IB Physics

Test and Exam Review

Most Questions taken from November exams up to 2004

Note some items may no longer be in syllabus

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Topic 1 – Physics and Physical Measurement

1. The ratio $\dfrac{\text{diameter of a nucleus}}{\text{diameter of an atom}}$ is approximately equal to

A. 10^{-15}.
B. 10^{-8}.
C. 10^{-5}.
D. 10^{-2}.

2. The mass of an atom of the isotope strontium-92 (^{92}Sr) is of the order of

A. 10^{-23} kg.
B. 10^{-25} kg.
C. 10^{-27} kg.
D. 10^{-29} kg.

3. Which of the following is the best estimate, to one significant digit, of the quantity shown below?

$$\frac{\pi \times 8.1}{\sqrt{(15.9)}}$$

A. 1.5
B. 2.0
C. 5.8
D. 6.0

4. Which **one** of the following measurements is stated correctly to two significant digits?

A. 0.006 m
B. 0.06 m
C. 600 m
D. 620 m

5. Which **one** of the following is a fundamental unit in the SI system?

A. Ampere
B. Volt
C. Ohm
D. Tesla

6. Which **one** of the following lists a fundamental unit and a derived unit?

A.	ampere	second
B.	coulomb	kilogram
C.	coulomb	newton
D.	metre	kilogram

7. The resistive force F acting on a sphere of radius r moving at speed v through a liquid is given by

$$F = cvr$$

where c is a constant. Which of the following is a correct unit for c?

A. N
B. N s^{-1}
C. N m^2 s^{-1}
D. N m^{-2} s

8. A student measures two lengths as follows:

$T = 10.0 \pm 0.1$ cm

$S = 20.0 \pm 0.1$ cm.

The student calculates:

F_T, the fractional uncertainty in T

F_S, the fractional uncertainty in S

F_{T-S}, the fractional uncertainty in $(T - S)$

F_{T+S}, the fractional uncertainty in $(T + S)$.

Which of these uncertainties has the **largest** magnitude?

A. F_T

B. F_S

C. F_{T-S}

D. F_{T+S}

9. A student measures a distance several times. The readings lie between 49.8 cm and 50.2 cm. This measurement is best recorded as

A. 49.8 ± 0.2 cm.

B. 49.8 ± 0.4 cm.

C. 50.0 ± 0.2 cm.

D. 50.0 ± 0.4 cm.

10. The frequency f of an oscillating system is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$$

where g and π are constants.

The frequency f is measured for different values of l and a graph is plotted.

Which **one** of the following will produce a straight-line graph?

	***x*-axis**	***y*-axis**
A.	$\sqrt{f}$	$\sqrt{l}$
B.	$\sqrt{f}$	l
C.	f^2	$\frac{1}{l}$
D.	f^2	$\sqrt{l}$

11. The relationship between two measured quantities P and Q is of the form

$$P = kQ^n$$

where k and n are constants.

A plot of lg P (y-axis) against lg Q (x-axis) will enable the value of k to be determined by measuring only

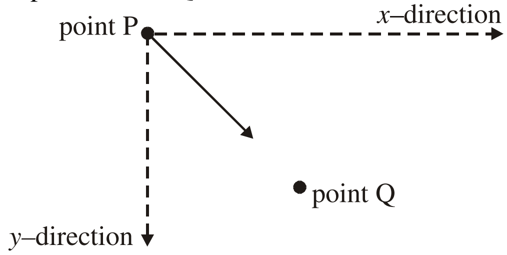
A. the intercept on the lg P axis.

B. the intercept on the lg Q axis.

C. the slope of the graph.

D. the reciprocal of the slope of the graph.

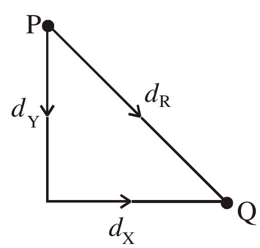
12. A student moves between two points P and Q as shown below.



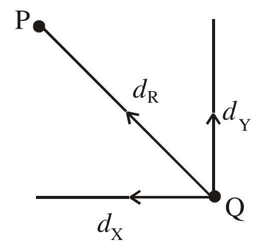
The displacement from P in the *x*-direction is d_X. The displacement from P in the *y*-direction is d_Y. The resultant displacement from P is d_R.

Which of the following diagrams shows the **three** displacements from point P?

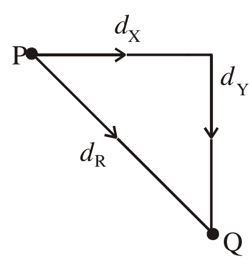
A.



B.



C.



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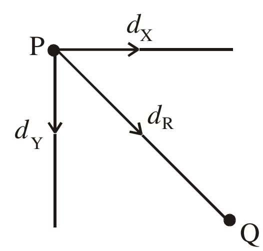
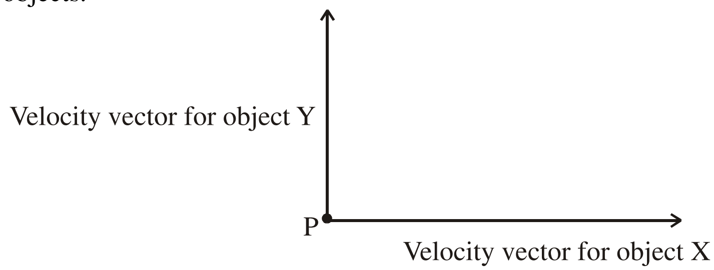


13. Two forces of magnitudes 7 N and 5 N act at a point. Which **one** of the following is **not** a possible value for the magnitude of the resultant force?

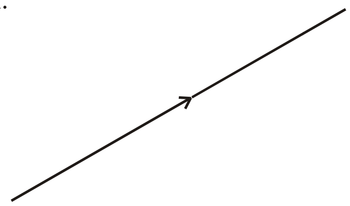
A. 1 N
B. 3 N
C. 5 N
D. 7 N

14. Two objects X and Y are moving away from the point P. The diagram below shows the velocity vectors of the two objects.

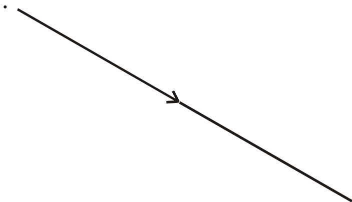


Which of the following velocity vectors best represents the velocity of object X relative to object Y?

A.



B.



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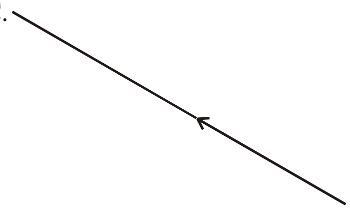
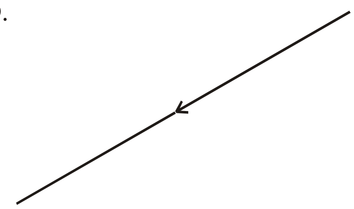
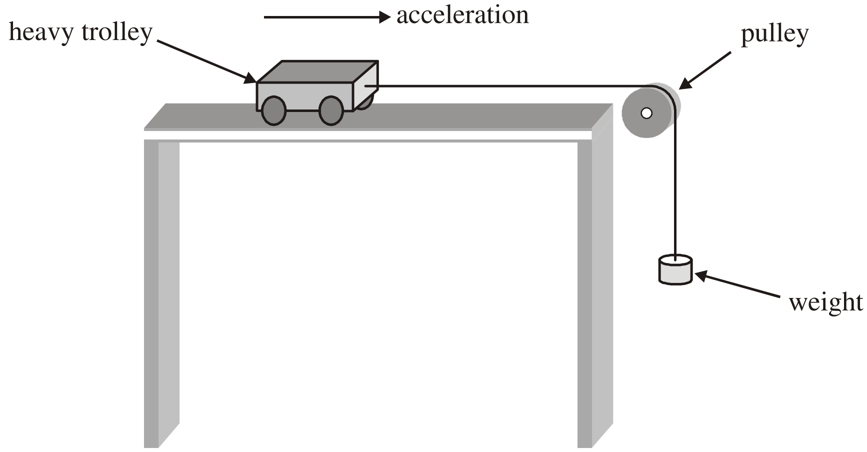


D.



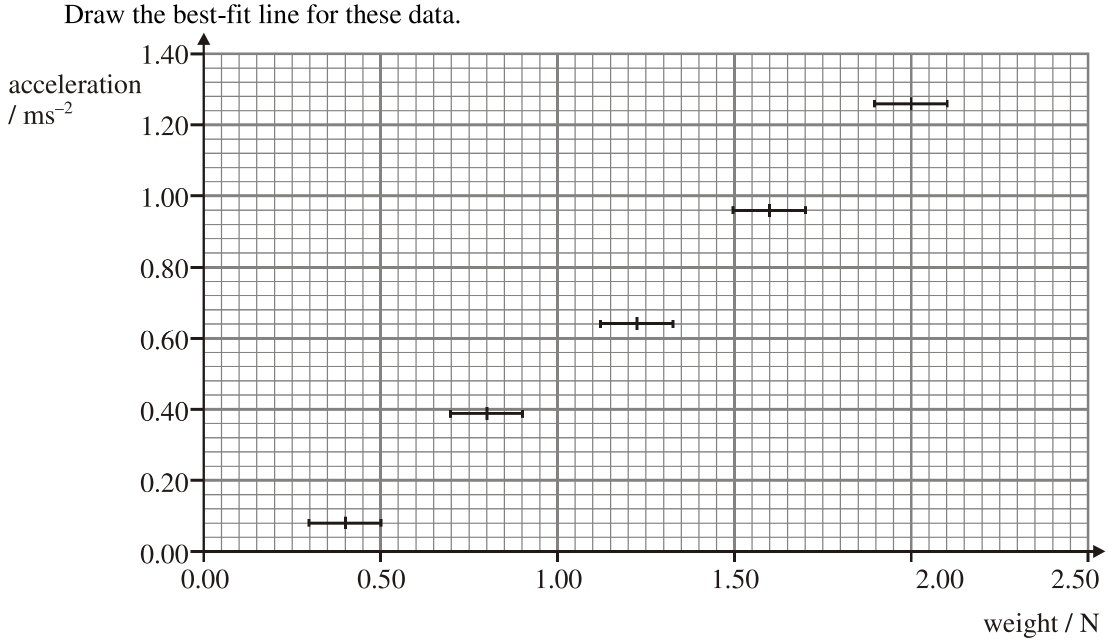
15. This question is about an experiment designed to investigate Newton's second law.
In order to investigate Newton's second law, David arranged for a heavy trolley to be accelerated by small weights, as shown below. The acceleration of the trolley was recorded electronically. David recorded the acceleration for different weights up to a maximum of 3.0 N. He plotted a graph of his results.



(a) Describe the graph that would be expected if two quantities are proportional to one another.

(2)

(b) David's data are shown below, with uncertainty limits included for the value of the weights. Draw the best-fit line for these data.



(2)

(c) Use the graph to

(i) explain what is meant by a *systematic* error.

(2)

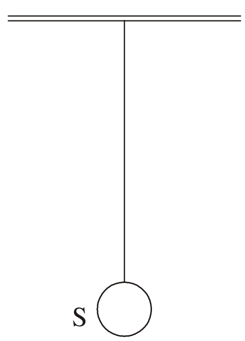
(ii) estimate the value of the frictional force that is acting on the trolley.

(1)

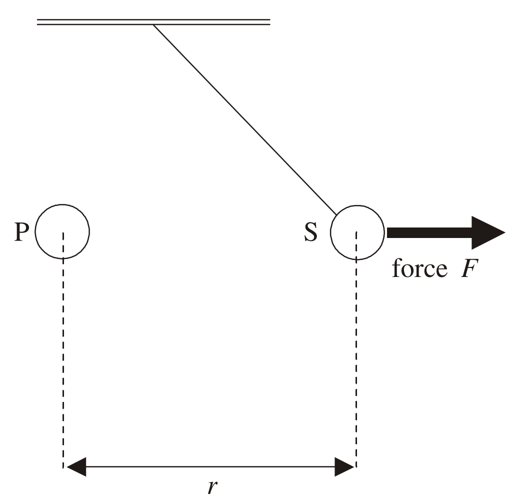
(iii) estimate the mass of the trolley.

(2)
(Total 9 marks)

16. This question is about an electrostatics experiment to investigate how the force between two charges varies with the distance between them.
A small charged sphere S hangs vertically from an insulating thread as shown below.



A second identically charged sphere P is brought close to S. S is repelled as shown below



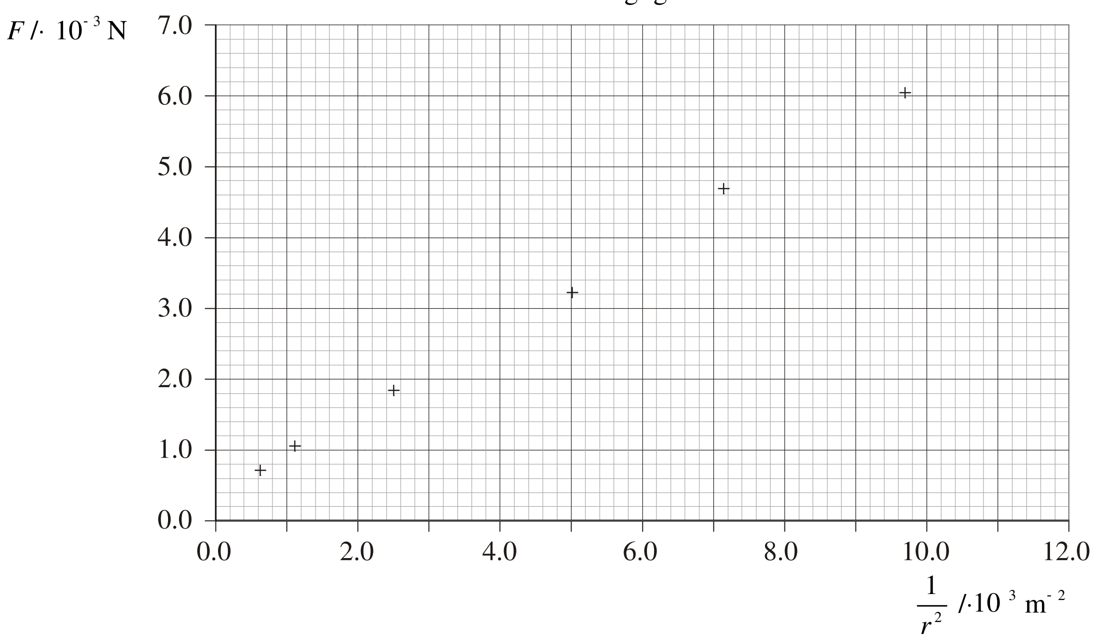
The magnitude of the electrostatic force on sphere S is F. The separation between the two spheres is r. Coulomb's law is given as

$$F = G\frac{Qq}{r^2}$$

(a) On the axes below draw a sketch graph to show how, based on Coulomb's law, you would expect F to vary with $\frac{1}{r^2}$.

(2)

Values of F are determined for different values of r. The variation with $\frac{1}{r^2}$ of these values is shown below. The estimated uncertainties in these values are negligible.



(b) (i) Draw the best-fit line for these data points.

(2)

(ii) Use the graph to explain whether, in the experiment, there are random errors, systematic errors or both.

(3)

(iii) Calculate the gradient of the line drawn in (b) (i).

(2)

(iv) The magnitude of the charge on each sphere is the same. Use your answer to (b) (iii) to calculate this magnitude.

(4)

(c) Explain how a graph showing the variation with lg *r* of lg *F* can be used to verify the relation between *r* and *F*.

