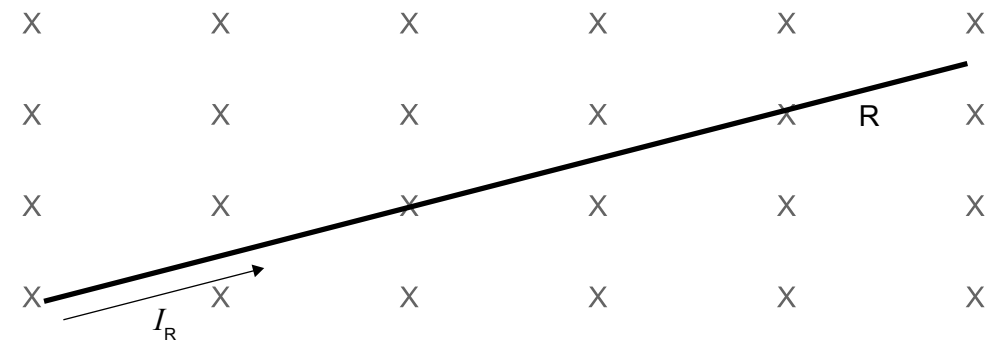


8. A rod, R, lies perpendicular to a uniform magnetic field *B* of strength 0.50 T directed into the plane of the page. R is connected to a circuit and the electric current I_R is 2.0 A.

(a) (i) Calculate the magnitude of the force per unit length on R. [2]

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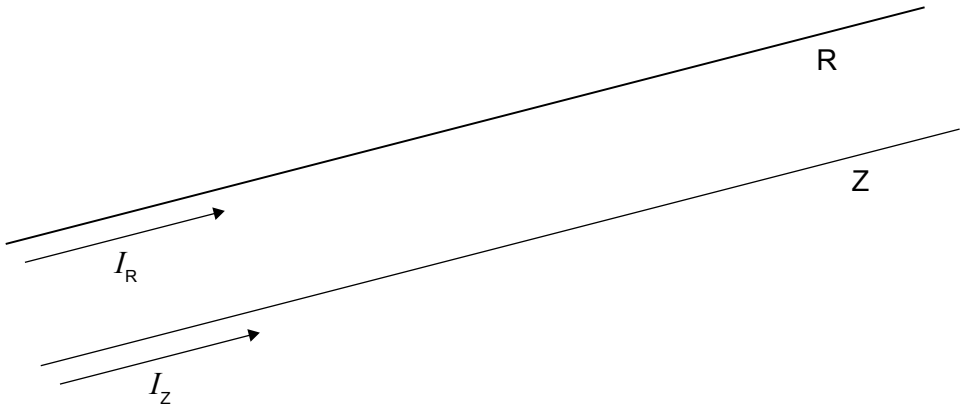
(ii) Identify on the diagram the direction of the force on R. [1]



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(Question 8 continued)

(b) *B* is removed and a wire Z, carrying a current I_Z, is placed parallel to R.



(i) Show that the magnetic field strength B_R due to R at a point on Z is

$$B_R = \frac{\mu_0}{2\pi}\frac{I_R}{r}$$

where *r* is the distance between R and Z. [2]

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(ii) Derive the units of μ_0 in SI fundamental units. [1]

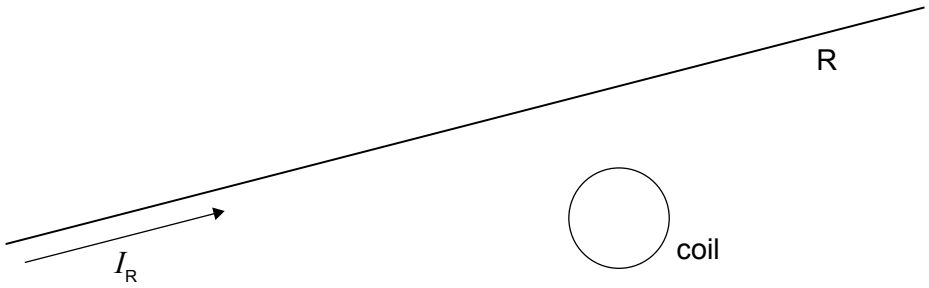
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(Question 8 continued)

(c) A small coil of wire of radius 2.0 cm and 20 turns is now located with its centre 10.0 cm from R. The current in R is kept constant at 2.0 A.

diagram not to scale



(i) Explain why there is no current induced in the coil. [2]

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(ii) The current in R increases at a constant rate from 2.0 A to 10.0 A in 0.5 seconds.

Calculate the emf induced in the coil. [3]

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(Question 8 continued)

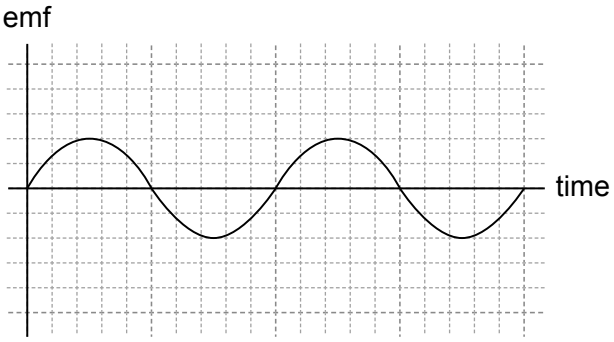
(iii) Deduce the direction of the current induced in (c)(ii). [2]

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(Question 8 continued)

(d) The coil is made to rotate such that an emf is induced. The graph shows the variation with time of the emf induced in the coil.



The frequency of rotation is doubled. Draw on the graph the variation with time of the new emf induced. [2]

(This question continues on the following page)

(Question 8 continued)

(e) An electron is moving at constant velocity $v = 9.0 \times 10^5\,\text{m s}^{-1}$ parallel to a rod T, at a perpendicular distance d. T is connected to a cell via a switch. When the switch is closed the electron's path curves with initial radius r. The magnetic field strength at the position of the electron at d is $4.0 \times 10^{-6}\,\text{T}$.

(i) Calculate the initial radius of the electron's path. [3]

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(ii) Explain the subsequent change in the radius of the electron's path. [2]

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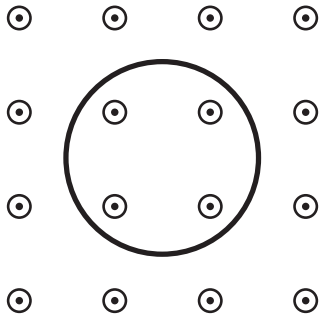
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Question 8 - working space

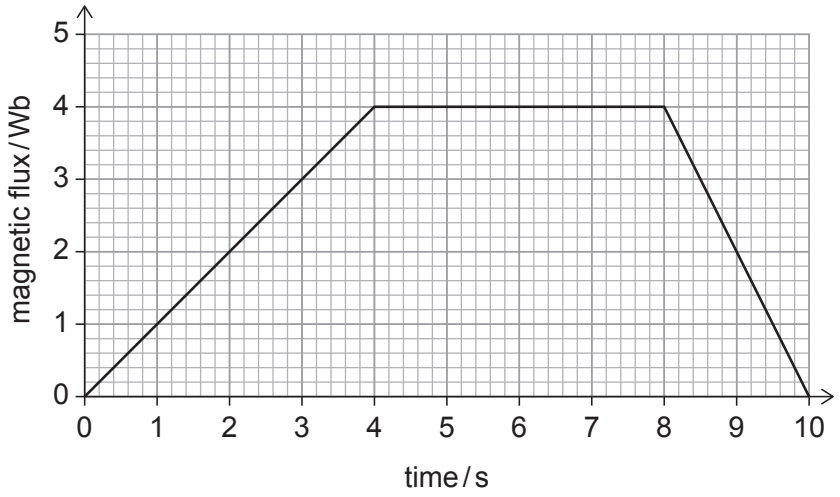
30. A conducting ring is perpendicular to a uniform magnetic field directed out of the page.



The magnitude of the magnetic field strength increases. What are the direction of the conventional current induced in the ring and the net magnetic force on the ring?

	Current induced in the ring	Magnetic force on the ring
A.	clockwise	zero
B.	counter-clockwise	zero
C.	clockwise	non-zero
D.	counter-clockwise	non-zero

31. The graph shows how the magnetic flux linked through a conducting coil varies with time. The coil has only one turn.



What is the maximum emf induced in the coil?

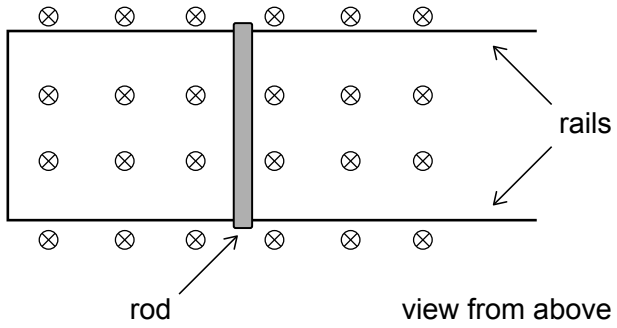
A. 0.40 V

B. 1.0 V

C. 2.0 V

D. 4.0 V

8. (a) A conducting rod is placed on horizontal, conducting, frictionless rails.



A uniform magnetic field is directed into the plane of the page.

The rod begins to move to the right after it is given a short push. Explain why the rod will quickly stop moving. [3]

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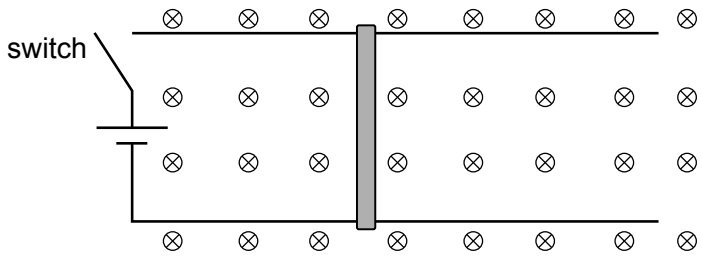
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(Question 8 continued)

(b) In another experiment, the rod is at rest on the rails. A cell and a switch are inserted as shown.



The switch is closed.