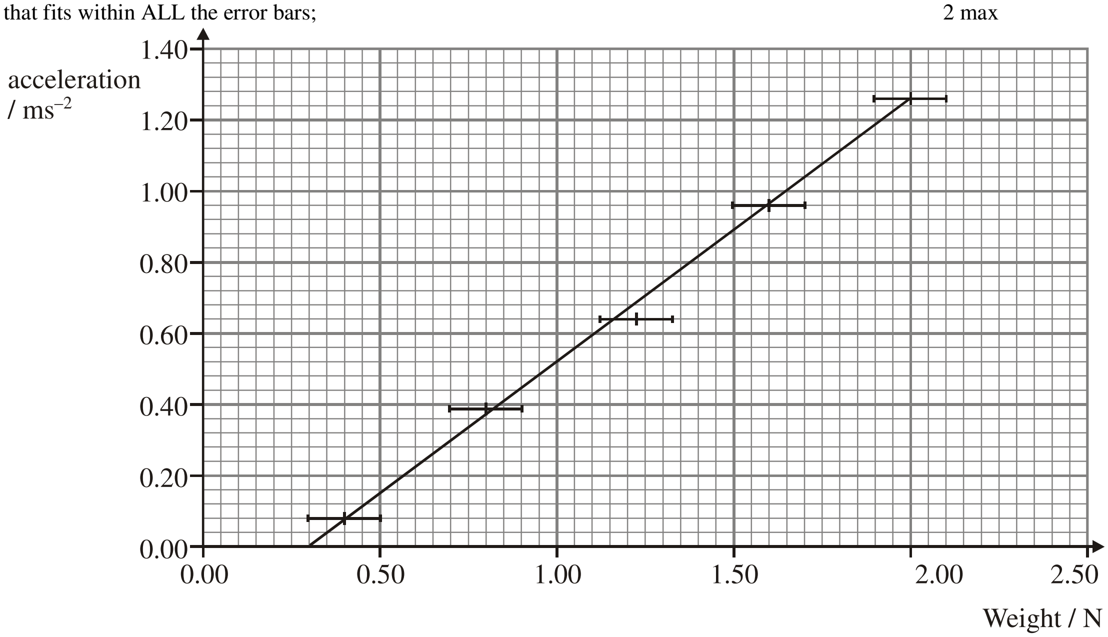
(3)
(Total 16 marks)

Topic 1 – Mark Scheme

1. C
2. B
3. D
4. D
5. A
6. C
7. D
8. C
9. C
10. C
11. A
12. D
13. A
14. B

15. (a) a straight line;
through the origin; 2 max

(b) any straight line;
that fits within ALL the error bars; 2 max



(c) (i) a *systematic* error is when every data point deviates from the "correct" value;
by the same fixed amount as seen by intercept on graph / *OWTTE*; 2 max
Accept answers that explain by giving an example of a possible systematic error eg friction.

(ii) 0.3 N; 1
Accept 0.25 N ± 0.35 N. ***NB*** *Watch for use of wrong axis!*

(iii) realization that mass = (gradient)$^{-1}$;
Award this mark for full Newton II equation (with friction)
to give mass = 1.4 kg *(Accept 1.2 kg ± 1.6 kg.)*; 2 max
Use of F = ma for 1 data point receives ***[0]*** *(unless candidate's line is through origin).*
Watch for ecf from candidate's own line.

[9]

16. (a) any line (curve) through the origins;
straight-line; 2

(b) (i) a straight-line drawn with (ruler);
which is appropriate *ie* does not or would not go through the origin; 2
*Award **[2 max]** for answers that confuse random with systematic but are otherwise correct. Award **[1 max]** for stating that there is only one type of error with correct explanation. Award **[0]** if points joined "dot to dot".*

(ii) data subjected to both types of error;
Can be implied in subsequent answer.
random since points are scattered above and below the line;
systematic since line does not / would not go through origin; 3
Accept answers that get this general idea across but do not accept answers that try to explain the source of the error without naming type of error.

(iii) use of "large triangle" for gradient (seen or implied);
Hypotenuse of triangle used should be at least half the distance between the first and the last point on the graph ie 5 cm.
to get gradient = $0.59 \times 10^{-6} = 5.9 \times 10^{-7}$; 2
*Ignore any units. Award **[1 max]** for 0.59 without power of ten.*
Accept from 5.3 to 6.5×10^{-7}.
*Award **[0]** if using a single point unless student's line goes through that point **and** the origin as well. Award **[0]** if using two data points as opposed to the gradient unless both data points are on candidate's line.*

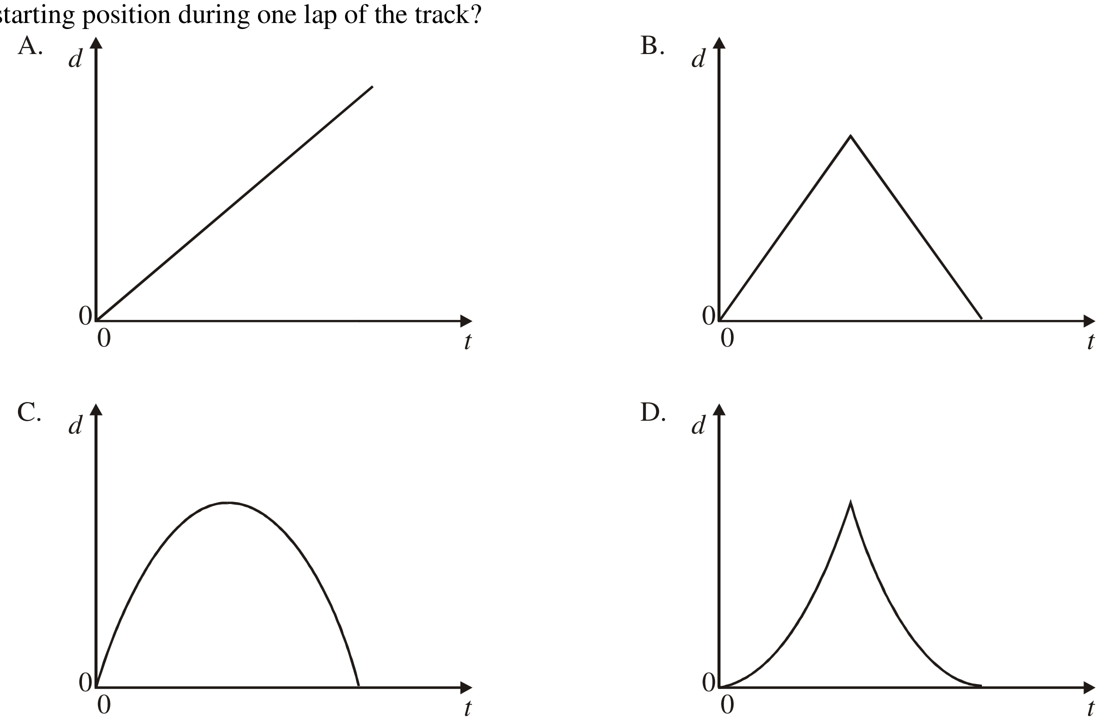
(iv) use of Coulomb's law (seen or implied);
correct identification of gradient = $kq_1q_2 = kq^2$;
$q^2 = 6.56 \times 10^{-17}\ \mathrm{C}^2$;
$q = 8.1 \times 10^{-9}$ C; 4
*Award **[3 max]** for a bald answer without any working. Award **[1 max]** if the candidate uses a point on the graph to calculate q.*

(c) correct taking of lgs of Coulomb's law;
eg $lgF = lg\,(q_1q_2) - 2lg\,r$
to identify a straight-line graph of form $y = mx + c$;
of gradient = -2, which does not go through the origin;
(accept $c = lg\,(kq_1q_2)$*)* 3

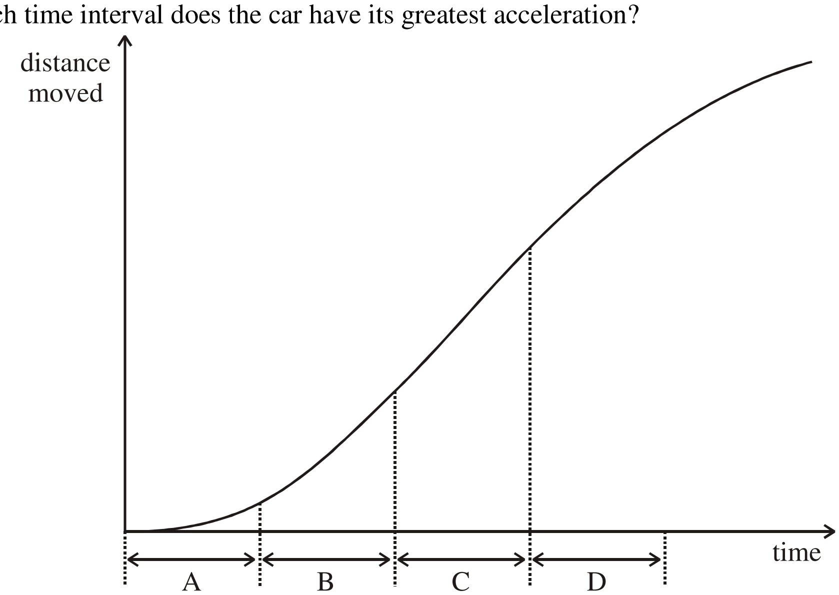
[16]

Topic 2 – Mechanics

1. An athlete runs round a circular track at constant speed. Which **one** of the following graphs best represents the variation with time t of the magnitude d of the **displacement** of the athlete from the starting position during one lap of the track?

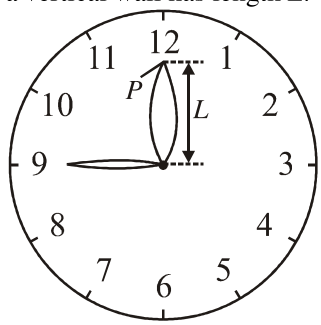


2. The graph below shows the variation with time of the distance moved by a car along a straight road. During which time interval does the car have its greatest acceleration?



(1)

3. The minute hand of a clock hung on a vertical wall has length *L*.



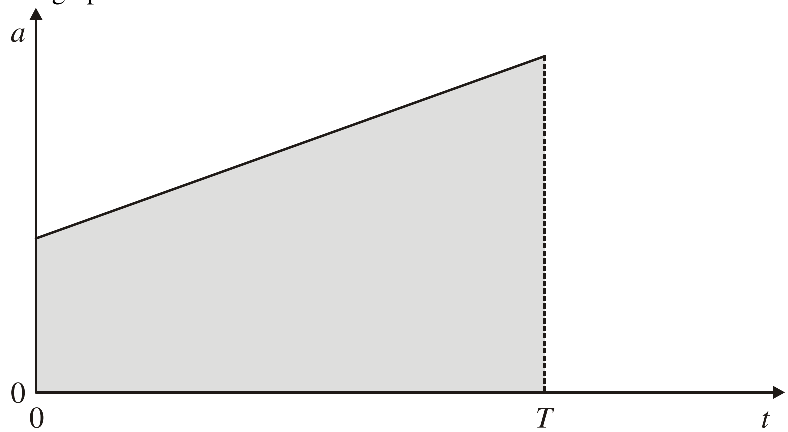
The minute hand is observed at the time shown above and then again, 30 minutes later.
What is the displacement of, and the distance moved by, the end P of the minute hand during this time interval?

	displacement	distance moved
A.	$2L$ vertically downwards	πL
B.	$2L$ vertically upwards	πL
C.	$2L$ vertically downwards	$2L$
D.	$2L$ vertically upwards	$2L$

4. A particle moves from a point P to a point Q in a time *T*. Which **one** of the following correctly defines both the average velocity and average acceleration of the particle?

	Average velocity	Average acceleration
A.	$\dfrac{\text{displacement of Q and P}}{T}$	$\dfrac{\text{change in speed from Q to P}}{T}$
B.	$\dfrac{\text{displacement of Q and P}}{T}$	$\dfrac{\text{change in velocity from Q to P}}{T}$
C.	$\dfrac{\text{distance between Q and P}}{T}$	$\dfrac{\text{change in speed from Q to P}}{T}$
D.	$\dfrac{\text{distance between Q and P}}{T}$	$\dfrac{\text{change in velocity from Q to P}}{T}$

5. The graph below shows the variation with time t of the acceleration a of a spaceship.



The spaceship is at rest at $t = 0$.
The shaded area represents

A. the distance travelled by the spaceship between $t = 0$ and $t = T$.
B. the speed of the spaceship at $t = T$.
C. the rate at which the speed of the spaceship changes between $t = 0$ and $t = T$.
D. the rate at which the acceleration changes between $t = 0$ and $t = T$.

6. A stone is thrown horizontally from the top of a high cliff. Assuming air resistance is negligible, what is the effect of gravitational force on the horizontal and on the vertical components of the velocity of the stone?

	Vertical component of velocity	Horizontal component of velocity
A.	increases to a constant value	stays constant
B.	increases continuously	stays constant
C.	increases to a constant value	decreases to zero
D.	increases continuously	decreases to zero

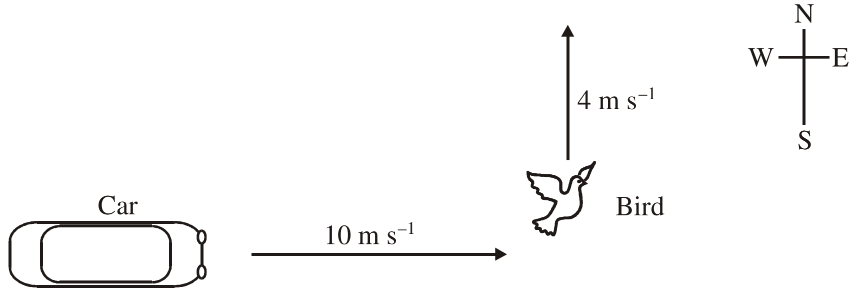
7. Two stones, X and Y, of different mass are dropped from the top of a cliff. Stone Y is dropped a short time after stone X. Air resistance is negligible.
Whilst the stones are falling, the distance between them will

A. decrease if the mass of Y is greater than the mass of X.
B. increase if the mass of X is greater than the mass of Y.
C. decrease whether the mass of X is greater or less than the mass of Y.
D. increase whether the mass of X is greater or less than the mass of Y.

8. A ball is released from rest near the surface of the Moon. Which **one** of the following quantities increases at a constant rate?

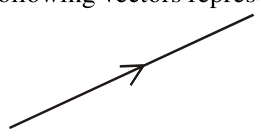
A. Only distance fallen
B. Only speed
C. Only speed and distance fallen
D. Only speed and acceleration

9. A car is heading due East at a speed of 10 m s^{-1}. A bird is flying due North at a speed of 4 m s^{-1}, as shown below.

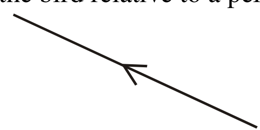


Which **one** of the following vectors represents the velocity of the bird relative to a person in the car?

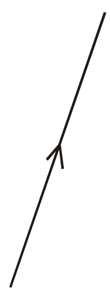
A.



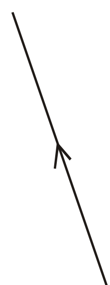
B.



C.



D.



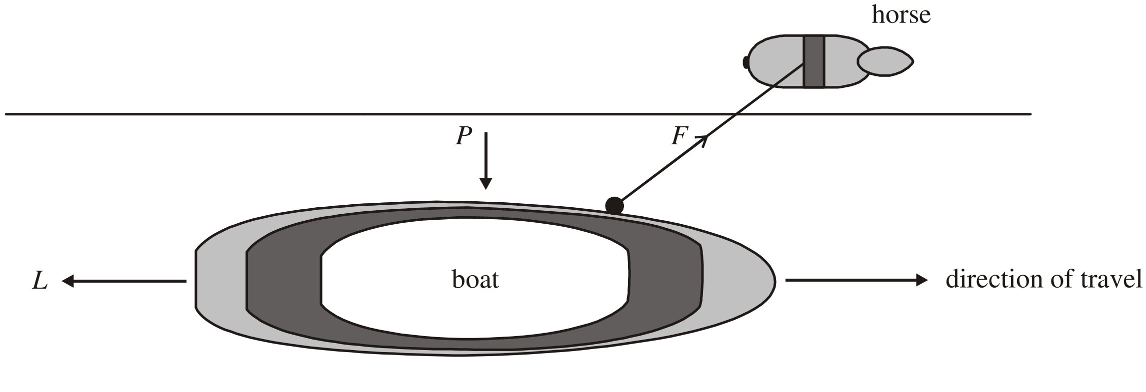
10. If the resultant external force acting on a particle is zero, the particle

A. must have constant speed.
B. must be at rest.
C. must have constant velocity.
D. must have zero momentum.

11. Two blocks having different masses slide down a frictionless slope.
Which of the following correctly compares the accelerating force acting on each block and also the accelerations of the blocks down the slope?

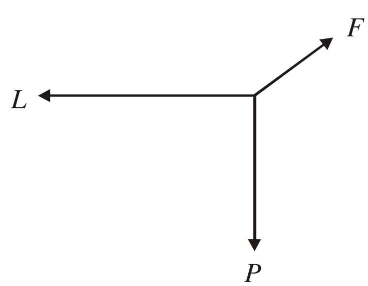
	Accelerating force	**Acceleration**
A.	Equal	Equal
B.	Equal	Different
C.	Different	Equal
D.	Different	Different

12. A horse pulls a boat along a canal at constant speed in a straight-line as shown below.

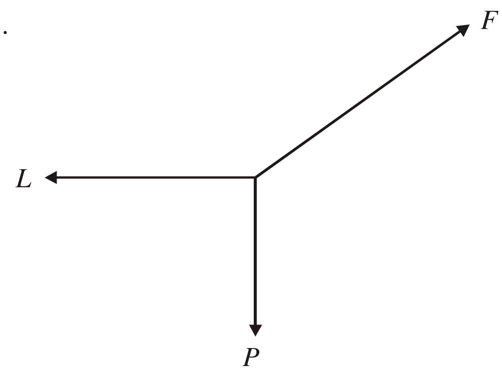


The horse exerts a constant force F on the boat. The water exerts a constant drag force L and a constant force P on the boat. The directions of F, L and P are as shown. Which **one** of the following best represents a free-body diagram for the boat?

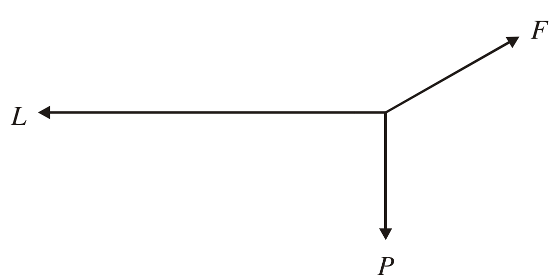
A.



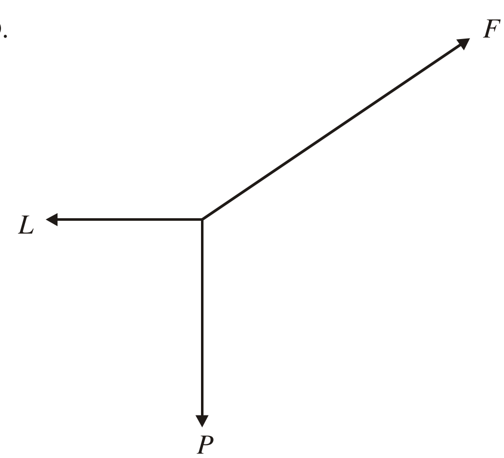
B.



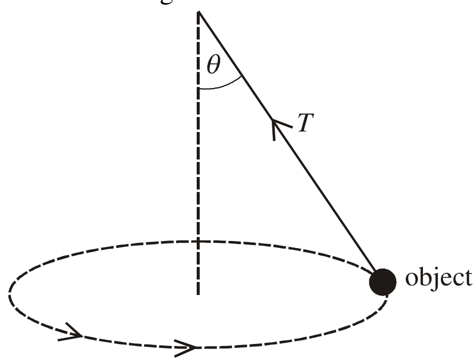
C.



D.



13. An object on the end of a light flexible string rotates in a circle as shown below.



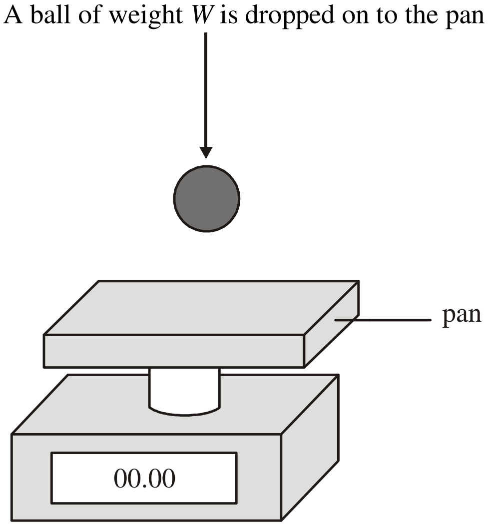
The tension in the string is T when the string is at angle θ to the vertical. Which of the following is true?

	State	Resultant force
A.	not in equilibrium	T
B.	not in equilibrium	$T\sin\theta$
C.	in equilibrium	T
D.	in equilibrium	$T\sin\theta$

14. An object is moving at constant velocity. Which **one** of the following quantities **must** have zero magnitude?

A. Weight of object
B. Momentum of object
C. Kinetic energy of object
D. Resultant force on object

15. A ball of weight W is dropped on to the pan of a top pan weighing balance and rebounds off the pan.

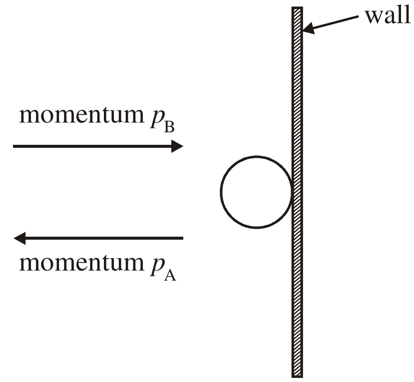


At the instant that the ball has zero velocity when in contact with the pan, the scale will read

A. zero.
B. a value less than W but greater than zero.
C. W.
D. a value greater than W.

16. A sphere of mass m strikes a vertical wall and bounces off it, as shown below.

The magnitude of the momentum of the sphere just before impact is p_B and just after impact is p_A. The sphere is in contact with the wall for time t. The magnitude of the average force exerted by the wall on the sphere is

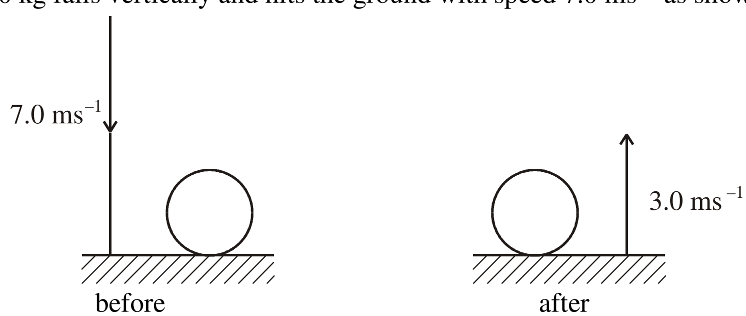


A. $\frac{(p_B - p_A)}{t}$.
B. $\frac{(p_B + p_A)}{t}$.
C. $\frac{(p_B - p_A)}{mt}$.
D. $\frac{(p_B + p_A)}{mt}$.

17. An object of mass m is initially at rest. An impulse I acts on the object. The change in kinetic energy of the object is

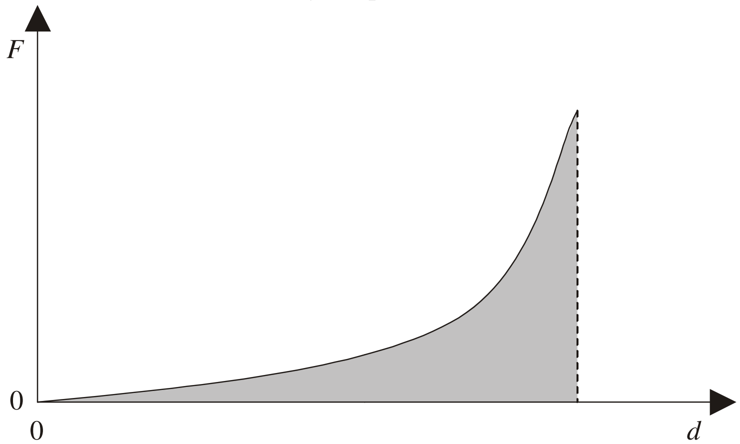
A. $\frac{I^2}{2m}$.
B. $\frac{I^2}{m}$.
C. I^2m.
D. $2I^2m$.

18. A ball of mass 2.0 kg falls vertically and hits the ground with speed 7.0 ms^{-1} as shown below.



The ball leaves the ground with a vertical speed 3.0 ms^{-1}.
The magnitude of the change in momentum of the ball is
A. zero.
B. 8.0 Ns.
C. 10 Ns.
D. 20 Ns.

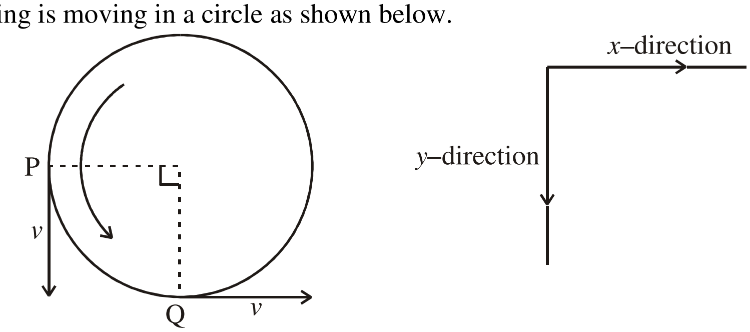
19. A particle moves under the influence of a force F. The graph below shows the variation of the force F with the distance d moved by the particle.



The shaded area is equal to

A. the average value of F.
B. the impulse produced by F.
C. the work done by F.
D. the power produced by F.

20. A stone on a string is moving in a circle as shown below.



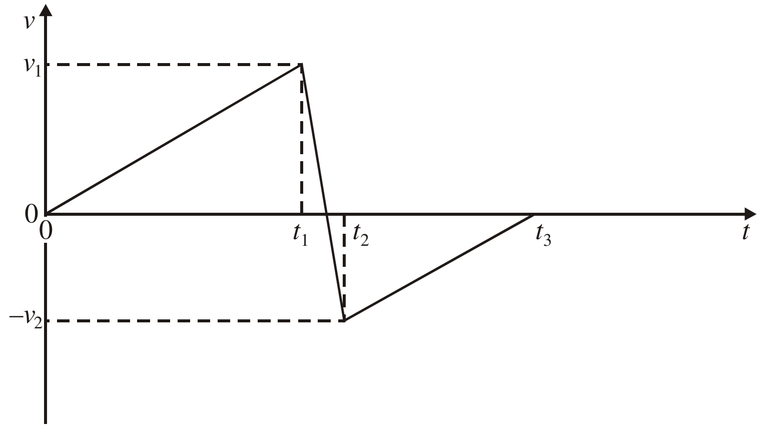
At point P, the stone of mass m has speed v in the y-direction. A quarter of a revolution later, the stone at point Q has speed v in the x-direction.
What is the change, in the y-direction **only**, of the magnitude of the momentum of the stone?

A. zero
B. mv
C. $\sqrt{2}mv$
D. $2mv$

21. The velocity of a body of mass m changes by an amount Δv in a time Δt. The impulse given to the body is equal to

A. $m\Delta t$.
B. $\dfrac{\Delta v}{\Delta t}$.
C. $m\dfrac{\Delta v}{\Delta t}$.
D. $m\Delta v$.

22. A ball of mass m falls from rest on to a horizontal plate and bounces off it. The magnitudes of its velocity just before and just after the bounce are v_1 and v_2 respectively. The variation with time t of the velocity v of the ball is shown below.



The magnitude of the net force on the ball is given by which **one** of the following?

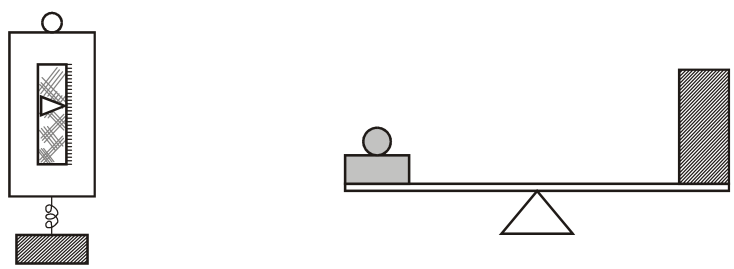
A. $\dfrac{mv_1}{t_1}$

B. $\dfrac{mv_2}{(t_3 - t_2)}$

C. $\dfrac{m(v_1 - v_2)}{(t_2 - t_1)}$

D. $\dfrac{m(v_1 + v_2)}{(t_2 - t_1)}$

23. The weight of a mass is measured on Earth using a spring balance and a lever balance, as shown below.

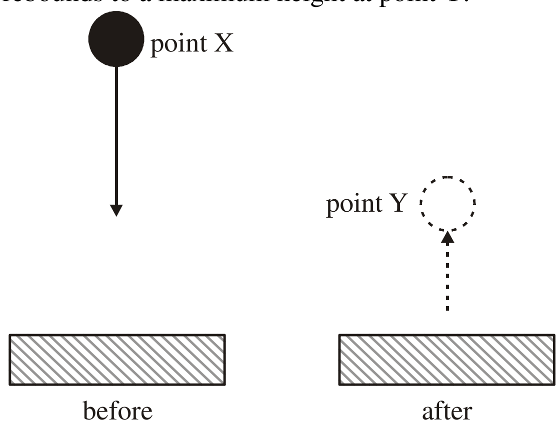


spring balance　　　　lever balance

What change, if any, would occur in the measurements if they were repeated on the Moon's surface?

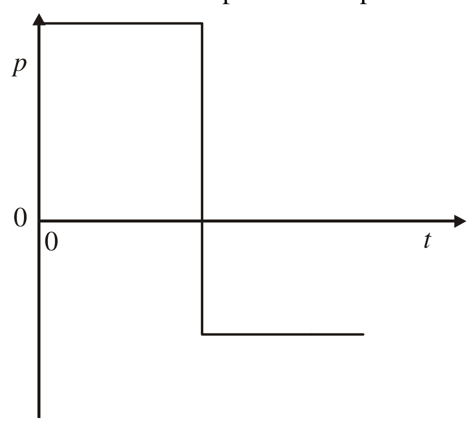
	Spring balance	Lever balance
A.	same	same
B.	same	decrease
C.	decrease	same
D.	decrease	decrease

24. A ball is held at rest at point X and is then released. It drops on to a flat horizontal surface and rebounds to a maximum height at point Y.

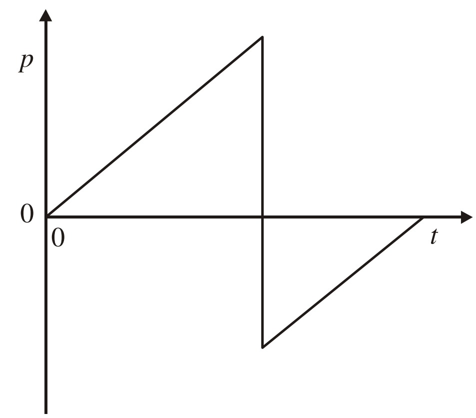


Which **one** of the following graphs best shows the variation with time *t* of the momentum *p* of the ball as it moves between point X and point Y?

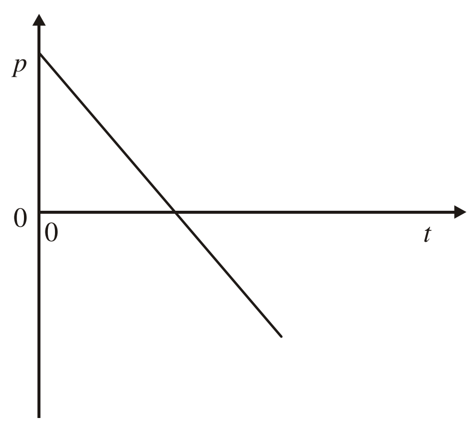
A.



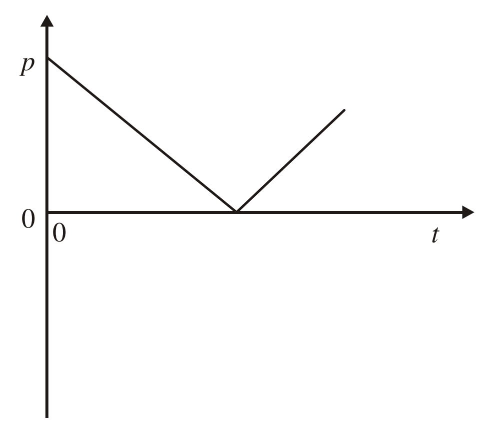
B.



C.



D.



(1)

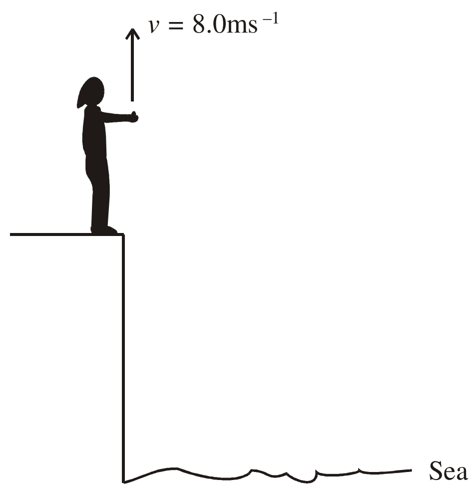
25. The centripetal force F acting on a particle of mass m that is travelling with linear speed v along the arc of a circle of radius r is given by

A. $F = \frac{v^2}{mr}$.
B. $F = mv^2r$.
C. $F = mr^2v$.
D. $F = \frac{mv^2}{r}$.

26. Two satellites of equal mass, S_1 and S_2, orbit the Earth. S_1 is orbiting at a distance r from the Earth's centre at speed v. S_2 orbits at a distance $2r$ from the Earth's centre at speed $\frac{v}{\sqrt{2}}$. The ratio of the centripetal force on S_1 to the centripetal force on S_2 is

A. $\frac{1}{8}$.
B. $\frac{1}{4}$.
C. 4.
D. 8.

27. This question is about throwing a stone from a cliff. Antonia stands at the edge of a vertical cliff and throws a stone vertically upwards.