(i) Suggest what happens to the rod. [1]

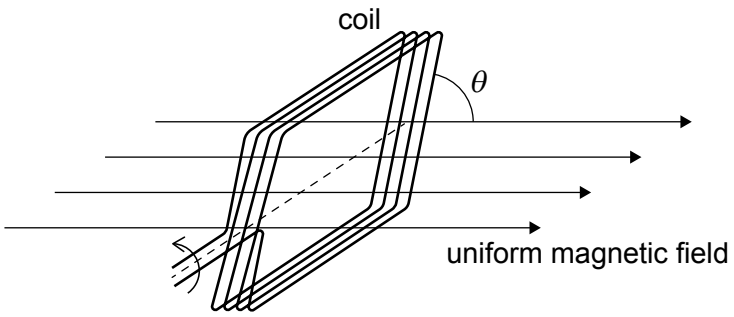
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(ii) Explain why the rod will eventually reach terminal speed. [2]

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Question 8 - working space

29. A rectangular conducting coil rotates at a constant angular velocity in a uniform magnetic field. The rotation axis of the coil is perpendicular to the field.



At one instant the plane of the coil is at an angle θ to the direction of the field.

The magnitude of the emf induced in the coil is

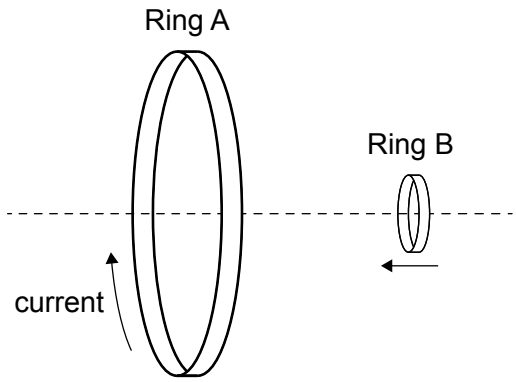
A. never zero.

B. at a maximum when $\theta = 0°$ or 180°.

C. at a maximum when $\theta = 45°$ or 225°.

D. at a maximum when $\theta = 90°$ or 270°.

5. Two conducting rings, A and B, have their centres on the same line. The planes of A and B are parallel. There is a constant clockwise current in A. Ring A is stationary and ring B moves towards ring A at a constant speed.



(a) Outline why the magnetic flux in ring B increases. [1]

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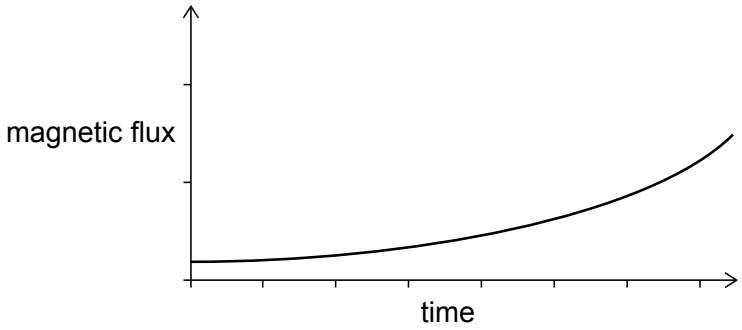
(b) State the direction of the induced current in ring B. [1]

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(Question 5 continued)

(c) The graph shows how the magnetic flux in ring B varies with time.



Discuss the variation with time of the induced current in ring B. [3]

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(d) Outline why work must be done on ring B as it moves towards ring A at a constant speed. [2]

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Question 5 - working space

APOLLO

Structure of the atom

11 questions

32. An ion X contains the following particles:

- 53 protons
- 89 neutrons
- 54 electrons.

What is the nuclear notation for X?

A. $^{142}_{53}X$

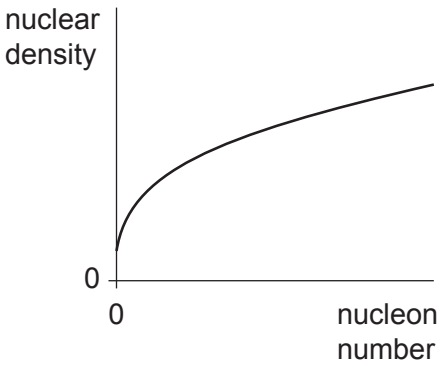
B. $^{89}_{53}X$

C. $^{143}_{54}X$

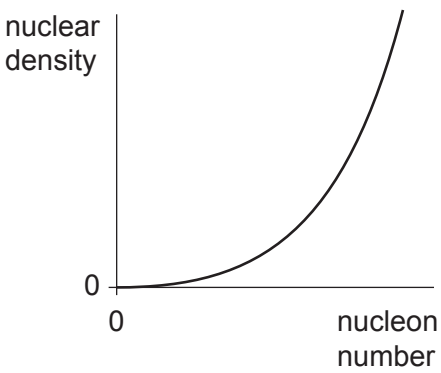
D. $^{107}_{54}X$

33. What is the variation with nucleon number of the density of nuclei?

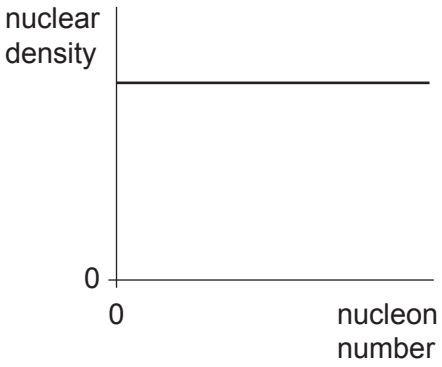
A.



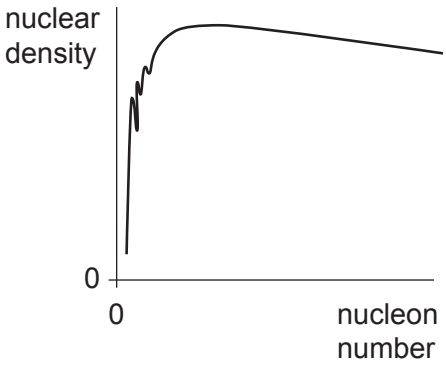
B.



C.



D.



33. In the Geiger–Marsden–Rutherford experiment, alpha particles were accelerated through a potential difference of 7.7 MV and incident on a thin foil of gold. The proton number of gold is 79.

What is the distance of closest approach?

A. $\frac{158ke}{7.7\times10^{6}}$

B. $\frac{158ke^{2}}{7.7\times10^{6}}$

C. $\frac{79ke}{7.7\times10^{6}}$

D. $\frac{79ke^{2}}{7.7\times10^{6}}$

33. The nucleus of an element X has radius R and density ρ.

The nucleon number of an element Y is 8 times that of X.

What is the radius and density of the nucleus of Y?

	Radius of nucleus of Y	Density of nucleus of Y
A.	$8R$	8ρ
B.	$2R$	8ρ
C.	$8R$	ρ
D.	$2R$	ρ

5. (a) A stationary isotope of $_{88}$Ra (Radium) decays into Rn (Radon) and an alpha particle.

(i) Identify the proton number of Rn. [1]

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The following data are available:

Atomic mass of Ra $= 226.02540\,\text{u}$
Atomic mass of Rn $= 222.01757\,\text{u}$
Mass of $\alpha = 4.00260\,\text{u}$

(ii) Show that the energy released in this decay is about 5 MeV. [2]

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(iii) Show that about 98 % of the energy released is carried by the alpha particle. [2]

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(This question continues on the following page)

(Question 5 continued)

(b) In an experiment performed by Geiger, Marsden and Rutherford to investigate the atomic structure, alpha particles were directed into a thin metal foil.

(i) Describe two observations of this experiment. [2]

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(ii) Outline how the experiment was interpreted. [2]

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(iii) In this experiment, $^{197}_{79}Au$ (gold) foil was used.

Calculate the distance of closest approach for alpha particles of 4.8 MeV in head-on scattering. [3]

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(Question 5 continued)

(iv) Calculate $\frac{\text{radius of } {}^{197}_{79}\text{Au nucleus}}{\text{radius of } {}^{27}_{13}\text{Al}\left(\text{aluminium}\right) \text{ nucleus}}$. [2]

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Question 5 - working space

32. Which claim about the structure of the atom is falsified by the results of the Geiger–Marsden–Rutherford experiment?

A. The nucleus is only made up of positively charged particles.

B. The electrons in the atom move in orbits of fixed radius.

C. The positive charge occupies all of the atom's volume.

D. The electrons in the atom have continuous energy.

33. Three statements are made about emission and absorption spectra.

I. They provide information on the chemical composition of substances.

II. They provide evidence for mass-energy equivalence.

III. They arise from transitioning electrons between energy levels.

Which of the statements are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

34. For which of the following atoms would the Bohr model apply, if one electron was removed from the atom?

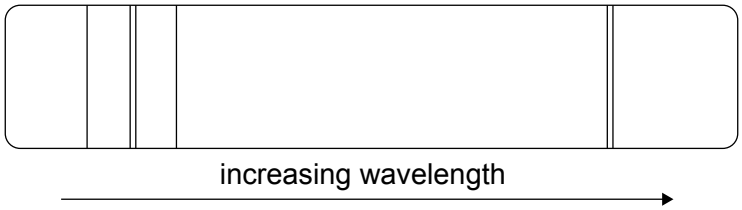
A. $^{22}_{11}\text{Na}$

B. $^{5}_{3}\text{Li}$

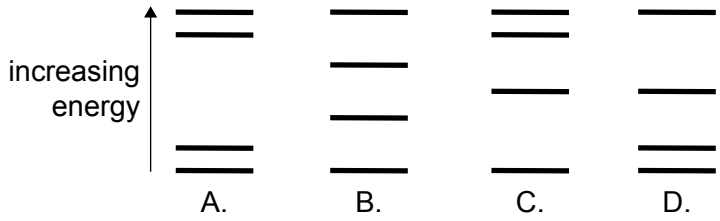
C. $^{235}_{92}\text{U}$

D. $^{4}_{2}\text{He}$

34. The diagram shows the emission spectrum of an atom.



Which of the following atomic energy level models can produce this spectrum?