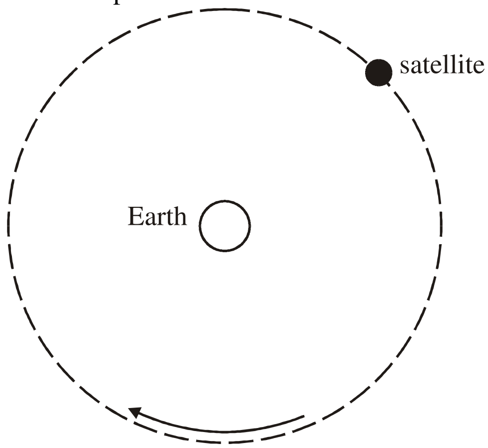
The stone leaves Antonia's hand with a speed v = 8.0ms^{-1}.
The acceleration of free fall g is 10 m s^{-2} and all distance measurements are taken from the point where the stone leaves Antonia's hand.

(a) Ignoring air resistance calculate
(i) the maximum height reached by the stone
(ii) the time taken by the stone to reach its maximum height.

The time between the stone leaving Antonia's hand and hitting the sea is 3.0 s.
(b) Determine the height of the cliff.

(Total 6 marks)

28. A satellite orbits the Earth at constant speed as shown below.



(a) Draw on the diagram

(i) an arrow labelled F to show the direction of the gravitational force of the Earth on the satellite.

(ii) an arrow labelled V to show the direction of the velocity of the satellite.

(2)

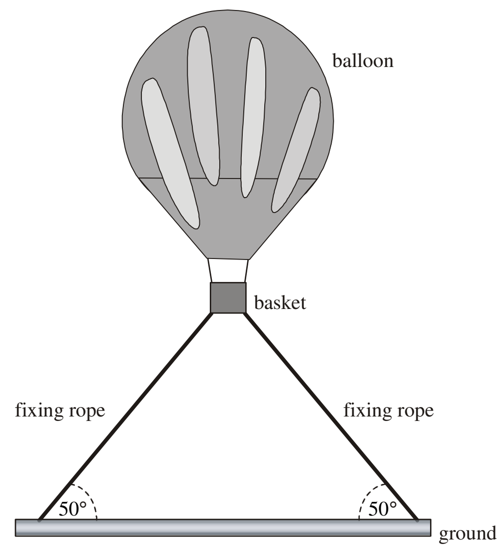
(b) Although the speed of the satellite is constant, it is accelerating. Explain why it is accelerating.

(2)

(c) Discuss whether or not the gravitational force does work on the satellite.

(3)
(Total 7 marks)

29. This question is about a balloon used to carry scientific equipment.
The diagram below represents a balloon just before take-off. The balloon's basket is attached to the ground by two fixing ropes.



There is a force F vertically upwards of 2.15×10^3 N on the balloon. The total mass of the balloon and its basket is 1.95×10^2 kg.

(a) State the magnitude of the resultant force on the balloon when it is attached to the ground. **(1)**

(b) Calculate the tension in **either** of the fixing ropes.

(3)

(c) The fixing ropes are released and the balloon accelerates upwards. Calculate the magnitude of this initial acceleration.

(2)

(d) The balloon reaches a terminal speed 10 seconds after take-off. The upward force F remains constant. Describe how the magnitude of air friction on the balloon varies during the first 10 seconds of its flight.

(2)
(Total 8 marks)

30. Linear momentum

(a) Define

(i) *linear momentum*;

(1)

(ii) *impulse*.

(1)

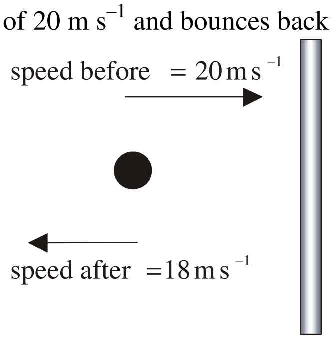
(b) Explain whether momentum and impulse are scalar or vector quantities.

(1)

(c) By reference to Newton’s laws of motion, deduce that when two particles collide, momentum is conserved.

(5)

A rubber ball of mass 50 g is thrown towards a vertical wall. It strikes the wall at a horizontal speed of 20 m s^{-1} and bounces back with a horizontal speed of 18 m s^{-1} as shown below.



The ball is in contact with the wall for 0.080 s.

(d) (i) Calculate the change in momentum of the ball.

(2)

(ii) Calculate the average force exerted by the ball on the wall.

(2)

(iii) Suggest, in terms of Newton's laws of motion, why a steel ball of the same mass and the same initial horizontal speed exerts a greater force on the wall.

(3)
(Total 15 marks)

31. This question is about conservation of momentum and conservation of energy.

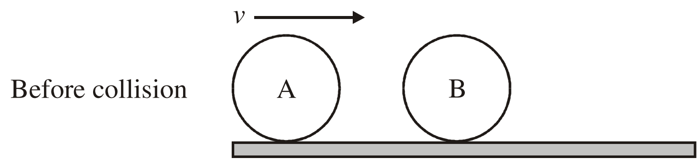
(a) State Newton's third law.

(1)

(b) State the law of conservation of momentum.

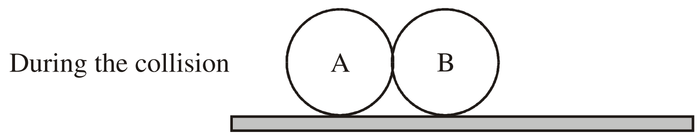
(2)

The diagram below shows two identical balls A and B on a horizontal surface. Ball B is at rest and ball A is moving with speed V along a line joining the centres of the balls. The mass of each ball is M.



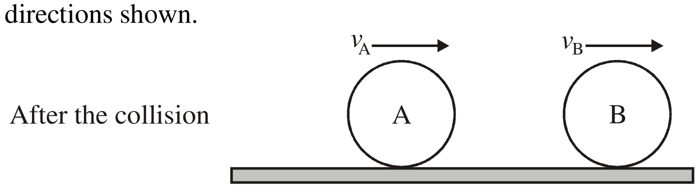
During the collision of the balls, the magnitude of the force that ball A exerts on ball B is F_{AB} and the magnitude of the force that ball B exerts on ball A is F_{BA}.

(c) On the diagram below, add labelled arrows to represent the magnitude and direction of the forces F_{AB} and F_{BA}.



(3)

The balls are in contact for a time Δt. After the collision, the speed of ball A is $+v_A$ and the speed of ball B is $+v_B$ in the directions shown.



As a result of the collision, there is a change in momentum of ball A and of ball B.

(d) Use Newton's second law of motion to deduce an expression relating the forces acting during the collision to the change in momentum of

(i) ball B.

(2)

(ii) ball A.

(2)

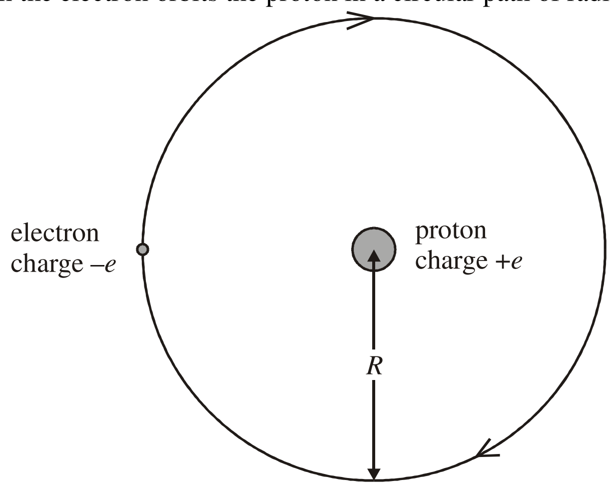
(e) Apply Newton's third law and your answers to (d), to deduce that the change in momentum of the system (ball A and ball B) as a result of this collision, is zero.

(4)

(f) Deduce, that if kinetic energy is conserved in the collision, then after the collision, ball A will come to rest and ball B will move with speed *V*.

(3)
(Total 17 marks)

32. This question is about atomic models. The diagram below (not to scale) shows a simple model of the hydrogen atom in which the electron orbits the proton in a circular path of radius *R*.



(a) On the diagram, draw an arrow to show the direction of

(i) the acceleration of the electron (label this A);

(1)

(ii) the velocity of the electron (label this V).

(1)

(b) State an expression for the magnitude of the electrostatic force *F* acting on the electron.

(1)

(c) The orbital speed of the electron is 2.2×10^{6} m s^{-1}.
Deduce that the radius *R* of the orbit is 5.2×10^{-11} m.

(3)

Topic 2 – Mark Scheme

1.	C	**14.**	D
2.	B	**15.**	D
3.	A	**16.**	B
4.	B	**17.**	A
5.	B	**18.**	D
6.	B	**19.**	C
7.	D	**20.**	B
8.	B	**21.**	D
9.	B	**22.**	D
10.	C	**23.**	C
11.	C	**24.**	B
12.	B	**25.**	D
13.	B	**26.**	C

27. (a) (i) $h = \frac{v^2}{2g}$;
to give $h = 3.2$ m; 2

(ii) 0.80 s; 1

(b) time to go from top of cliff to the sea = 3.0 – 1.6 = 1.4 s;
recognize to use $s = ut + \frac{1}{2}at^2$ with correct substitution,
$s = 8.0 \times 1.4 + 5.0 \times (1.4)^2$;
to give $s = 21$ m; 3
Answers might find the speed with which the stone hits the sea from $v = u + at$, (42 $m\ s^{-1}$) and then use $v^2 = u^2 + 2as$.

[6]

28. (a) (i) from satellite towards centre of Earth;
(ii) tangent to circle at satellite in correct direction;
(no labels, ***[1 max]***) 2

(b) direction of motion is changing / force acts on satellite;
and changing direction means changing velocity / any further detail; 2

(c) work done is product of force and distance moved in direction of force;
force is always normal to direction of motion;
hence no work done;
(accept argument based on changes in E_k and E_p) 3

[7]

29. (a) zero; 1

(b) resultant vertical force from ropes = $(2.15 \times 10^3$ – weight) = 237N;
equating their result to $2T \sin 50$;
ie $2T \sin 50 = 237$
calculation to give $T = 154.7\text{N} \approx 150\text{N}$; 3
*Accept any value of tension from 130 N to 160 N. Award **[2]** for missing factor of 2 but otherwise correct ie 309 N.*

(c) correct <u>substitution</u> into $F = ma$;
to give $a = \frac{237}{1.95 \times 10^2} = 1.21\ \text{ms}^{-2}$; 2
Watch for ecf.
***NB** Depending on value of g answer will vary from 1.0(3) ms^{-2} to 1.2(3) ms^{-2} all of which are acceptable.*

(d) statement that air friction increases with increased speed seen / implied;
in 10 seconds friction goes from 0 N to 237 N / force increases from zero
until it equals the net upward accelerating force; 2

[8]

30. Linear momentum

(a) (i) product of mass and velocity / *OWTTE*; 1

(ii) change of momentum / *OWTTE*; 1
Accept product of force and time taken / OWTTE.

(b) they are vectors because they have magnitude and direction; 1
Answer needs some form of explanation to receive the mark but it can be simple.

(c) appropriate reference / naming of Newton III;
to give forces equal and opposite;
time of collision the same for each particle;
appropriate reference / naming of Newton II;
impulse / change in momentum equal and opposite; 5

(d) (i) change of momentum = $0.05 \times (20 - (-18))$;
$= 1.9\ \text{kgms}^{-1}$; 2
*Award **[1 max]** for forgetting vector nature ie 0.1 kg ms^{-1}.*

(ii) force = answer to (i) / 0.08;
$= 23.75\text{N} \approx 24\text{N}$; 2

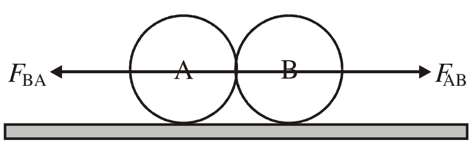
(iii) shorter contact time / greater rebound speed;
so rate of change in momentum larger / *OWTTE*;
appropriate reference to Newton's laws; 3

[15]

31. (a) when two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A;
or
when a force acts on a body an equal and opposite force acts on another body somewhere in the universe; 1 max
*Award **[0]** for "action and reaction are equal and opposite" unless they explain what is meant by the terms.*

(b) if the net external force acting on a system is zero;
then the total momentum of the system is constant (or in any one direction, is constant); 2
*To achieve **[2]** answers should mention forces and should show what is meant by conserved. Award **[1 max]** for a definition such as "for a system of colliding bodies, the momentum is constant" and **[0]** for "a system of colliding bodies, momentum is conserved".*

(c)



arrows of equal length;
acting through centre of spheres;
correct labelling consistent with correct direction; 3

(d) (i) *Ball B:*
change in momentum = Mv_B;
hence $F_{AB}\Delta t = Mv_B$; 2

(ii) *Ball A:*
change in momentum = $M(v_A - V)$;
hence from Newton 2, $F_{BA}\Delta t = M(v_A - V)$; 2

(e) from Newton 3, $F_{AB} + F_{BA} = 0$, ***or*** $F_{AB} = -F_{BA}$;
therefore $-M(v_A - V) = Mv_B$;
therefore $MV = Mv_B + Mv_A$;
that is, momentum before equals momentum after collision such that the net change in momentum is zero (unchanged) / *OWTTE*; 4

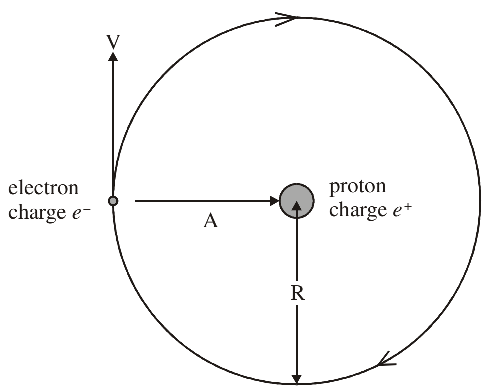
Some statement is required to get the fourth mark ie an interpretation of the maths result.

(f) from conservation of momentum $V = v_B + v_A$;
from conservation of energy $V^2 = v_B^{\ 2} + v_A^{\ 2}$;
if $v_A = 0$, then both these show that $v_B = V$;
or
from conservation of momentum $V = v_B + v_A$;
from conservation of energy $V^2 = v_B^{\ 2} + v_A^{\ 2}$;
so, $V^2 = (v_B + v_A)^2 = v_B^{\ 2} + v_A^{\ 2} + 2v_Av_B$ therefore v_A has to be zero; 3 max

Answers must show that effectively, the only way that both momentum and energy conservation can be satisfied is that ball A comes to rest and ball B moves off with speed V.

[17]

32. (a)



(i) correct A; 1
(ii) correct V; 1

(b) $F = k\dfrac{e^2}{R^2}$ ***or*** $F = \dfrac{e^2}{4\pi\varepsilon_o R^2}$; 1

Accept if answer is seen in (c).

(c) $F = k\dfrac{e^2}{R^2} = \dfrac{mv^2}{R}$;

to give $R = \dfrac{ke^2}{mv^2}$;

correct substitution $R = \dfrac{9\times10^9 \times (1.6)^2 \times 10^{-38}}{9.1\times10^{-31}\times(2.2)^2\times10^{12}}$ to give $R = 5.2 \times 10^{-11}$ m; 3

Topic 3 – Thermal Physics

1. Temperature is the **only** property that determines
A. the total internal energy of a substance.
B. the phase (state) of a substance.
C. the direction of thermal energy transfer between two bodies in thermal contact.
D. the process by which a body loses thermal energy to the surroundings.

2. A temperature scale is to be constructed using the property X of a substance. Which of the following must be a characteristic of the property X?
A. The value of the property must be zero at zero kelvin.
B. The property must increase with increase of temperature.
C. The property must have a different value at each temperature to be measured.
D. The value of the property must vary linearly with kelvin temperature.

3. Which two values of temperature are equivalent to the nearest degree when measured on the Kelvin and on the Celsius scales of temperature?