38. The energy of the *n*th level of hydrogen is given by $-\frac{E_0}{n^2}$. What is the frequency of the photon emitted in the transition from $n = 4$ to $n = 2$?

A. $\frac{1}{16} \times \frac{E_0}{h}$

B. $\frac{3}{16} \times \frac{E_0}{h}$

C. $\frac{1}{4} \times \frac{E_0}{h}$

D. $\frac{3}{4} \times \frac{E_0}{h}$

40. An alpha particle ($^{4}_{2}\text{He}$) of initial energy 5.5 MeV moves towards the centre of a nucleus of gold-197 ($^{197}_{79}\text{Au}$).

What is the distance of closest approach of the alpha particle?

A. $1.0 \times 10^{-13}\,\text{m}$

B. $4.1 \times 10^{-14}\,\text{m}$

C. $2.1 \times 10^{-14}\,\text{m}$

D. $6.6 \times 10^{-33}\,\text{m}$

APOLLO

Quantum physics

19 questions

34. A photoelectron is emitted when a photon of energy E is incident on a metal surface.

The work function of the surface is Φ.

What is the maximum possible speed of the photoelectron as it leaves the surface?

A. $\sqrt{\frac{2(E-\Phi)}{m_e}}$

B. $\sqrt{\frac{E-\Phi}{m_e}}$

C. $\sqrt{\frac{E-\Phi}{m_e h}}$

D. $\sqrt{\frac{2(E-\Phi)}{m_e h}}$

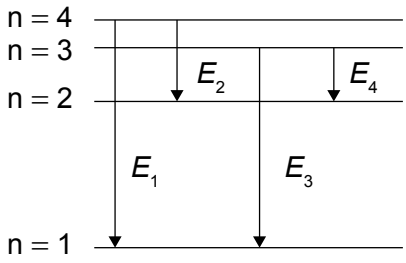
35. In a Compton scattering experiment a photon of wavelength λ_0 and frequency f_0 interacts with an electron.

After the interaction the wavelength and frequency of the photon are λ and f.

What are $\frac{\lambda}{\lambda_0}$ and $\frac{\lambda \times f}{\lambda_0 \times f_0}$?

	$\frac{\lambda}{\lambda_0}$	$\frac{\lambda \times f}{\lambda_0 \times f_0}$
A.	Greater than 1	Equal to 1
B.	Greater than 1	Less than 1
C.	Less than 1	Equal to 1
D.	Less than 1	Less than 1

32. Some transitions between the energy states of an atom are shown.



Which transition will emit a photon with the longest wavelength?

A. E_1

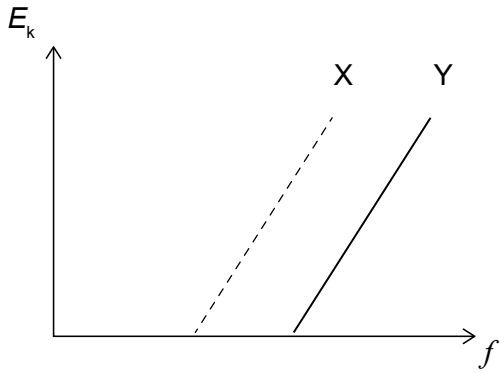
B. E_2

C. E_3

D. E_4

34. In two experiments X and Y measurements were made of the kinetic energies E_k of photoelectrons emitted when light is incident on two different metal surfaces.

The graph shows the variation of E_k with frequency f of the incident photons for both surfaces.



It can be deduced that in experiment Y…

A. the surface has a smaller work function than the surface in experiment X.

B. the surface has a larger work function than the surface in experiment X.

C. the intensity of the incident light is less than in experiment X.

D. the intensity of the incident light is more than in experiment X.

35. The intensity of electromagnetic radiation incident on a surface is I. The wavelength of the radiation is doubled and the number of photons incident per unit time per unit area is doubled.

What is the new intensity of radiation incident on the surface?

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

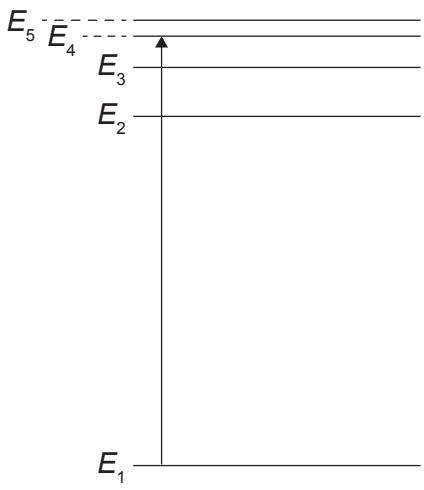
B. I

C. $2I$

D. $4I$

32. The energy levels of an atom in which an electron transitions from E_1 to E_4 are shown. E_1 is the ground state.

diagram to scale



How many different wavelengths can be emitted when electrons return to the ground state from E_4?

A. 1

B. 3

C. 6

D. 8

34. Which of the following expressions gives the de Broglie wavelength, in metres, of a tennis ball of mass 0.06 kg and kinetic energy 3 J?

A. $\frac{h}{3}$

B. $\frac{h}{0.6}$

C. $\frac{h}{(0.6)^2}$

D. $\frac{h}{0.06}$

5. (a) Outline why Compton scattering offers better evidence for the particle nature of light than the photoelectric effect. [2]

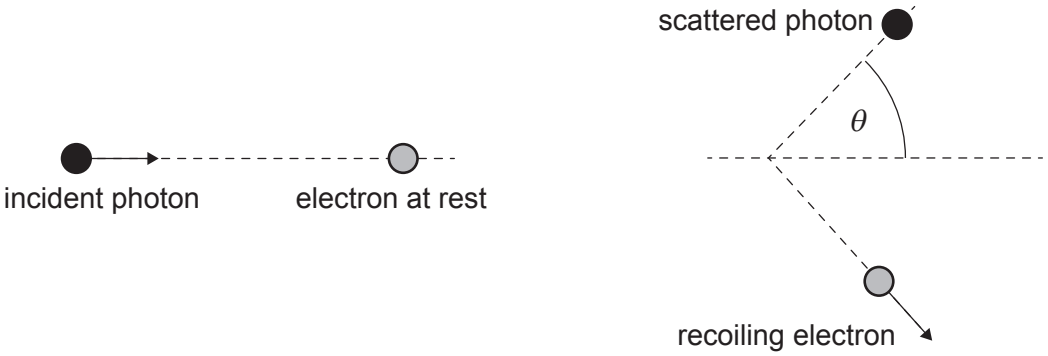
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A photon of wavelength 6.40×10^{-12} m and energy 0.194 MeV is incident on an electron at rest. The photon scatters at an angle θ with wavelength 7.47×10^{-12} m. The electron recoils.



(b) Outline why the wavelength of the scattered photon is longer than that of the incident photon. [2]

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(c) (i) Show that the energy of the scattered photon is about 0.17 MeV. [1]

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(Question 5 continued)

(ii) Calculate the kinetic energy of the recoiling electron. [1]

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(iii) For an electron, $\frac{h}{m_e c} = 2.43 \times 10^{-12}$ m. Determine θ. [2]

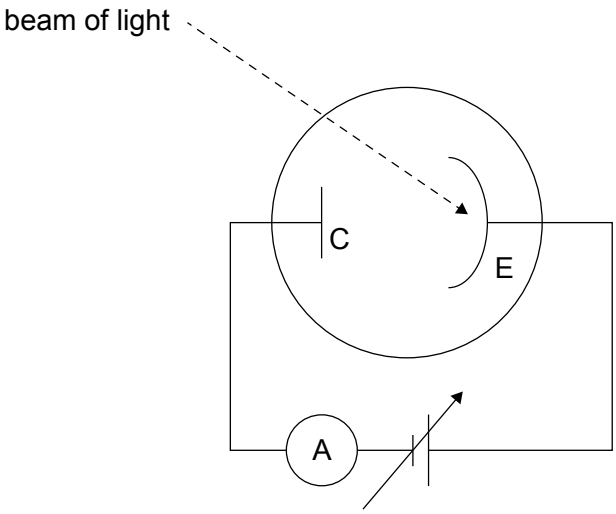
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Question 5 - working space

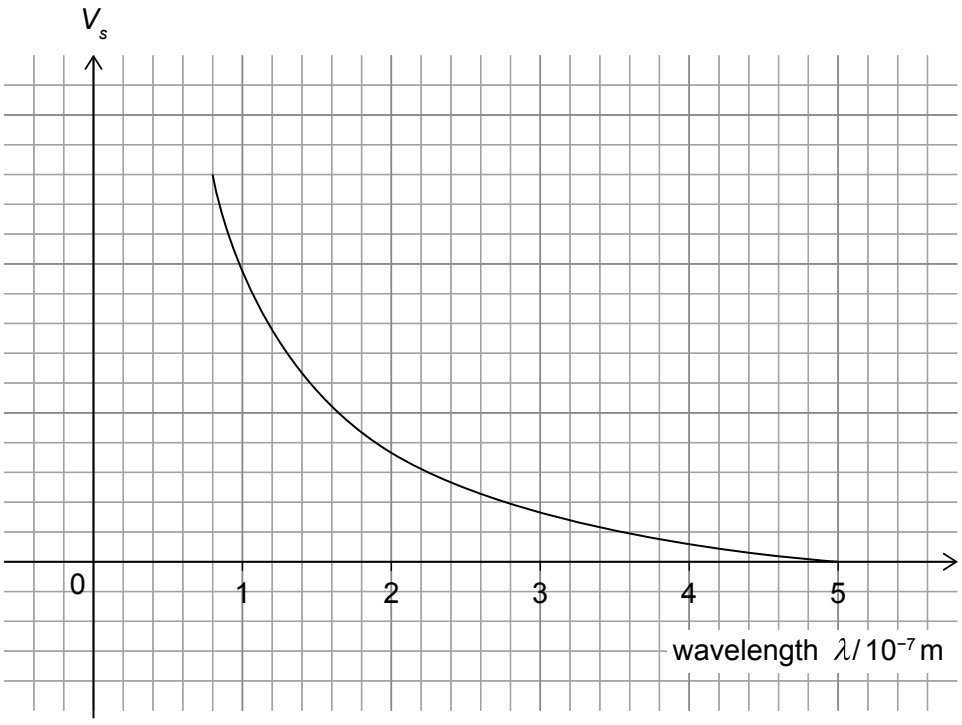
6. An electric circuit is used to investigate the photoelectric effect.

A beam of light from a laser of variable wavelength λ and constant intensity I is used to illuminate a curved metallic electrode E. Another electrode, C, is near E. Both electrodes are in vacuum. For each λ tuned in the laser, the voltage across CE is raised. The minimum voltage V_s that shows no current in the ammeter is recorded.

diagram not to scale



The graph shows the variation of V_s with λ.



(This question continues on the following page)

(Question 6 continued)

(a) Show that the work function of the metal used in C is about 2.5 eV. [2]

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(b) Calculate V_s when λ is 4.0×10^{-7} m. [2]

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The laser is now replaced by a monochromatic laser of red light and variable intensity.

Although the intensity of the laser is increased significantly, no current is read in the ammeter.

(c) Explain how this observation is consistent with the particle nature of light. [2]

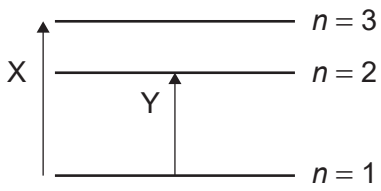
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Question 6 - working space

33. Some energy levels for a hydrogen atom are shown.

diagram not to scale



What is $\frac{\text{energy absorbed in transition X}}{\text{energy absorbed in transition Y}}$?

A. $\frac{32}{27}$

B. $\frac{3}{2}$

C. 2

D. $\frac{9}{4}$

34. Monochromatic electromagnetic radiation is incident on a metal surface. Three observations about the electrons emitted from the surface are:

I. The maximum energy of the electrons does not depend on radiation intensity.

II. The number of electrons emitted in a unit time increases with radiation intensity.

III. No electrons are emitted when the frequency of radiation is less than a threshold value.

Which observations are inconsistent with the wave model of electromagnetic radiation?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

35. A photon of wavelength λ_0 scatters off an electron at rest. The shift in photon wavelength is $\Delta\lambda$. What is the kinetic energy of the scattered electron?

A. $\frac{hc}{\Delta\lambda}$

B. $\frac{hc}{\lambda_0 + \Delta\lambda}$

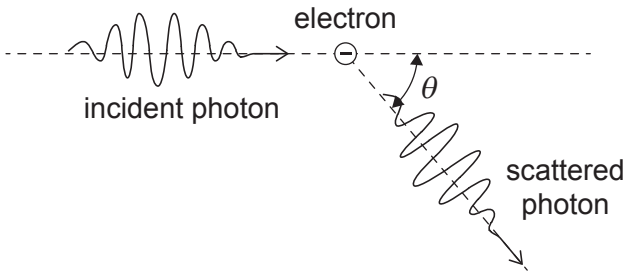
C. $\frac{hc}{\lambda_0} - \frac{hc}{\Delta\lambda}$

D. $\frac{hc}{\lambda_0} - \frac{hc}{\lambda_0 + \Delta\lambda}$

36. Two particles are accelerated from rest through the same electric potential difference. The particles have the same charge and different masses. Which row correctly compares the kinetic energy and the de Broglie wavelength of the particles after the acceleration?

	Kinetic energy	De Broglie wavelength
A.	same	same
B.	different	same
C.	same	different
D.	different	different

35. A photon scatters off an electron at an angle θ, as shown. The shift in the photon wavelength after scattering is $\frac{h}{2m_e c}$.



What is correct about the frequency of the photon after scattering and θ?

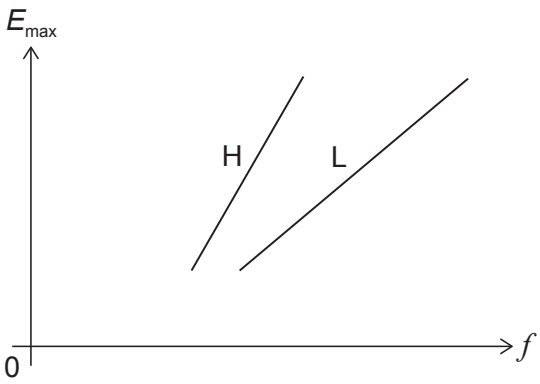
	Frequency	θ
A.	increases	30°
B.	increases	60°
C.	decreases	30°
D.	decreases	60°

Turn over

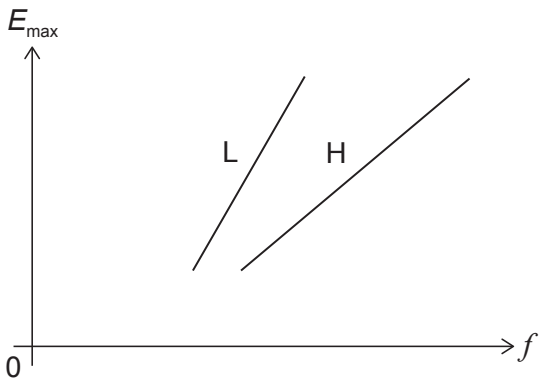
36. Light is incident on two different metal surfaces L and H. The minimum photon energy required to emit electrons from surface H is less than that from surface L.

Which graph shows the variation with light frequency f of the maximum kinetic energy E_{max} of photoelectrons emitted from both surfaces?

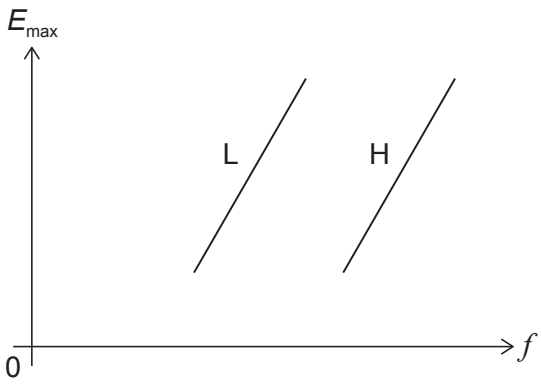
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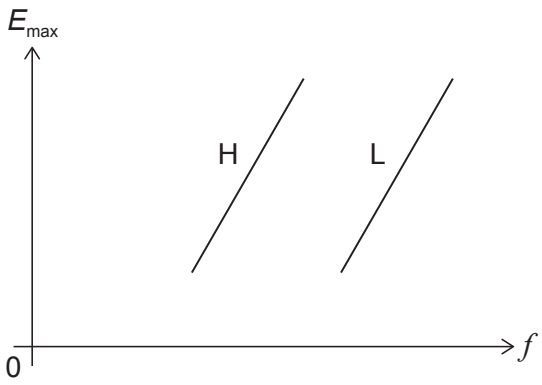
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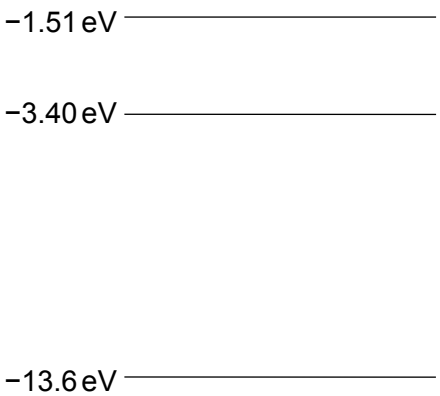


D.



1. The diagram shows the three lowest energy levels of the hydrogen atom.
The energy of each level is indicated.

diagram not to scale



(a) State the number of transitions between these levels that result in the emission of photons. [1]

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(b) Calculate the largest photon wavelength for these transitions. [3]

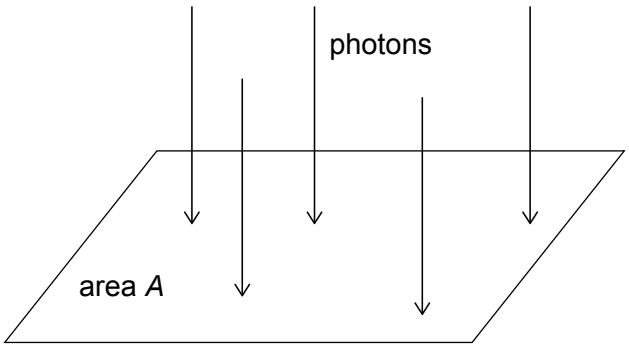
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Question 1 - working space

10. (a) Outline **one** experimental piece of evidence that shows that photons have momentum. [2]

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(b) Photons of wavelength λ are incident normally on a flat surface of area *A*.
The photons are reflected without change in wavelength.



There are *N* photons incident per second.