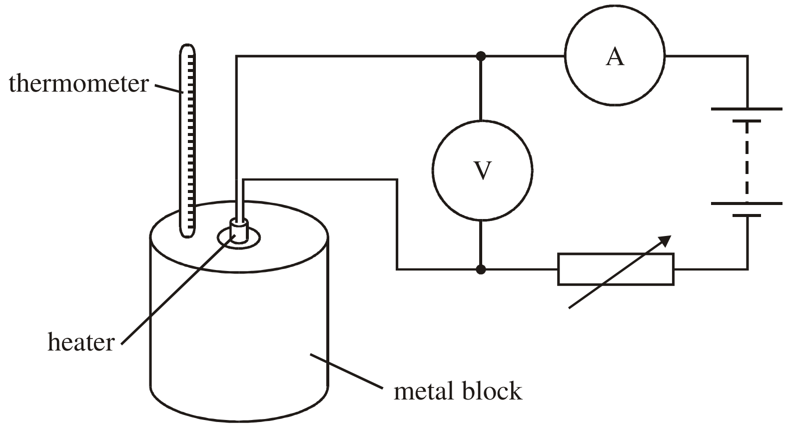
	Kelvin scale	Celsius scale
A.	40	313
B.	273	100
C.	313	40
D.	373	0

4. Two different objects are in thermal contact with one another. The objects are at different temperatures. The temperatures of the two objects determine
A. the process by which thermal energy is transferred.
B. the heat capacity of each object.
C. the direction of transfer of thermal energy between the objects.
D. the amount of internal energy in each object.

5. Which of the following is the internal energy of a system?
A. The total thermal energy gained by the system during melting and boiling.
B. The sum of the potential and the kinetic energies of the particles of the system.
C. The total external work done on the system during melting and boiling.
D. The change in the potential energy of the system that occurs during melting and boiling.

6. The specific heat capacity of a metal block of mass *m* is determined by placing a heating coil in its centre, as shown in the diagram. The block is heated for time *t* and the maximum temperature change recorded is $\Delta\theta$. The ammeter and voltmeter readings during the heating are *I* and *V* respectively.

The specific heat capacity is best calculated using which **one** of the following expressions?



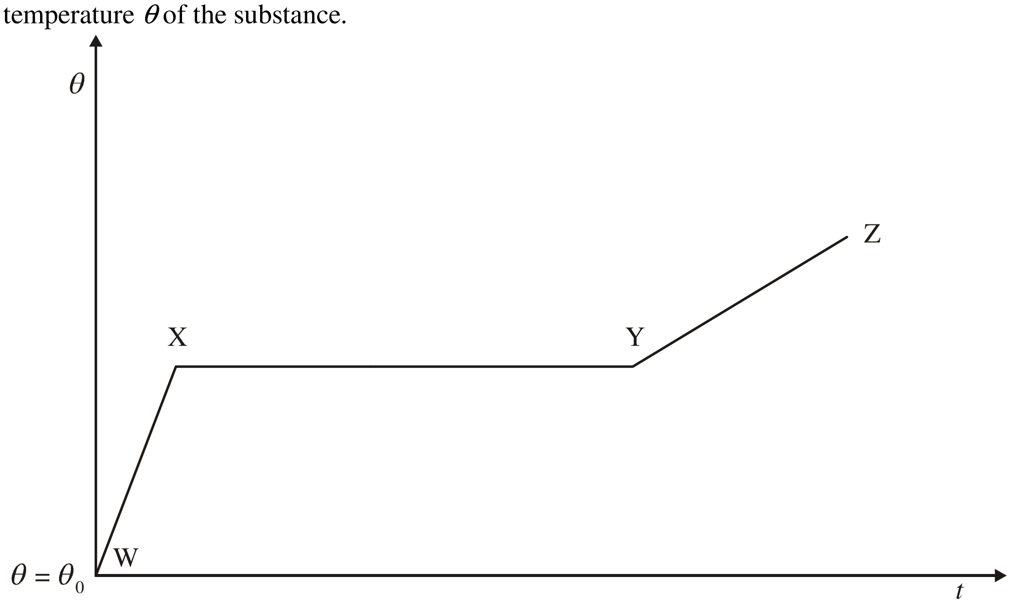
A. $c = \dfrac{VIt}{m\Delta\theta}$

B. $c = \dfrac{VI}{m\Delta\theta}$

C. $c = \dfrac{m\Delta\theta}{VI}$

D. $c = \dfrac{m\Delta\theta}{VIt}$

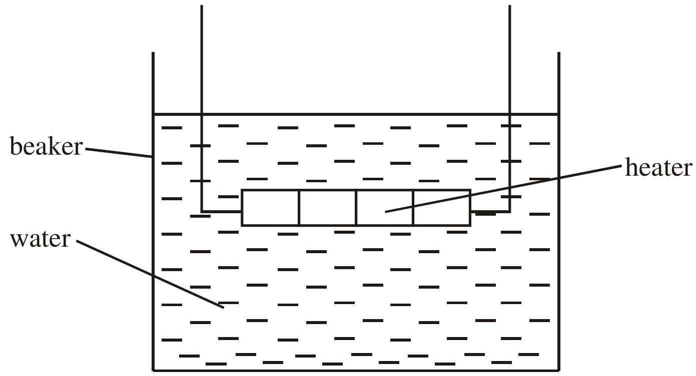
7. A substance is heated at a constant rate. The sketch graph shows the variation with time *t* of the temperature θ of the substance.



In which region **or** regions of the graph must there be more than one phase of the substance present?

A. WX and YZ
B. WX only
C. WX, XY and YZ
D. XY only

8. As part of an experiment to determine the latent heat of vaporisation of water, a student boils some water in a beaker using an electric heater as shown below.



The student notes two sources of error.

Error 1: thermal energy is lost from the sides of the beaker
Error 2: as the water is boiling, water splashes out of the beaker

Which of the following gives the correct effect of these two errors on the calculated value for the specific latent heat?

	Error 1	**Error 2**
A.	Increase	Decrease
B.	Increase	No change
C.	Decrease	Increase
D.	Decrease	No change

9. Two ideal gases X and Y, are contained in a cylinder at constant temperature. The mass of the atoms of X is m and of Y is $4m$.

Which **one** of the following is the correct value of the ratio

$$\frac{\text{average kinetic energy of the atoms of Y}}{\text{average kinetic energy of the atoms of X}}?$$

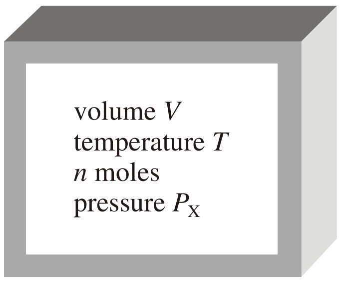
A. 1
B. 2
C. 4
D. 16

10. A container holds 20 g of neon (mass number 20) and also 8 g of helium (mass number 4).

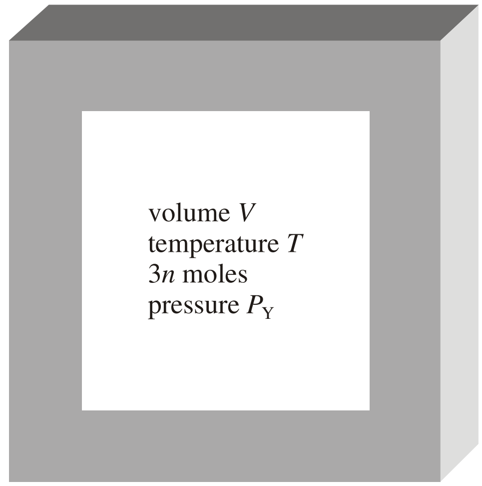
What is the ratio $\frac{\text{number of atoms of neon}}{\text{number of atoms of helium}}$?

A. 0.4
B. 0.5
C. 2.0
D. 2.5

11. Container X below has volume V and holds n moles of an ideal gas at kelvin temperature T. Container Y has volume $2V$ and holds $3n$ moles of an ideal gas also at kelvin temperature T.



container X



container Y

The pressure of the gas in X is P_X and in Y is P_Y.

The ratio $\frac{P_X}{P_Y}$ is

A. $\frac{2}{3}$.
B. $\frac{3}{2}$.
C. 5.
D. 6.

12. Which of the following is **not** an assumption on which the kinetic model of an ideal gas is based?
A. All molecules behave as if they are perfectly elastic spheres.
B. The mean-square speed of the molecules is proportional to the kelvin temperature.
C. Unless in contact, the forces between molecules are negligible.
D. The molecules are in continuous random motion.

13. This question is about specific heat capacity and specific latent heat.
(a) Define *specific heat capacity*.

(1)

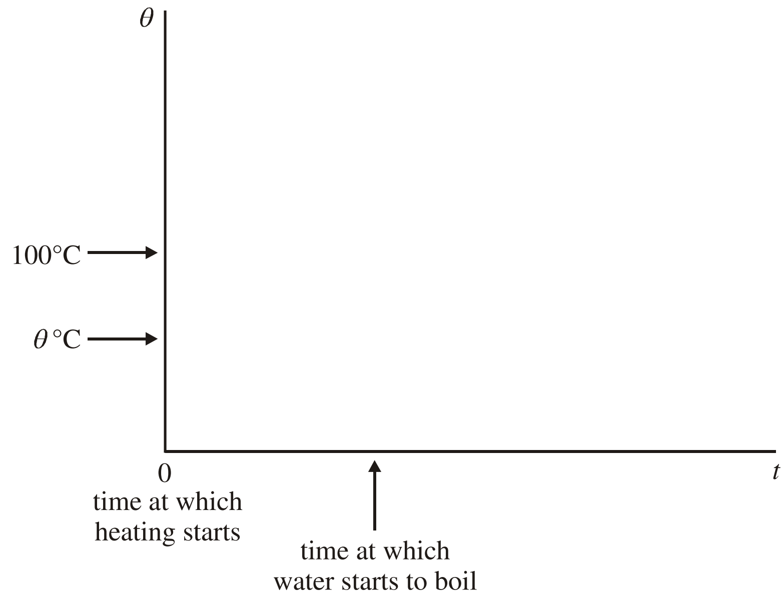
(b) Explain briefly why the specific heat capacity of different substances such as aluminium and water are not equal in value.

(2)

A quantity of water at temperature θ is placed in a pan and heated at a constant rate until some of the water has turned into steam. The boiling point of the water is 100°C.

(c) (i) Using the axes below, draw a sketch-graph to show the variation with time t of the temperature θ of the water. *(**Note**: this is a sketch-graph; you do not need to add any values to the axes.)*

(1)



(ii) Describe in terms of energy changes, the molecular behaviour of water and steam during the heating process.

(5)

Thermal energy is supplied to the water in the pan for 10 minutes at a constant rate of 400 W. The thermal capacity of the pan is negligible.

(d) (i) Deduce that the total energy supplied in 10 minutes is 2.4×10^5 J.

(1)

(ii) Using the data below, estimate the mass of water turned into steam as a result of this heating process.

initial mass of water	= 0.30 kg
initial temperature of the water θ	= 20°C
specific heat capacity of water	= 4.2×10^{3} J kg^{-1} K^{-1}
specific latent heat of vaporization of water	= 2.3×10^{6} Jkg^{-1}

(3)

(iii) Suggest **one** reason why this mass is an estimate.

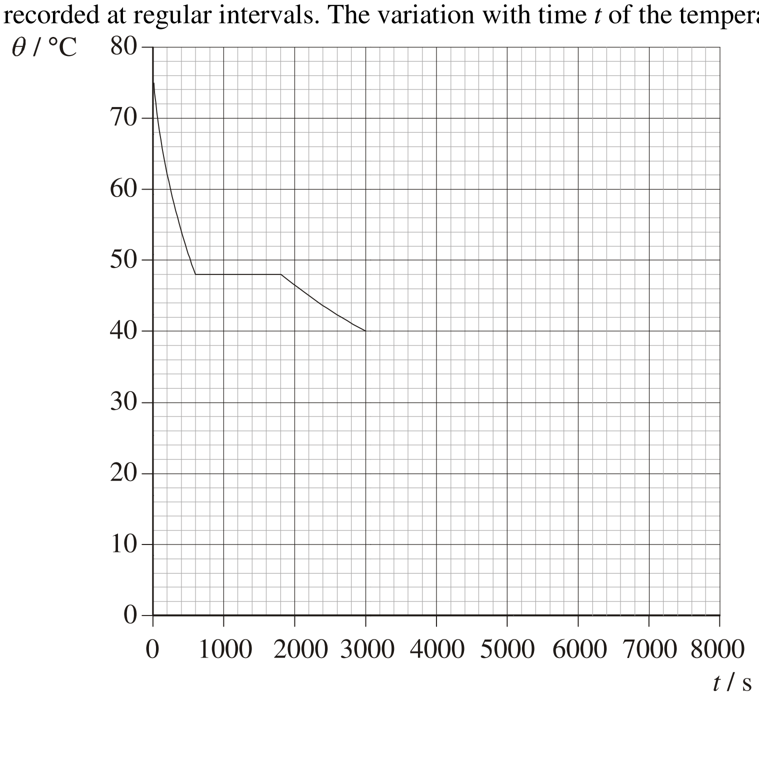
(1)
(Total 14 marks)

14. The physics of cooling

(a) Explain what is meant by *the temperature of a substance*.

(2)

A thermometer is placed in a liquid contained in an open beaker. The reading of the thermometer is recorded at regular intervals. The variation with time t of the temperature θ is shown below.



(b) The temperature of the surroundings is 20°C. On the graph continue the line to show the variation with time of the temperature for the next 3000 s.

(2)

(c) By reference to the graph, state and explain the rate of loss of thermal energy from the substance between

(i) 0 and 600 s;

(2)

(ii) 600 and 1800 s.

(4)

The mass of the liquid is 0.11 kg and the specific heat capacity of the liquid is 1300 J kg^{-1} K^{-1}.

(d) (i) Use the graph to deduce that the rate of loss of thermal energy at time t = 600 s is approximately 4 W.

(3)

(ii) Calculate the specific latent heat of fusion of the liquid.

(3)

(Total 16 marks)

15. This question is about modelling the thermal processes involved when a person is running.
When running, a person generates *thermal energy* but maintains approximately constant *temperature*.

(a) Explain what *thermal energy* and *temperature* mean. Distinguish between the two concepts.

(4)

The following simple model may be used to estimate the rise in temperature of a runner assuming no thermal energy is lost.
A closed container holds 70 kg of water, representing the mass of the runner. The water is heated at a rate of 1200 W for 30 minutes. This represents the energy generation in the runner.

(b) (i) Show that the thermal energy generated by the heater is 2.2×10^6 J.

(2)

(ii) Calculate the temperature rise of the water, assuming no energy losses from the water. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

(3)

(c) The temperature rise calculated in (b) would be dangerous for the runner. Outline **three** mechanisms, other than evaporation, by which the container in the model would transfer energy to its surroundings.

(6)

A further process by which energy is lost from the runner is the evaporation of sweat.

(d) (i) Describe, in terms of molecular behaviour, why evaporation causes cooling.

(3)

(ii) Percentage of generated energy lost by sweating: 50%
Specific latent heat of vaporization of sweat: 2.26×10^6 J kg^{-1}
Using the information above, and your answer to (b) (i), estimate the mass of sweat evaporated from the runner.

(3)

(iii) State and explain **two** factors that affect the rate of evaporation of sweat from the skin of the runner.

(4)
(Total 25 marks)

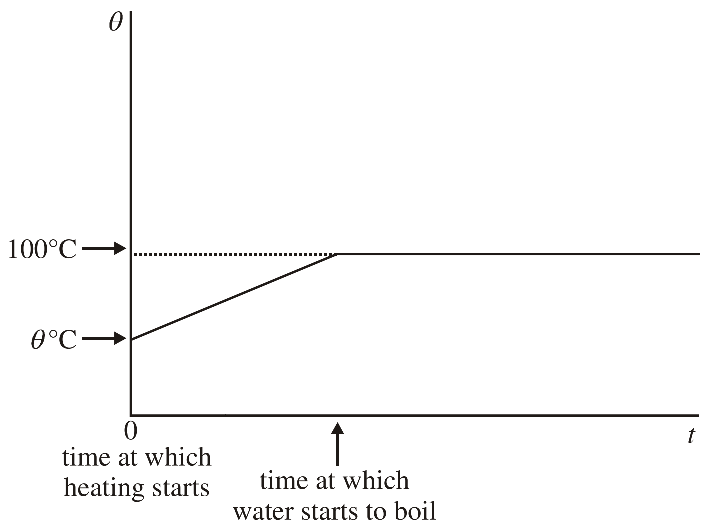
Topic 3 – Mark Scheme

1. C
2. C
3. C
4. C
5. B
6. A
7. D
8. A
9. A
10. B
11. A
12. B

13. (a) specific heat capacity is the amount of energy required to raise the temperature of unit mass through 1 K; 1

(b) raising the temperature means increasing the KE of the molecules;
there are different numbers of molecules of different mass in unit mass of aluminium and water (accept different densities) and therefore different amounts of energy will be needed / *OWTTE*; 2

(c) (i)



general shape (but constant θ range must be clear); 1

(ii) $\theta \rightarrow 100$°C:
the KE of the molecules is increasing;
100°C:
when the water starts to change phase, there is no further increase in KE;
the energy goes into increasing the PE of the molecules;
so increasing their separation;
until they are far enough apart to become gas / their molecular bonds are broken / until they are effectively an infinite distance apart / *OWTTE*; 5

(d) (i) total energy supplied = $400 \times 600 = 2.4 \times 10^5$ J; 1

(ii) energy required to raise temperature of water = $0.30 \times 80 \times 4.2 \times 10^3$
$= 1.0 \times 10^5$ J;
energy available to convert water to steam = $(2.4 - 1.0) \times 10^5 = 1.4 \times 10^5$ J;

mass of water converted to steam $= \dfrac{(1.4 \times 10^5)}{2.3 \times 10^6} \approx 60$ g; 3

(iii) energy is lost to the surroundings *(must specify where the energy is lost)* / water might bubble out of pan whilst boiling / anything sensible; 1 max

[14]

14. The physics of cooling

(a) temperature is proportional to a measure of the average kinetic energy;
of the molecules of the substance;
or:
idea that temperature shows natural direction of the flow of thermal energy;
from high to low temperature / *OWTTE; (do not accept hot to cold)* 2
*Award **[1 max]** for a rough and ready answer and **[2 max]** for a more detailed answer.*

(b) a curve of gradually decreasing rate of loss of temperature;
that is asymptotic to 20°C; 2
*Award **[0]** for a straight-line graph.*

(c) (i) temperature is falling because of thermal energy transfer to the surroundings;
with a decreasing rate;
the rate thermal energy transfer / heat loss in this region is greater;
because the temperature difference with the surroundings is greater / *OWTTE*; 2

(ii) realization that substance is still losing thermal energy; 1
*Award **[3 max]** for other relevant points:*
eg liquid and solid present / phase change taking place;
temperature stays constant until no more liquid;
at a constant rate;
loss of PE of atoms = thermal energy transfer;
because PE decreases;
KE of atoms constant; 4
*Award **[2 max]** for an answer that fails to realize that the liquid solidifies.*

(d) (i) calculation of the temperature rate of change in the range $(2.4 - 3.5) \times 10^{-2}$ °Cs^{-1};

$$\frac{\Delta Q}{\Delta t} = mc\frac{\Delta Q}{\Delta t};$$

$= 0.11 \times 1300 \times 2.9 \times 10^{-2}$;
$\simeq 4(\pm 1)$W; 3

(ii) energy lost while solidifying, $E = 3600 - 6000$J;

$$L = \frac{E}{m};$$

$L = 33 - 55$kJ kg^{-1}; 3

[17]

15. (a) *[1] for each appropriate and valid point eg*
thermal energy is the KE of the component particles of an object;
thus measured in joules;
the temperature of an object is a measure how hot something is (it can be used to work out the direction of the natural flow of thermal energy between two objects in thermal contact) / measure of the average KE of molecules;
it is measured on a defined scale (Celsius, Kelvin *etc*); 4 max

(b) (i) correct substitution: energy = power × time;
$= 1200 \text{ W} \times (30 \times 60) \text{ s}$;
$= 2.2 \times 10^6 \text{ J}$ 2 max

(ii) use of $E = m\,c\,\Delta\theta$;
to get $\Delta\theta = 2.2 \times 10^6 / (4200 \times 70) \text{ K}$;
$= 7.5 \text{ K}$; 3 max

(c) ***[1]*** *naming each process up to* ***[3 max]****.*
convection;
conduction;
radiation;
[1] *for an appropriate (matching) piece of information / outline for each process up to* ***[3 max]****.*

eg convection is the transfer of thermal energy via bulk movement of a gas due to a change of density;
conduction is transfer of thermal energy via intermolecular collisions;
radiation is the transfer of thermal energy via electromagnetic waves (IR part of the electromagnetic spectrum in this situation) */ OWTTE*; 6 max

(d) (i) ***[1]*** *for each valid and relevant point eg*
in evaporation the faster moving molecules escape;
this means the average KE of the sample left has fallen;
a fall in average KE is the same as a fall in temperature; 3 max

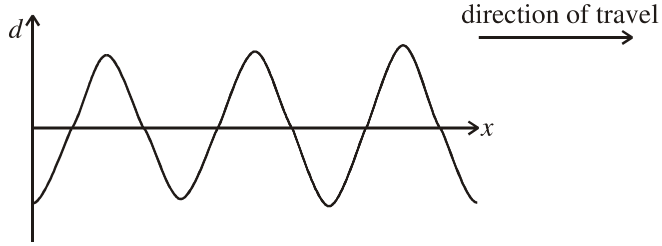
(ii) energy lost by evaporation $= 50\% \times 2.2 \times 10^6 \text{ J}$;
$= 1.1 \times 10^6 \text{ J}$;
correct substitution into $E = m\,l$
to give mass lost $= 1.1 \times 10^6 \text{ J} / 2.26 \times 10^6 \text{ J kg}^{-1}$
$= 0.487 \text{ kg}$
$= 487 \text{ g}$; 3 max

(iii) ***[1]*** *for any valid and relevant factors* ***[2 max]*** *eg*
area of skin exposed;
presence or absence of wind;
temperature of air;
humidity of air *etc*;
[1] *for appropriate and matching explanations* ***[2 max]*** *eg*
increased area means greater total evaporation rate;
presence of wind means greater total evaporation rate;
evaporation rate depends on temperature difference;
increased humidity decreases total evaporation rate *etc*; 4 max

[25]

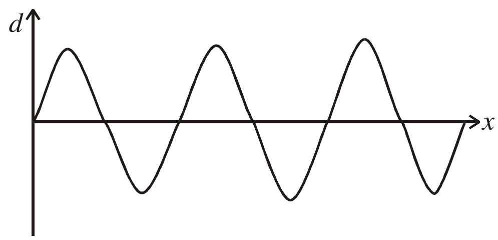
Topic 4 – Oscillations and Waves

1. The diagram shows the variation with distance x along a wave with its displacement d. The wave is travelling in the direction shown.

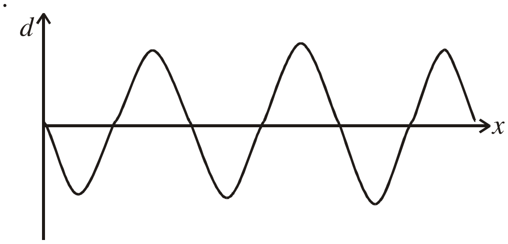


The period of the wave is T. Which **one** of the following diagrams shows the displacement of the wave at $\frac{T}{4}$ later?

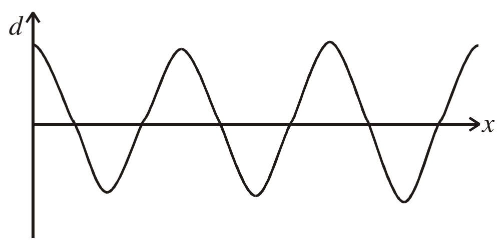
A.



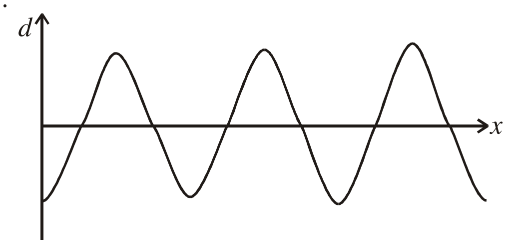
B.



C.

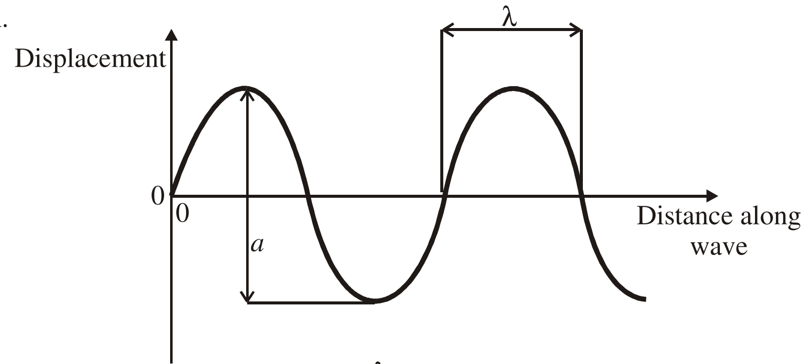


D.

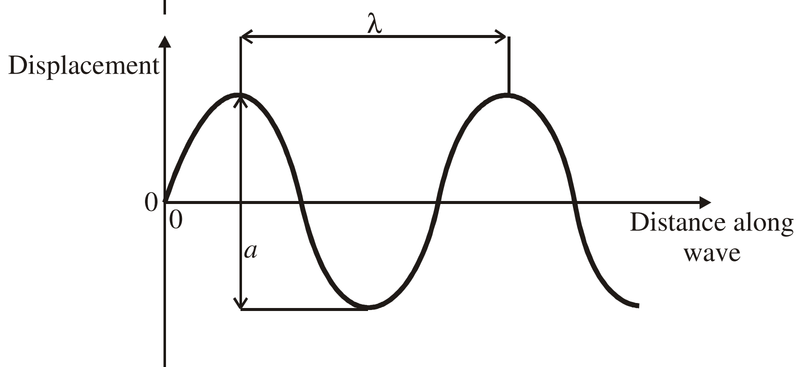


2. On which **one** of the following graphs is the wavelength λ and the amplitude a of a wave correctly represented?

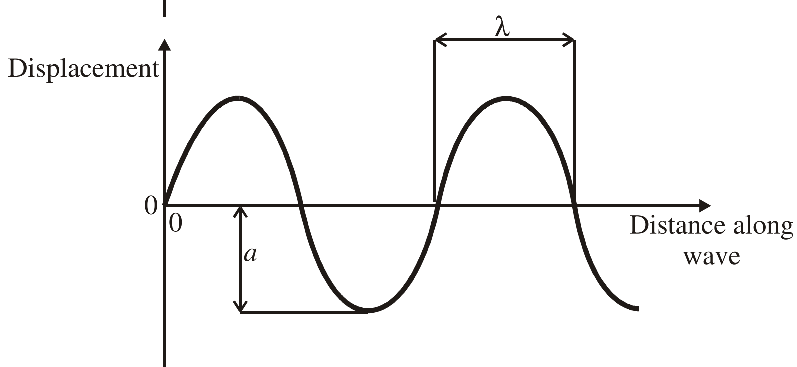
A.



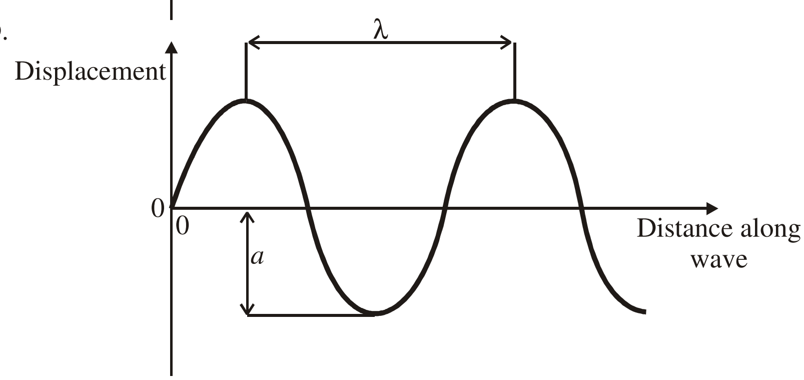
B.



C.



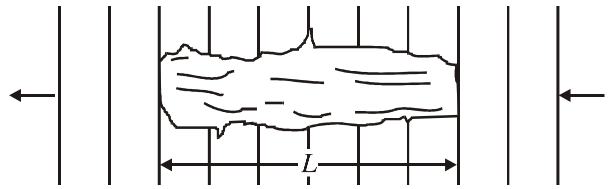
D.



3. The wavelength of a progressive transverse wave is defined as

A. the distance between a crest and its neighbouring trough.
B. the distance between any two crests of the wave.
C. the distance moved by a wavefront during one oscillation of the source.
D. the distance moved by a particle in the wave during one oscillation of the source.

4. Water waves at the surface of a pond pass a floating log of length *L*. The log is at rest relative to the bank. The diagram shows wave crests at one instant.



The number of crests passing the log per unit time is *N*. The speed of the water waves relative to the log at rest is

A. $\frac{L}{7}(N-1)$.

B. $\frac{L}{6}(N-1)$.

C. $\frac{L}{7}(N)$.

D. $\frac{L}{6}(N)$.

5. What change, if any, occurs in the wavelength and frequency of a light wave as it crosses a boundary from air into glass?

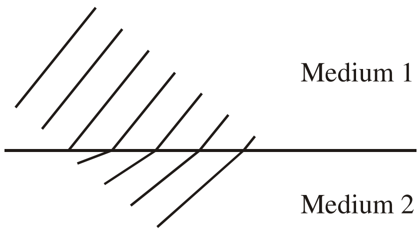
	Wavelength	Frequency
A.	Decreases	Decreases
B.	Decreases	Unchanged
C.	Increases	Increases
D.	Increases	Unchanged

6. When a wave crosses the boundary between two media, which **one** of the following properties of the wave does **not** change?

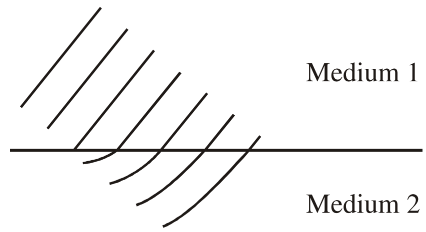
A. Amplitude
B. Wavelength
C. Frequency
D. Speed

7. A plane wave approaches and passes through the boundary between two media. The speed of the wave in medium 1 is greater than that in medium 2. Which **one** of the following diagrams correctly shows the wavefronts?

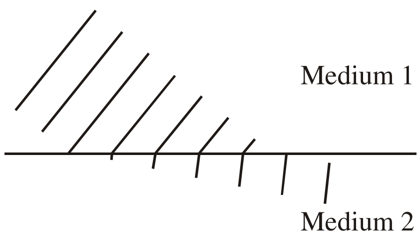
A.



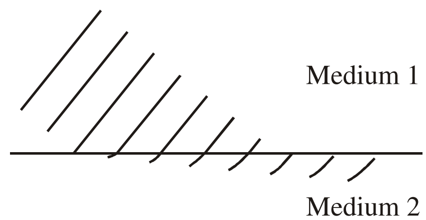
B.



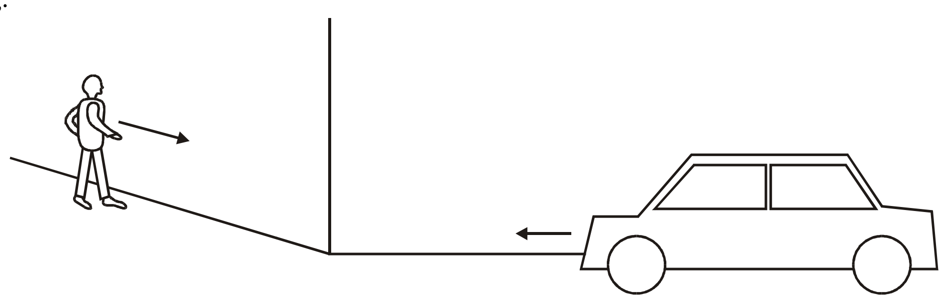
C.



D.



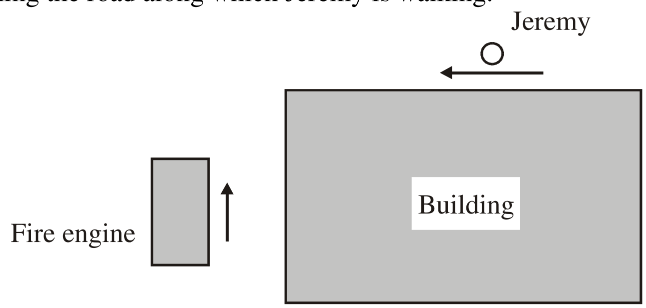
8. A person is walking along one side of a building and a car is driving along another side of the building.