(i) Show that the intensity I that is incident on the surface is given by $I = \frac{N}{A}\frac{hc}{\lambda}$. [2]

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(Question 10 continued)

(ii) Deduce that the pressure P exerted on the surface is given by $P = \frac{2I}{c}$. [3]

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(Question 10 continued)

(c) It is proposed to send a spacecraft to Jupiter. The spacecraft would be launched to a point Q far from Earth and would then be accelerated by the pressure of the Sun's radiation on a sail attached to the spacecraft. The following data are available:

$$\begin{aligned} \text{total mass of spacecraft} &= 1400\,\text{kg} \\ \text{sail area} &= 1600\,\text{m}^2 \\ \text{solar radiation intensity at Q} &= 420\,\text{W m}^{-2} \end{aligned}$$

(i) Show that the acceleration of the spacecraft at Q due to solar radiation alone is about $3 \times 10^{-6}\,\text{m s}^{-2}$. [2]

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(ii) The distance between Q and Jupiter is $6.1 \times 10^{11}\,\text{m}$. Estimate the time, in years, it would take the spacecraft to reach Jupiter, assuming that the spacecraft moves with the acceleration in (i). [2]

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(iii) State **one** reason why the acceleration of the spacecraft will **not** be constant. [1]

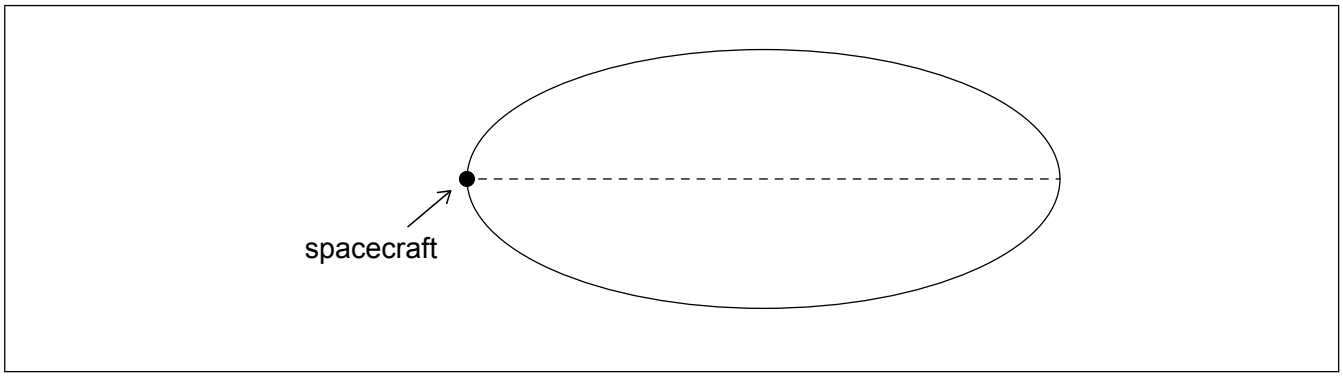
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(Question 10 continued)

(d) The spacecraft enters an elliptical orbit around Jupiter.



At the position shown, the spacecraft has its maximum orbital speed.

(i) Draw, on the diagram, a possible position of Jupiter. [1]

(ii) Explain your answer to (d)(i). [2]

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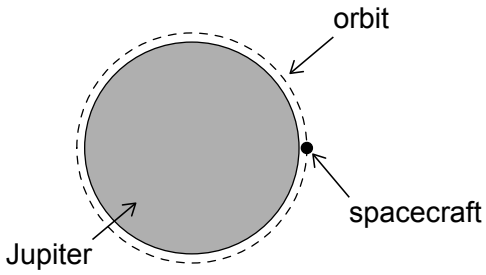
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(Question 10 continued)

(e) The spacecraft changes its orbit into a circular orbit just above the surface of Jupiter, so that the orbit radius is essentially equal to the radius of Jupiter.

diagram not to scale



(i) Show that the orbital period, T, of the spacecraft is given by $T = \sqrt{\frac{3\pi}{G\rho}}$, where ρ is the density of Jupiter. [3]

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(ii) The orbital period is 2.9 hours. Estimate the density of Jupiter. [2]

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Question 10 - working space

35. A photon of wavelength λ scatters off an electron at rest. The scattered photon has wavelength λ'.

What is the fraction of the incident photon energy that gets transferred to the electron?

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

B. $\frac{\lambda'}{\lambda}$

C. $\frac{\lambda' - \lambda}{\lambda}$

D. $\frac{\lambda' - \lambda}{\lambda'}$

Turn over

39. Monochromatic light of frequency f_1 is incident on the surface of a metal. The stopping voltage for this light is V_1. When the frequency of the radiation is changed to f_2, the stopping voltage is V_2.

What is the quantity $\frac{V_2 - V_1}{f_2 - f_1}$ equal to?

A. h

B. $\frac{h}{e}$

C. $\frac{h}{c}$

D. $\frac{hc}{e}$

APOLLO

Radioactive decay

9 questions

36. Three products of radioactive decay are:

I. alpha particles
II. beta particles
III. gamma photons.

Which products can be deflected by both magnetic and electric fields?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

37. A nucleus of nuclide X decays.

Which series of emissions will produce an isotope of X?

A. One α and two β^-

B. One α and two β^+

C. Two α and two β^-

D. Two α and two β^+

37. Three statements about gamma radiation are:

I. It travels faster than beta radiation in a vacuum.

II. It has a greater penetration ability than beta radiation.

III. It has a greater ionizing ability than beta radiation.

Which statements are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

38. A pure sample of 4.4 g of Radon-222 has an activity of 2.5×10^{16} Bq.

What is the decay constant of Radon-222?

A. $2.1 \times 10^{-10}\,s^{-1}$

B. $8.3 \times 10^{-10}\,s^{-1}$

C. $2.1 \times 10^{-6}\,s^{-1}$

D. $8.3 \times 10^{-6}\,s^{-1}$

35. Thorium-232 ($^{232}_{90}\text{Th}$) is an unstable nuclide. It decays by emitting an alpha particle followed by a beta minus (β^-) particle.

What is the number of protons and neutrons in the final nuclide?

	Number of protons	Number of neutrons
A.	87	139
B.	87	141
C.	89	139
D.	89	141

36. A pure sample of radon-222 decays into polonium with a half-life of 4 days. A measurement is made of its radioactivity. The initial count rate is 420 counts per second. The measured background count is 20 counts per second.

What is the measured count rate after 8 days?

A. 85

B. 100

C. 105

D. 120

37. The table shows how the count rate from a sample of a radioactive nuclide varies with time t. The nuclide has a half-life of 50 s. The average background count rate is constant.

t / s	Count rate / s^{-1}
0	72
50	40

What count rate will the detector measure when $t = 150$ s?

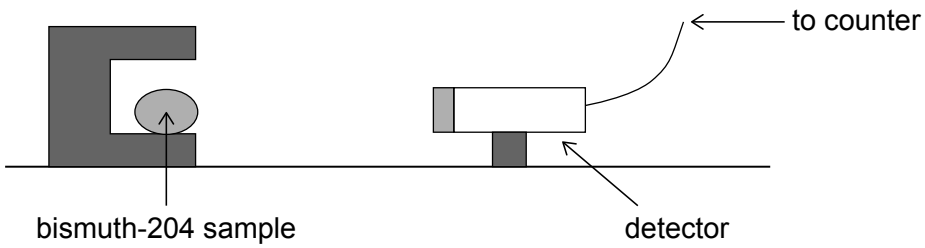
A. $8\,s^{-1}$

B. $16\,s^{-1}$

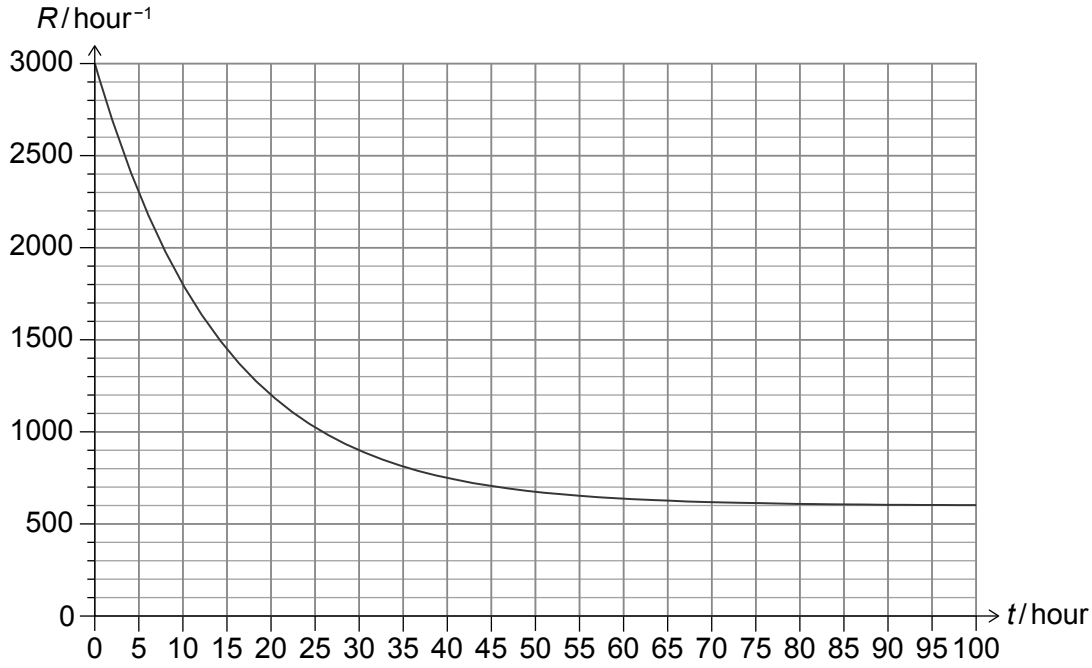
C. $24\,s^{-1}$

D. $32\,s^{-1}$

4. (a) A pure radioactive sample of bismuth-204 ($^{204}_{83}\text{Bi}$) is placed near a detector, which is connected to a counter.



Bismuth-204 decays into lead ($^{204}_{82}\text{Pb}$) by beta-plus decay according to the equation $^{204}_{83}\text{Bi} \rightarrow {}^{204}_{82}\text{Pb} + e^{+} + \nu$. The graph shows the variation with time t of the count rate R.



(i) State the background count rate. [1]

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(This question continues on the following page)

(Question 4 continued)

(ii) Estimate the half-life of $^{204}_{83}Bi$. [3]

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(iii) State and explain how the binding energy per nucleon of $^{204}_{83}Bi$ compares with that of $^{204}_{82}Pb$. [2]

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(iv) The distance between the sample and the detector is 20 cm. State why this would be an inappropriate distance for a sample that decayed by alpha decay. [1]

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(b) The following data are available for **nuclear** masses:

bismuth = 203.932254 u
lead = 203.928034 u

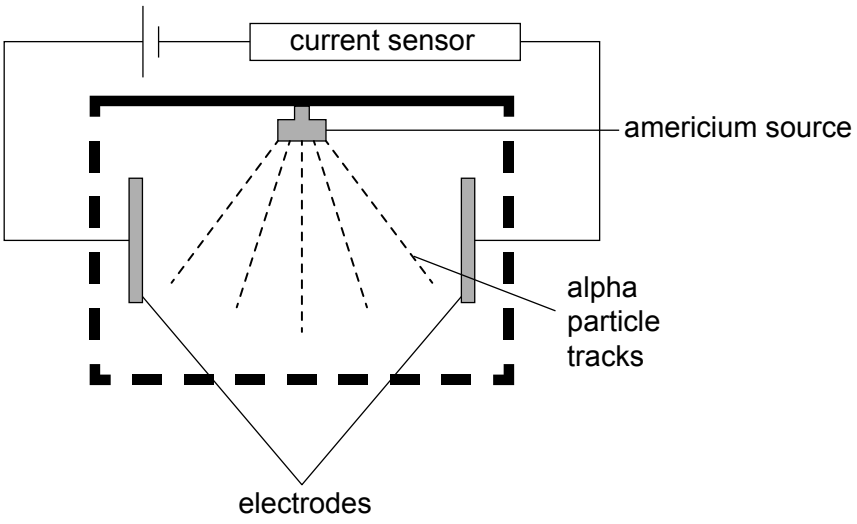
Calculate the energy released in the decay of one nucleus of bismuth-204. [2]

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Question 4 - working space

6. A smoke detector uses the radioactive nuclide americium-241.

The americium is contained in a chamber that is open to the air. There are two electrodes in the chamber that are connected to a power supply and a current sensor.



Americium-241 emits alpha particles that ionize the air in the chamber. Each ionization forms one positive ion and one electron; these are called an ion pair. The electrons and the positive ions move towards the electrodes and the sensor detects a current in the air.

When smoke enters the chamber, fewer ion pairs are formed and the current in the sensor decreases, sounding an alarm.

The decay constant of americium-241 is $5.08 \times 10^{-11}\,\text{s}^{-1}$.
The chamber is 0.10 m in each dimension.

(a) A nucleus of americium-241 has 146 neutrons. This nuclide decays to neptunium through alpha emission.

Complete the nuclear equation for this decay. [2]

$$\_\_^{\_\_}\text{Am} \rightarrow \_\_^{\_\_}\text{Np} + \_\_^{\_\_}\alpha$$

(This question continues on the following page)

(Question 6 continued)

(b) Outline why the radioactive source is safe for use in a house. [1]

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(c) Deduce whether the radioactive source will need to be replaced during the life of the detector. [3]

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The initial activity of the source is 42 kBq. 33 % of the alpha particles emitted by this source enter the chamber and form an ion pair.
Each alpha particle has an initial kinetic energy of 5.5 MeV.
The energy required to form one ion pair is 15 eV.

(d) Calculate the maximum current in the chamber due to the electrons when there is no smoke in the chamber. [3]

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Question 6 - working space

APOLLO

Fission

8 questions

38. A suitable material for use as a moderator in a nuclear reactor is...

A. cadmium.

B. concrete.

C. uranium-238.

D. water.

39. In a simple model of a nuclear reactor, four neutrons are emitted per fission on average.

The average number of neutrons absorbed by the control rods is N_c per fission.

The average number of neutrons that are lost through the walls of the reactor is N_1 per fission.

Any remaining neutrons induce further fissions.

What are possible values for N_c and N_1 for the reactor to maintain a steady reaction?

	N_c	N_1
A.	1	1
B.	1	3
C.	2	1
D.	2	2

39. The moderator in a nuclear power station…

A. increases the proportion of U-235 in the fuel source.

B. transfers internal energy from the reactor to the turbines.

C. allows operators to regulate the rate of power production.

D. decreases the kinetic energy of neutrons in the reactor.

37. Which component is responsible for slowing down neutrons in a nuclear reactor to increase the likelihood of nuclear fission?

A. Moderator

B. Control rods

C. Fuel rods

D. Heat exchanger

38. A nucleus of uranium-235 ($^{235}_{92}U$) absorbs a neutron and decays into two nuclides, xenon-140 ($^{140}_{54}Xe$) and strontium-94 ($^{94}_{38}Sr$).

How many neutrons are released in this reaction?

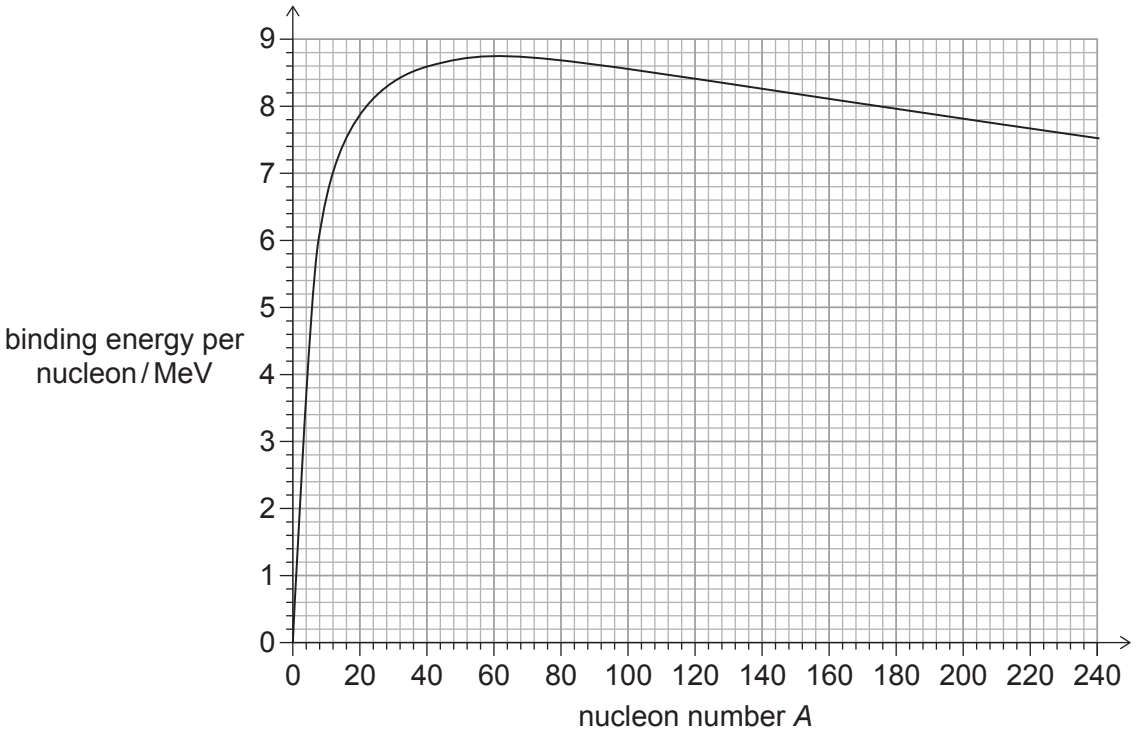
A. 1

B. 2

C. 3

D. 4

37. A graph of the variation with nucleon number *A* of the binding energy per nucleon is shown.



What is the approximate total energy, in MeV, needed to completely separate the nucleons of a $^{180}_{72}Hf$ nucleus?

A. 580

B. 620

C. 1440

D. 2020

38. Which two components of a nuclear power station are primarily responsible for ensuring that a controlled chain reaction is maintained?

A. Control rods and heat exchangers

B. Moderators and shielding

C. Shielding and heat exchangers

D. Moderators and control rods

36. Three statements about a nuclear fission reactor are:

I. The heat exchanger transfers energy from the fuel rods to the moderator.

II. The control rods must be good absorbers of neutrons.

III. The moderator must slow neutrons down.

Which statements about the reactor are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

APOLLO

Fusion and stars

16 questions

40. A star has a parallax angle of 1×10^{-2} arc-second at the orbit of the Earth.

What is the distance from the Sun to the star?

A. 0.01 pc

B. 0.02 pc

C. 50 pc

D. 100 pc

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40. Stars X and Y have the same surface temperature. Star X has a radius R and is a distance d from Earth. The distance of star Y from Earth is $\frac{d}{2}$. The apparent brightness of Y is double that of X.

What is the radius of star Y?

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

B. $\frac{\sqrt{2}}{2}R$

C. R

D. $2R$

11. Star X has a surface temperature T, luminosity L and radius R.

The luminosity of star Y is $4L$ and the surface temperature is $2T$.

What is the radius of star Y?

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

B. $\frac{R}{\sqrt{2}}$

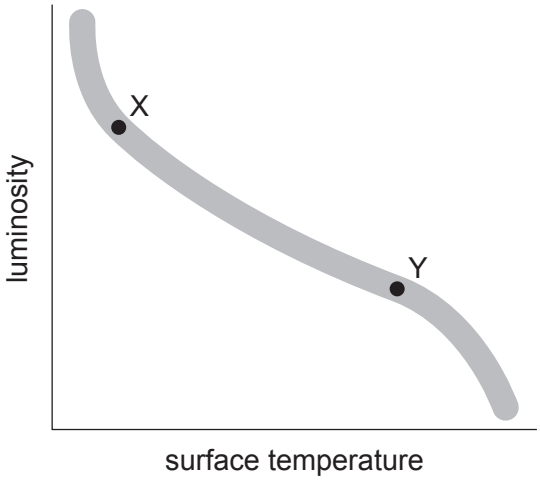
C. $2R$

D. $4R$

38. Which of the following temperature and density conditions are necessary for fusion to occur in a star?

	Temperature of the star	Density of the star
A.	High	High
B.	High	Low
C.	Low	High
D.	Low	Low

39. The HR diagram shows two stars, X and Y.



Three statements are made about star X and star Y.

I. Star X is hotter than star Y.

II. Star X has a larger radius than star Y.

III. Star X is more luminous than star Y.

Which of the statements are correct?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

40. X is a star of luminosity *L* and apparent brightness *b*. Y is a star of luminosity *L* and apparent brightness 2*b*.

As viewed from Earth, what is $\frac{\text{parallax angle subtended by X}}{\text{parallax angle subtended by Y}}$?