The person can hear the car approach but cannot see it. This is explained by the fact that sound waves

A. travel more slowly than light waves.
B. are diffracted more at the corner of the building than light waves.
C. are refracted more at the corner of the building than light waves.
D. are longitudinal waves.

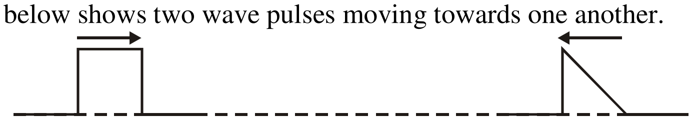
9. Jeremy is walking alongside a building and is approaching a road junction. A fire engine is sounding its siren and approaching the road along which Jeremy is walking.



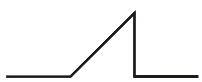
Jeremy cannot see the fire engine but he can hear the siren. This is due mainly to

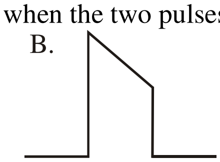
A. reflection.
B. refraction.
C. the Doppler effect.
D. diffraction.

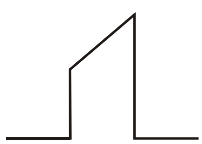
10. The diagram below shows two wave pulses moving towards one another.



Which **one** of the following diagrams shows the resultant pulse when the two pulses are superposed?

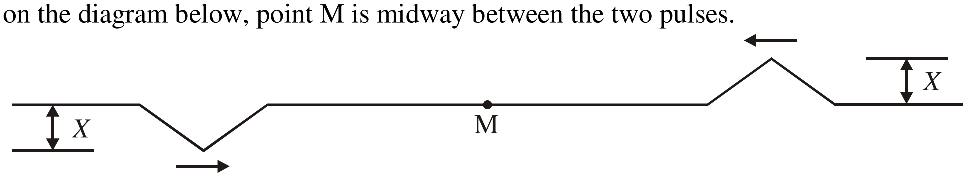
A.


B.


C.


D.

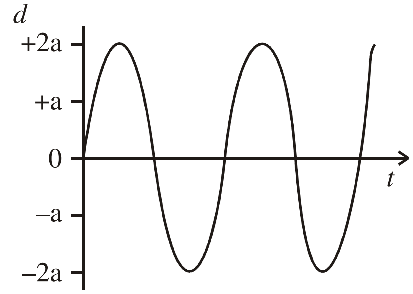

11. Two identical triangular pulses of amplitude X travel toward each other along a string. At the instant shown on the diagram below, point M is midway between the two pulses.

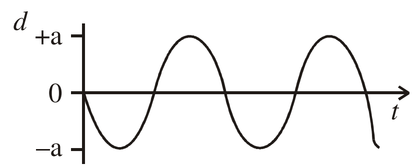


The amplitude of the disturbance in the string as the pulses move through M is

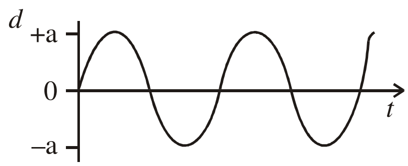
A. $2X$.
B. X.
C. $\frac{X}{2}$.
D. 0.

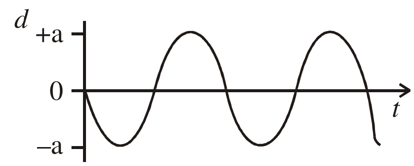
12. The variation with time *t* of the separate displacements *d* of a point in a medium due to two waves is shown below.

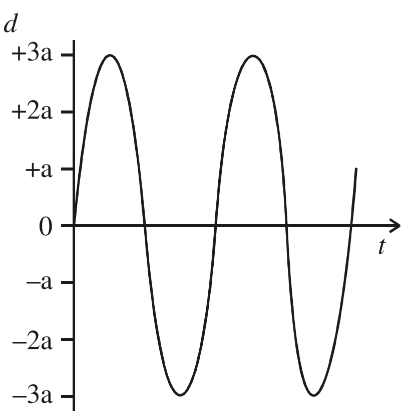


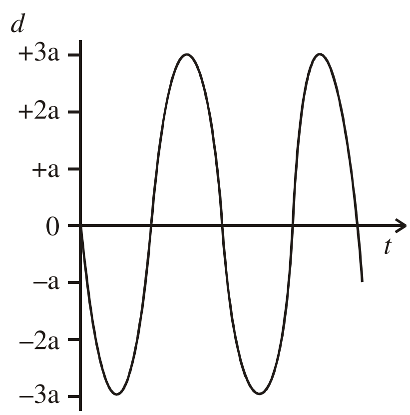


The waves are superposed. Which of the following diagrams shows the variation with time *t* of the resultant displacement *d* of the point in the medium?

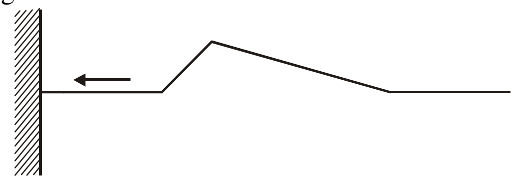
A.


B.


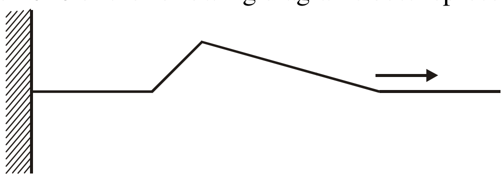
C.


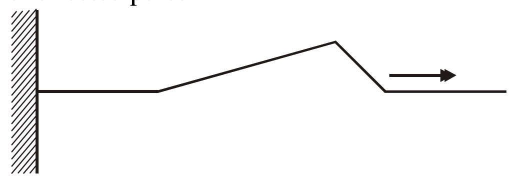
D.


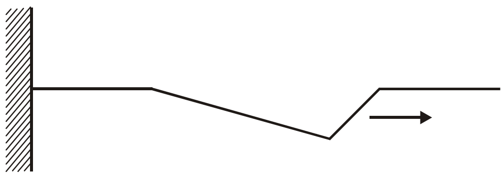
13. A pulse is sent down a string fixed at one end.

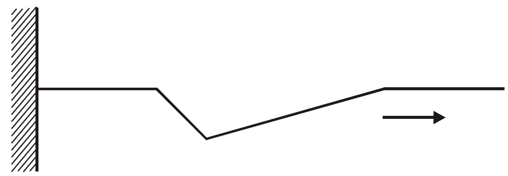


Which **one** of the following diagrams best represents the reflected pulse?

A.


B.


C.


D.


(1)

14. Wave properties

(a) By reference to the energy of a travelling wave, state what is meant by

(i) a ray.

....

....

(1)

(ii) wave speed.

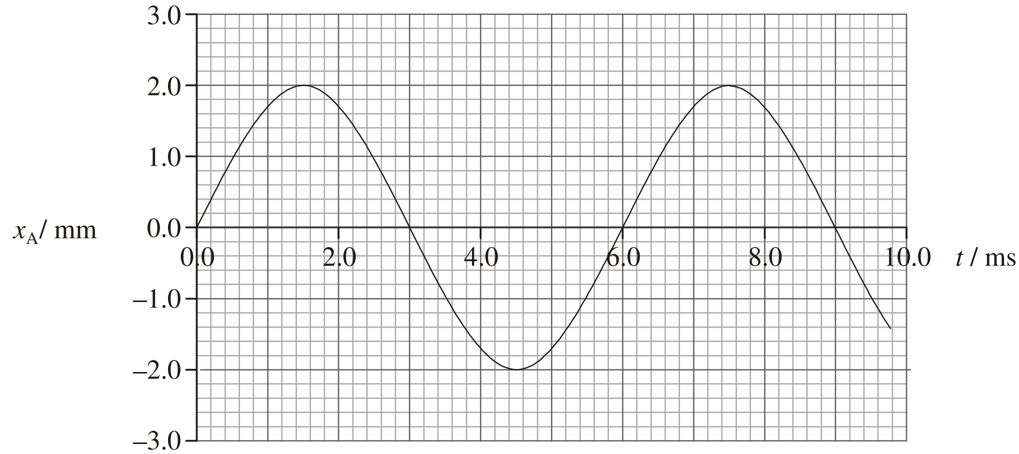
....

....

(1)

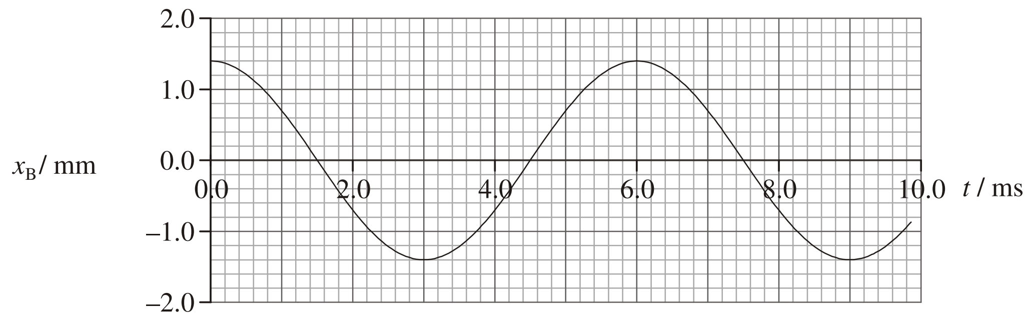
(b) The graph below shows the variation with time t of the displacement x_A of wave A as it passes through a point P.

Wave A



The graph below shows the variation with time t of the displacement x_B of wave B as it passes through point P.

Wave B



(i) Calculate the frequency of the waves.

(1)

(ii) The waves pass simultaneously through point P. Use the graphs to determine the resultant displacement at point P of the two waves at time t = 1.0 ms and at time t = 8.0 ms.

At t = 1.0 ms: ....

At t = 8.0 ms: ....

.

(3)
(Total 6 marks)

15. This question is about waves and wave properties.

(a) By making reference to waves, distinguish between a *ray* and a *wavefront*.

....

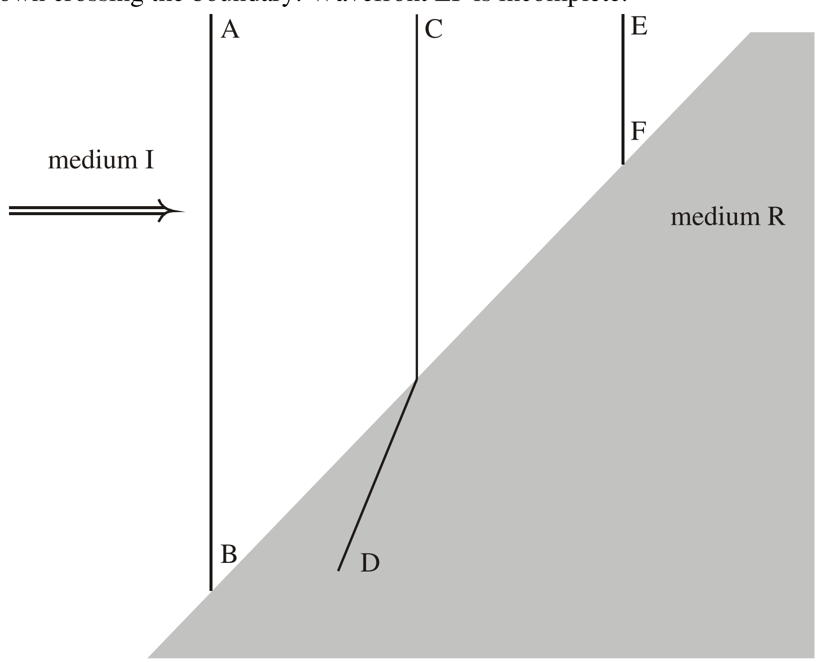
....

....

....

(3)

The diagram below shows three wavefronts incident on a boundary between medium I and medium R. Wavefront CD is shown crossing the boundary. Wavefront EF is incomplete.



(b) (i) On the diagram above, draw a line to complete the wavefront EF.

(1)

(ii) Explain in which medium, I **or** R, the wave has the higher speed.

....

....

....

....

(3)

(iii) By taking appropriate measurements from the diagram, determine the ratio of the speeds of the wave travelling from medium I to medium R.

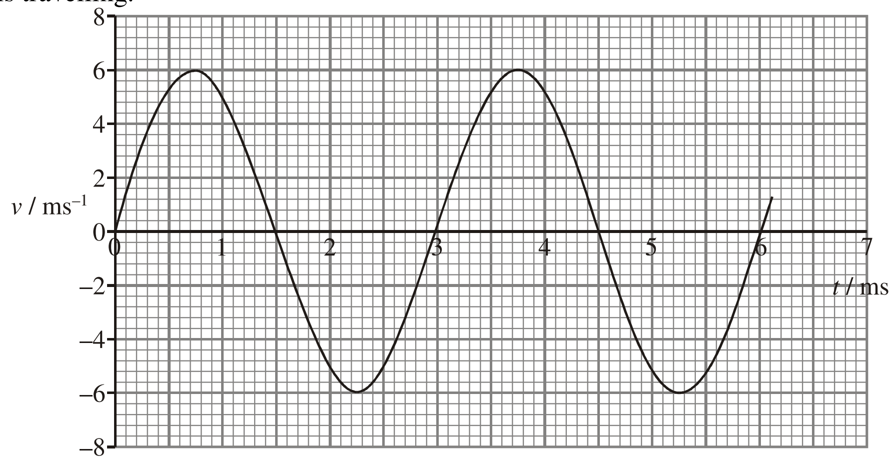
....

....

....

(2)

The graph below shows the variation with time *t* of the velocity *v* of one particle of the medium through which the wave is travelling.



(c) (i) Explain how it can be deduced from the graph that the particle is oscillating.

....

....

....

(2)

(ii) Determine the frequency of oscillation of the particle.

....

....

(2)

(iii) Mark on the graph with the letter M one time at which the particle is at maximum displacement.

(1)

(iv) Estimate the area between the curve and the *x*-axis from the time $t = 0$ to the time $t = 1.5$ ms.

....

(2)

(v) Suggest what the area in c (iv) represents.

....

(1)

(Total 17 marks)

16. This question is about waves and wave motion.

(a) (i) Define what is meant by the *speed of a wave*.

....
....
....

(2)

(ii) Light is emitted from a candle flame. Explain why, in this situation, it is correct to refer to the "speed of the emitted light", rather than its velocity.

....
....
....

(2)

(b) (i) Define, by reference to wave motion, what is meant by *displacement*.

....
....

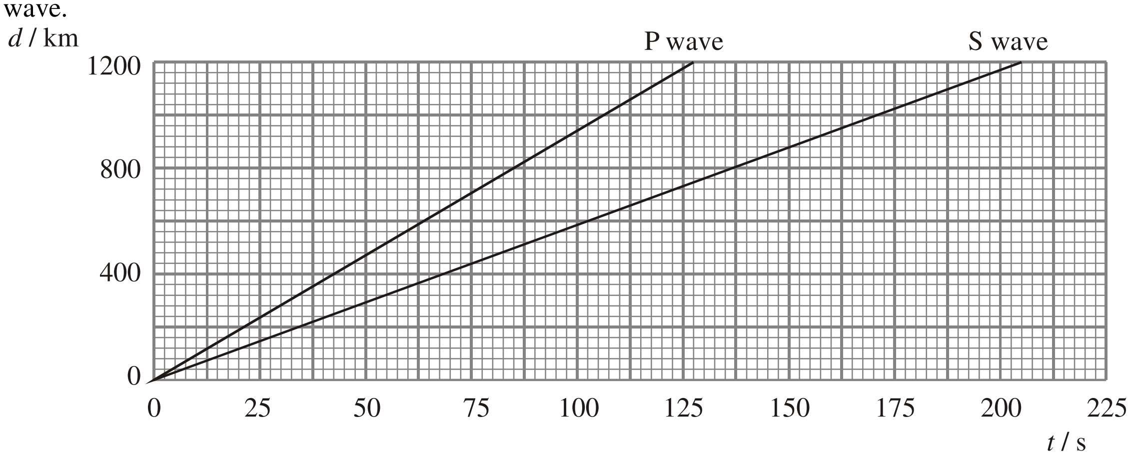
(2)

(ii) By reference to displacement, describe the difference between a longitudinal wave and a transverse wave.

....
....
....
....

(3)

The centre of an earthquake produces both longitudinal waves (P waves) and transverse waves (S waves). The graph below shows the variation with time t of the distance d moved by the two types of wave.



(c) Use the graph to determine the speed of

(i) the P waves.

....
....
....

(1)

(ii) the S waves.