A. $\frac{1}{\sqrt{2}}$

B. $\frac{1}{2}$

C. $\sqrt{2}$

D. 2

7. The following data are available for the Sun when it entered the main sequence.

$$\text{Mass} = 2.0 \times 10^{30}\,\text{kg}$$
$$\text{Radius} = 7.0 \times 10^{8}\,\text{m}$$
$$\text{Surface temperature} = 5800\,\text{K}$$
$$\text{Core temperature} = 1.5 \times 10^{7}\,\text{K}$$
$$\text{Core density} = 1.6 \times 10^{5}\,\text{kg}\,\text{m}^{-3}$$

(a) (i) State and explain which of the above features make nuclear fusion in the Sun possible. [3]

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(ii) Outline how the Sun maintains its equilibrium state. [2]

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(Question 7 continued)

(b) The following sequence of nuclear fusion reactions takes place in the Sun.

$$\text{Stage 1: } {}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{2}_{1}\text{H} + {}^{0}_{1}\bar{\text{e}}^{+} + {}^{0}_{0}\nu$$

$$\text{Stage 2: } {}^{1}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{0}_{0}\gamma$$

$$\text{Stage 3: } {}^{3}_{2}\text{He} + {}^{3}_{2}\text{He} \rightarrow {}^{4}_{2}\text{He} + 2 \times {}^{1}_{1}\text{H}$$

The nuclear mass of ${}^{1}_{1}\text{H}$ is 1.007276 u and that of ${}^{2}_{1}\text{H}$ is 2.013550 u. Estimate the energy released in stage 1 of these reactions. [2]

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(Question 7 continued)

(c) The Sun will leave the main sequence when it has converted 10 % of its hydrogen mass into helium. The **total** energy released in the reactions in (b) is 4.3×10^{-12} J. The current luminosity of the Sun is 3.8×10^{26} W. When the Sun entered the main sequence its hydrogen mass was 1.5×10^{30} kg.

(i) Show that the Sun will stay on the main sequence for about 8×10^{9} years. [3]

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(ii) State **one** assumption that was made in getting the answer to (c)(i). [1]

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(iii) Estimate the total mass lost by the Sun in this time. [2]

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(d) The surface temperature of the Sun is 5800 K. Determine the peak wavelength in the Sun's spectrum. [2]

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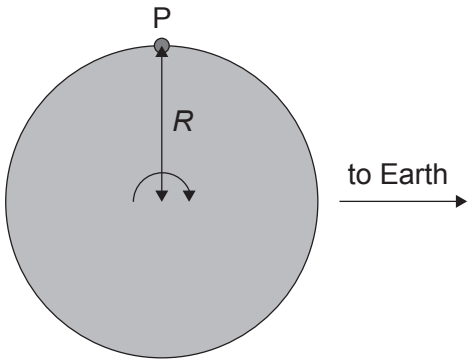
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(Question 7 continued)

(e) The Sun rotates about its axis. P is a point on the Sun's equator.



A particular spectral line of hydrogen from a laboratory source has wavelength 656.2797 nm. The same spectral line emitted from P has wavelength 656.2753 nm when measured on Earth.

(i) Explain this observation. [2]

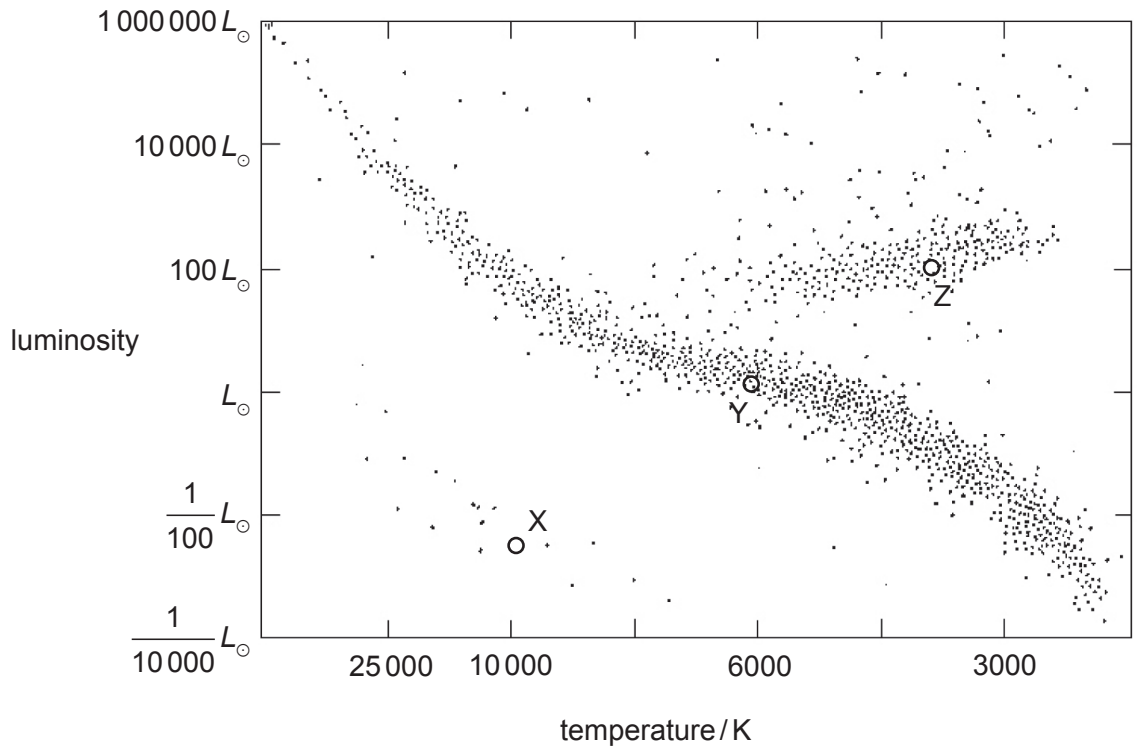
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(ii) Calculate the period of revolution of the Sun. [3]

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Question 7 - working space

39. The Hertzsprung–Russell diagram shows three stars X, Y and Z.



Which of the following lists the stars in the order of their evolutionary stage?

A. X, Y, Z

B. Z, Y, X

C. Y, X, Z

D. Y, Z, X

40. The stellar parallax method involves a measurement of...

A. the peak wavelength of radiation from a star.

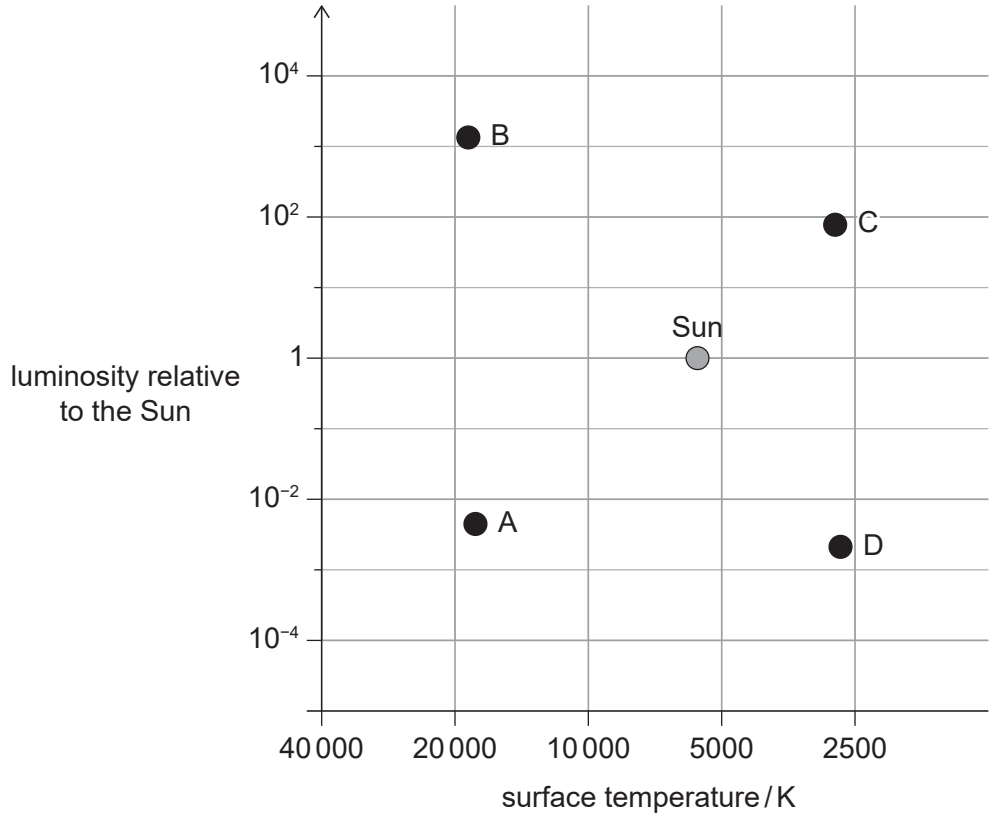
B. the frequency shift of the lines in a stellar spectrum.

C. the position of a star in the sky at different times of year.

D. the intensity of radiation from a star at different wavelengths.

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39. The Sun and positions of four stars A, B, C and D are plotted on the grid of a Hertzsprung–Russell (HR) diagram. Which star is a white dwarf?



40. A star is found to have a parallax angle of 0.25 arc-seconds. What is the distance to the star in light years?

A. 4.0

B. 13

C. 6.0×10^{11}

D. 38×10^{15}

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References:

7. Dorling Kindersley, 2010. *Illustration of ice skater starting to spin*. [image online] Available at: https://www.gettyimages.co.uk/detail/illustration/illustration-of-ice-skater-starting-to-spin-royalty-free-illustration/96168836?phrase=ice+skater+spinning&searchscope=image%2Cfilm&adppopup=true [Accessed 11 December 2024]. Source adapted.

2. A student investigates whether the Stefan–Boltzmann law, $L = 4\pi\sigma R^2T^4$, applies to stars.

L = luminosity of the star, in W

σ = Stefan–Boltzmann constant

R = radius of the star, in m

T = surface temperature of the star, in K

To verify the law, they obtain values from databases and manipulate the data as shown.

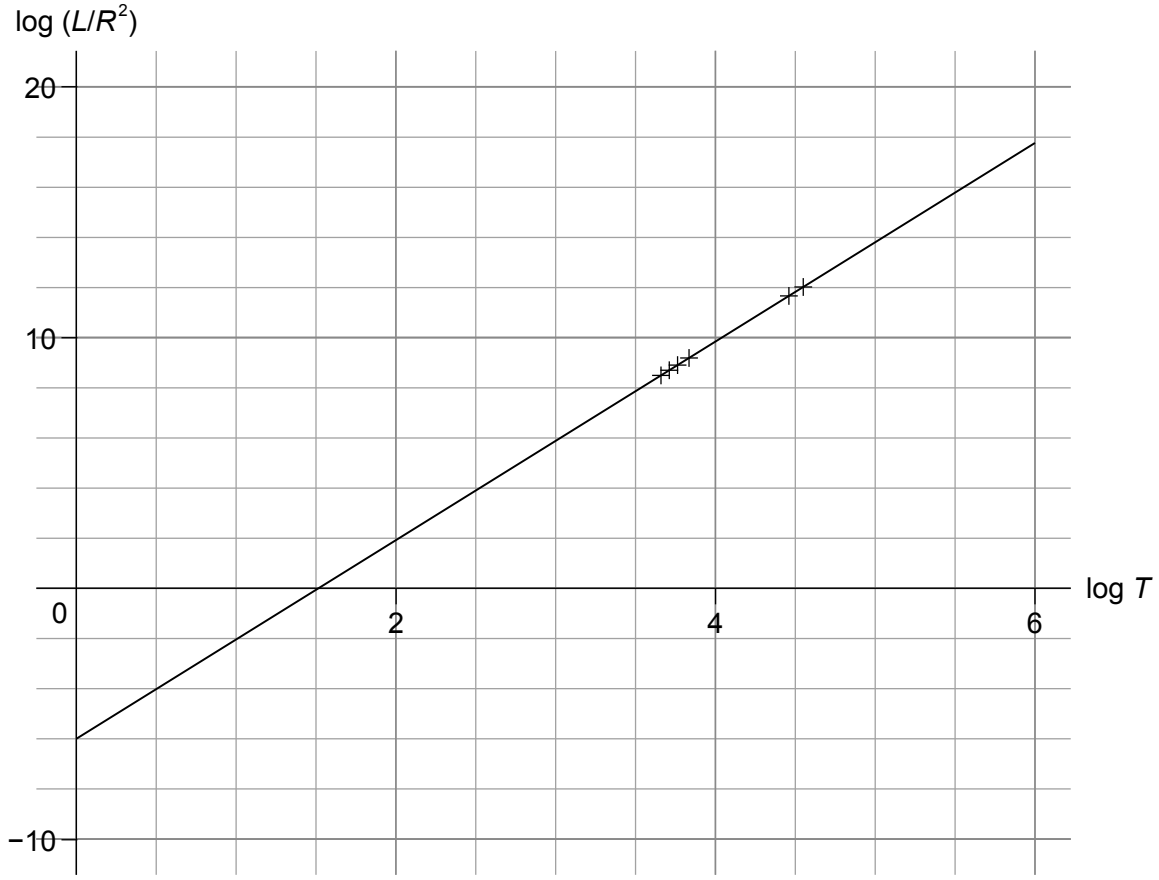
Star	L	R	T	$\frac{L}{R^2}$	$\log(\frac{L}{R^2})$	$\log(T)$
10 Lacertae	3.92×10^{31}	5.75×10^{9}	3.62×10^{4}	1.19×10^{12}	12.1	4.56
σ-Orionis A	1.60×10^{31}	3.90×10^{9}	3.49×10^{4}	1.05×10^{12}	12.0	4.54
σ-Orionis B	6.08×10^{30}	3.48×10^{9}	2.91×10^{4}	5.02×10^{11}	11.7	4.46
Polaris B	1.50×10^{27}	9.60×10^{8}	6.90×10^{3}		9.21	
α-Centauri A	5.77×10^{26}	8.49×10^{8}	5.79×10^{3}	8.00×10^{8}	8.90	3.76
α-Centauri B	1.92×10^{26}	5.97×10^{8}	5.26×10^{3}	5.39×10^{8}	8.73	3.72
ε-Indi	8.08×10^{25}	4.95×10^{8}	4.65×10^{3}	3.30×10^{8}	8.52	3.67
Sun	3.85×10^{26}	6.96×10^{8}	5.78×10^{3}	7.95×10^{8}	8.90	3.76

(a) Complete the table with the missing values for Polaris B. [2]

(This question continues on the following page)

(Question 2 continued)

The student plots the variation with log T of log $\left(\frac{L}{R^2}\right)$ and draws the line of best fit.



The student uses a GDC (graphical display calculator) to determine the equation of the line of best fit as $y = 3.99x - 6.15$.

(b) Explain how the gradient of the line of best fit relates to the Stefan–Boltzmann law. [2]

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(Question 2 continued)

(c) Calculate the Stefan–Boltzmann constant obtained in this investigation. [2]

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(d) Outline a conclusion for the investigation. [1]

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(e) Suggest a possible improvement of the investigation, related to the range of the surface temperatures of the stars selected. [1]

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Question 2 - working space

14. Star X has a luminosity L and an apparent brightness b. Star X is at a distance d from Earth.

Star Y has the same apparent brightness as X but is four times more luminous.

What is the distance of Star Y from Earth?

A. $4d$

B. $2d$

C. $\frac{d}{2}$

D. $\frac{d}{4}$

33. What is the sequence for the evolution of a main sequence star of about 2 solar masses?

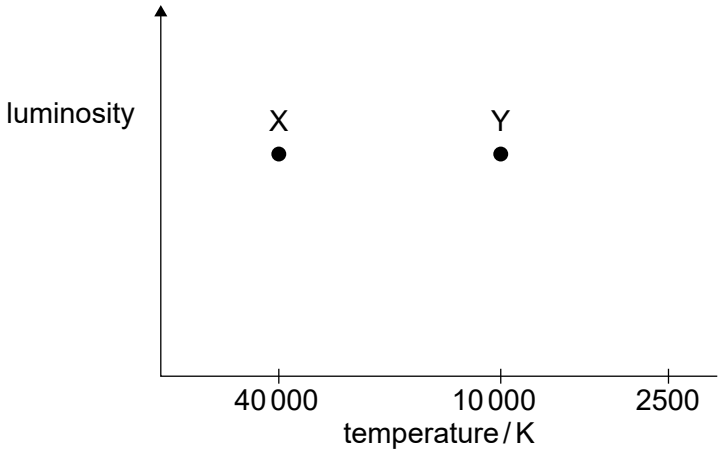
A. Red super giant → supernova → neutron star

B. Red giant → planetary nebula → white dwarf

C. Red giant → supernova → white dwarf

D. Red super giant → planetary nebula → neutron star

37. The Hertzsprung–Russell diagram shows two stars, X and Y.



What is $\frac{\text{radius of X}}{\text{radius of Y}}$?

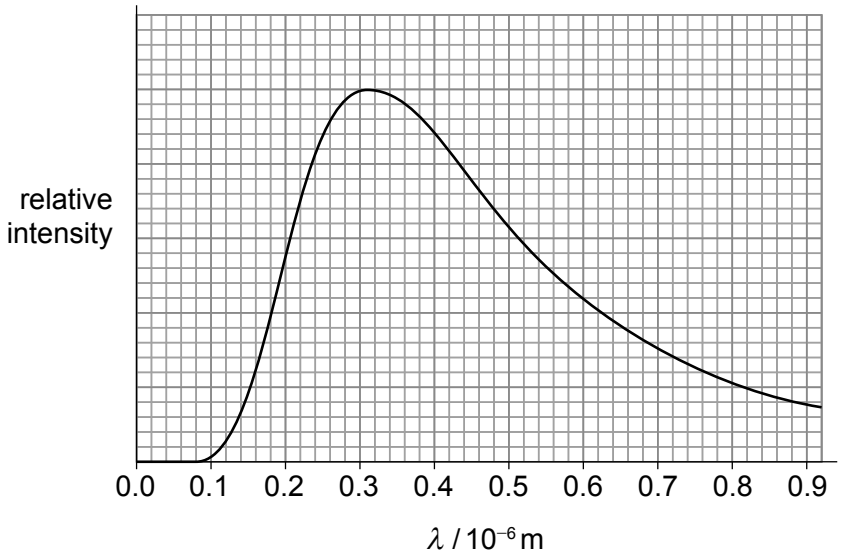
A. $\frac{1}{16}$

B. $\frac{1}{4}$

C. 4

D. 16

7. The star δ Vel A is a main sequence star that has a black-body spectrum as shown.



(a) Show that the surface temperature of δ Vel A is about 9000 K. [1]

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(b) The apparent brightness of δ Vel A is $2.2 \times 10^{-9}\,\text{W m}^{-2}$ and it is 6.2×10^{14} km from Earth.

Estimate the radius of δ Vel A. [3]

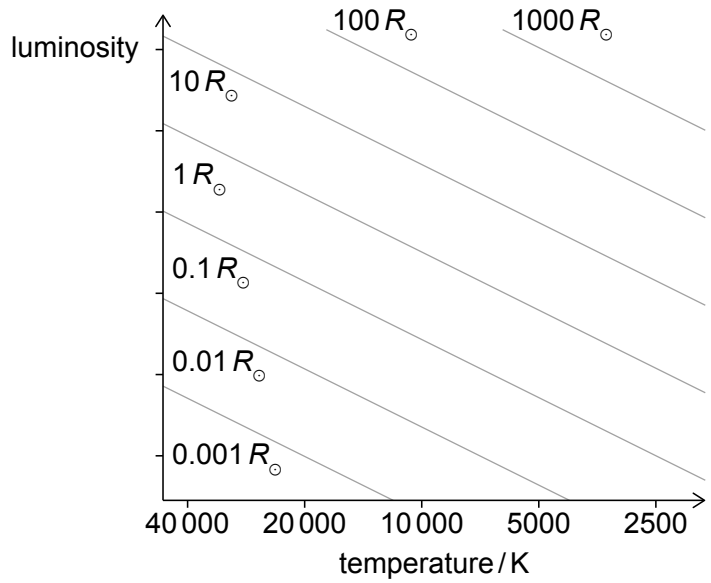
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(Question 7 continued)

(c) The radius of the Sun, $R_\odot$, is 7.0×10^5 km.

Sketch, on the Hertzsprung-Russell diagram, the position of δ Vel A. [2]



Please **do not** write on this page.

Answers written on this page
will not be marked.

Question 7 - working space