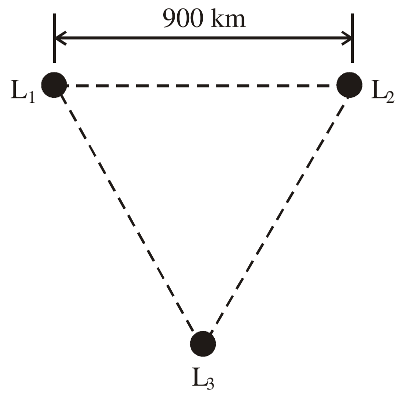
....

....

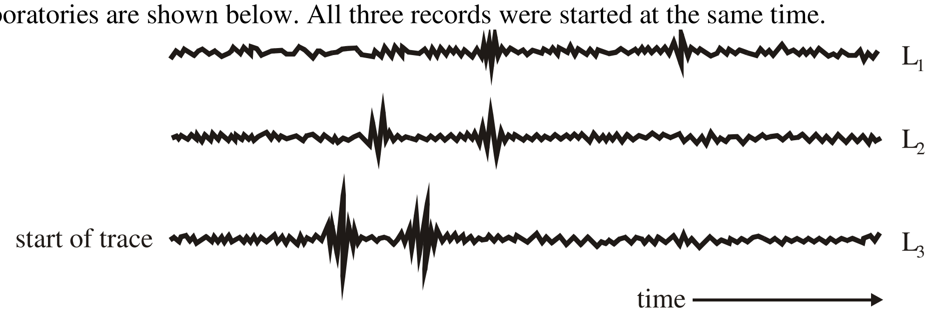
....

(1)

The waves from an earthquake close to the Earth's surface are detected at three laboratories L_1, L_2 and L_3. The laboratories are at the corners of a triangle so that each is separated from the others by a distance of 900 km, as shown in the diagram below.



The records of the variation with time of the vibrations produced by the earthquake as detected at the three laboratories are shown below. All three records were started at the same time.



On each record, one pulse is made by the S wave and the other by the P wave. The separation of the two pulses is referred to as the S-P interval.

(d) (i) On the trace produced by laboratory L_2, identify, by reference to your answers in (c), the pulse due to the P wave (label the pulse P).

(1)

(ii) Using evidence from the records of the earthquake, state which laboratory was closest to the site of the earthquake.

....

(1)

(iii) State **three** separate pieces of evidence for your statement in (d)(ii). **(3)**

1. ....
....

2. ....
....

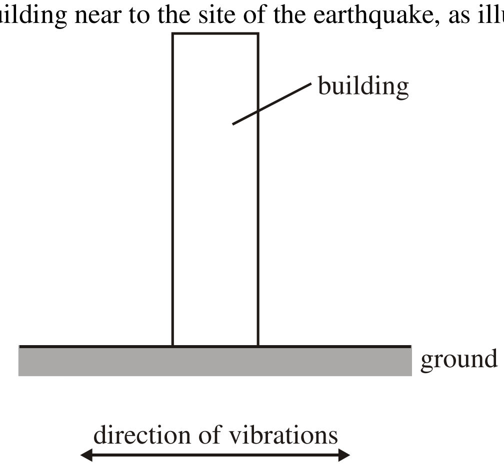
3. ....
....

(iv) The S-P intervals are 68 s, 42 s and 27 s for laboratories L_1, L_2 and L_3 respectively. Use the graph, or otherwise, to determine the distance of the earthquake from each laboratory. Explain your working.

(4)

(v) Mark on the diagram a possible site of the earthquake. **(1)**

(HL only) There is a tall building near to the site of the earthquake, as illustrated below.



The base of the building vibrates horizontally due to the earthquake.

(e) (i) On the diagram above, draw the fundamental mode of vibration of the building caused by these vibrations. **(1)**

The building is of height 280 m and the mean speed of waves in the structure of the building is 3.4×10^3 ms^{-1}.

(ii) Explain quantitatively why earthquake waves of frequency about 6 Hz are likely to be very destructive.

....
....
....
....

(3)
(Total 25 marks)

Topic 4 – Mark Scheme

1. B
2. D
3. C
4. B
5. B
6. C
7. A
8. B
9. D
10. B
11. D
12. A
13. C

14. Wave properties

(a) (i) direction in which energy is travelling / locus of one point on a wavefront; 1

(ii) speed at which energy is propagated along the wave; 1

(b) (i) frequency $\left(=\left\{6.0\times10^{-3}\right\}^{-1}\right)=170\,\text{Hz};$ 1

(ii) at t = 1.0ms , displacement (= 1.7 + 0.7) = 2.4mm;
at t = 8.0ms, displacement = 1.7 – 0.7;
= 1.0mm; 3

[6]

15. (a) ray: direction in which wave (energy) is travelling;
wavefront: line joining (neighbouring) points that have the same phase / displacement /
Or suitable reference to Huygen's principle;
ray is normal to a wavefront; 3

(b) (i) wavefront parallel to D; 1

(ii) frequency is constant;
since $v = f\lambda$, $v \propto \lambda$;
wavelength larger in medium I, **hence** higher speed in medium I; 3
Allow solution based on angles marked on diagram or speed of wavefronts.

(iii) ratio = $\frac{v_I}{v_R} = \frac{\lambda_I}{\lambda_R}$ (or based on Snell's law);

= $\frac{3.0}{1.5}$ = 2.0 *allow ±0.5*; 2

(c) (i) velocity / displacement / direction in (+) and (–) directions;
idea of periodicity; 2

(ii) period = 3.0 ms;
frequency = $\frac{1}{T}$ = 330 Hz; 2

(iii) *Accept any one of the following.*
at time t = 0, 1.5 ms, 3.0 ms, 4.5 ms, *etc*; 1

(iv) area of half-loop = 140 ± 10 squares / mean $v = 4.0 \text{ m s}^{-1}$ *accept ±0.2*;
= $140 \times 0.4 \times 0.1 \times 10^{-3}$ / $4.0 \times 1.5 \times 10^{-3}$;
= 5.6×10^{-3} m / 6.0×10^{-3} m; 2
*Award **[1]** for area of triangle.*

(v) (twice) the amplitude; 1
Allow distance moved in 1.5 m s.

[17]

16. (a) (i) distance travelled per unit time;
by the energy of the wave / by a wavefront; 2
(ii) velocity has direction; but light travels in all directions; 2

(b) (i) distance in a particular direction; *(accept in terms of energy transfer)*
(of a particle) from its mean position; 2
(ii) *longitudinal*: displacement along;
transverse: displacement normal to;
direction of transfer of wave energy / propagation, **not** motion; 3
*Award **[0]** for left / right and up / down for longitudinal / transverse.*

(c)	(i)	$\left(\dfrac{700}{75}\right) = 9.3\ \text{km s}^{-1}$; (±0.1)	1
	(ii)	$\left(\dfrac{700}{120}\right) = 5.8\ \text{km s}^{-1}$; (±0.1)	1
		*Award **[1 max]** if the answers to (i) and (ii) are given in reversed order.*	
(d)	(i)	P shown as the earlier (left hand) pulse;	1
	(ii)	laboratory L_3;	1
	(iii)	*eg* pulses arrive sooner; smaller S-P interval; larger amplitude of pulses; *Allow any feasible piece of evidence, award **[1]** for each up to **[3 max]**.*	3
	(iv)	*distance from* L_1 = 1060 km; (± 20) *distance from* L_2 = 650 km; (± 20) *distance from* L_3 = 420 km; (± 20) *Accept 3 significant digits in all three estimates.* some explanation of working;	4
	(v)	position marked, consistent with answers to (iv); to the right of line L_2L_3, closer to L_3; *If the answers given in (iv) means that the point cannot be plotted, then only allow the mark if the candidate states that the position cannot be plotted / does not make sense.*	1 max
(e)	(i)	illustration showing node at centre, antinode at each end;	1
	(ii)	wavelength of standing wave = (2 × 280) = 560 m / ecf ***or*** $\dfrac{3.4\times10^3}{6} = 570$ m; frequency = $\dfrac{(3.4\times10^3)}{560} \approx 6$Hz ***or*** wavelength of standing wave = (2 × 280) = 560 m; earthquake frequency is natural frequency of vibration of building / mention of resonance / multiple / submultiple if ecf;	3

[25]

Topic 14 – Oscillations and Waves

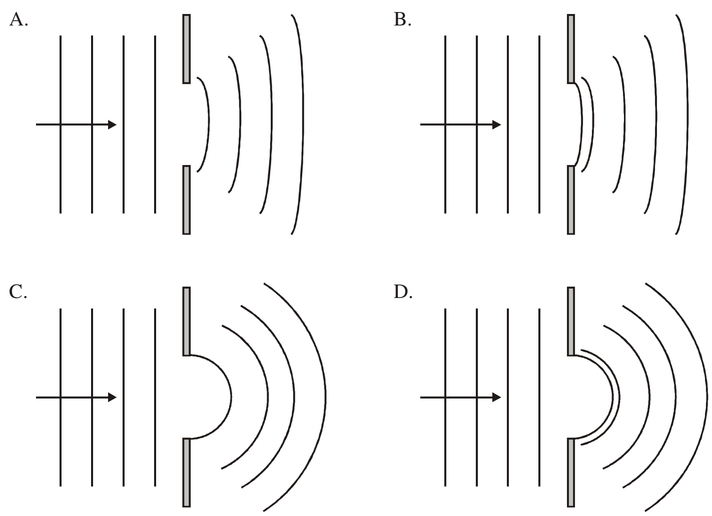
1. Two pipes P and Q are of the same length. Pipe P is closed at one end and pipe Q is open at both ends. The fundamental frequency (first harmonic) of the closed pipe P is 220 Hz.
The best estimate for the fundamental frequency of the open pipe Q is

A. 880 Hz.
B. 440 Hz.
C. 110 Hz.
D. 55 Hz.

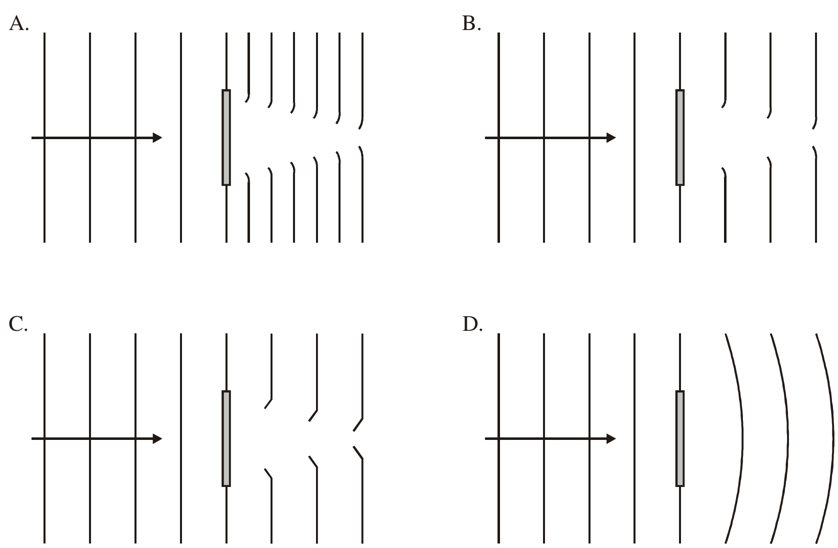
2. Which **one** of the following is correct for transfer of energy along a standing wave and for amplitude of vibration of the standing wave?

	Transfer of energy along a standing wave	Amplitude of vibration of the standing wave
A.	None	Constant amplitude
B.	None	Variable amplitude
C.	Energy is transferred	Constant amplitude
D.	Energy is transferred	Variable amplitude

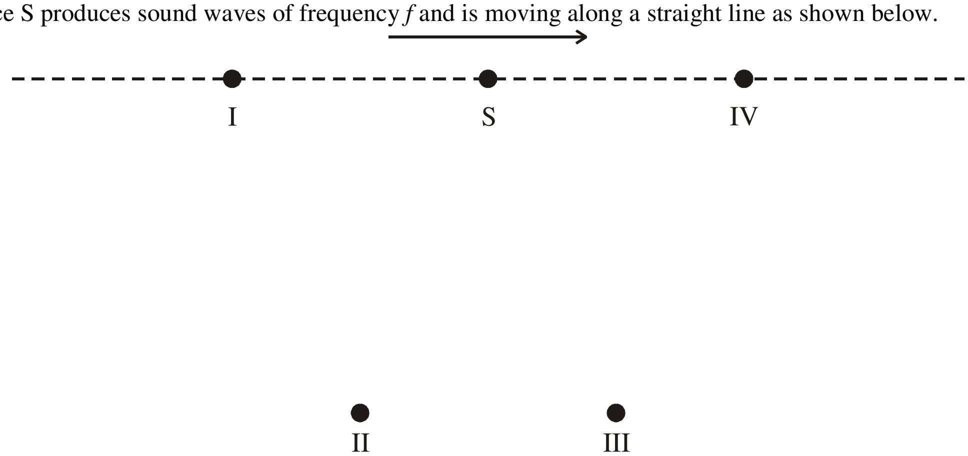
3. Which diagram best shows diffraction of plane wavefronts at a single slit?



4. Which of the following diagrams best illustrates the diffraction of waves by an obstacle?



5. A source S produces sound waves of frequency *f* and is moving along a straight line as shown below.



Which observer I, II, III or IV could hear a sound of frequency *f* when the source is in the position shown?

A. I
B. II
C. III
D. IV

6. This question is about wave properties and interference.

The diagram below represents the direction of oscillation of a disturbance that gives rise to a wave.

(a) By redrawing the diagram in the spaces below, add arrows to show the direction of wave energy transfer to illustrate the difference between

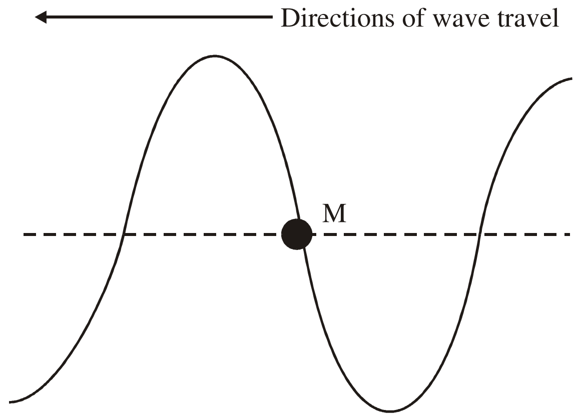
(i) a transverse wave and

(1)

(ii) a longitudinal wave.

(1)

A wave travels along a stretched string. The diagram below shows the variation with distance along the string of the displacement of the string at a particular instant in time. A small marker is attached to the string at the point labelled M. The undisturbed position of the string is shown as a dotted line.



(b) On the diagram above

(i) draw an arrow to indicate the direction in which the marker is moving.

(1)

(ii) indicate, with the letter A, the amplitude of the wave.

(1)

(iii) indicate, with the letter λ, the wavelength of the wave.

(1)

(iv) draw the displacement of the string a time $\frac{T}{4}$ later, where T is the period of oscillation of the wave. Indicate, with the letter N, the new position of the marker.

(2)

The wavelength of the wave is 5.0 cm and its speed is 10 cm s^{-1}.

(c) Determine

(i) the frequency of the wave.

(1)

(ii) how far the wave has moved in $\frac{T}{4}$ s.

(2)

Interference of waves

(d) By reference to the principle of superposition, explain what is meant by constructive interference.

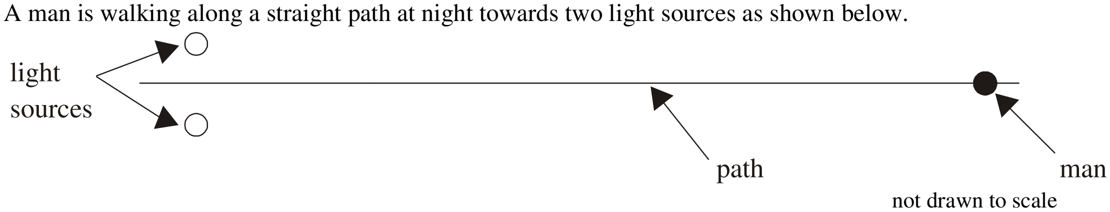
(4)
(Total 14 marks)

7. This question is about resolution.

(a) State the Rayleigh criterion for the images of two point sources to be just resolved.

(2)

A man is walking along a straight path at night towards two light sources as shown below.



When the man is 150 m from the sources, the images of the two sources are just resolved by his eye. The wavelength of the light from each source is 590 nm and the diameter of the aperture of his eye is 5.0 mm.

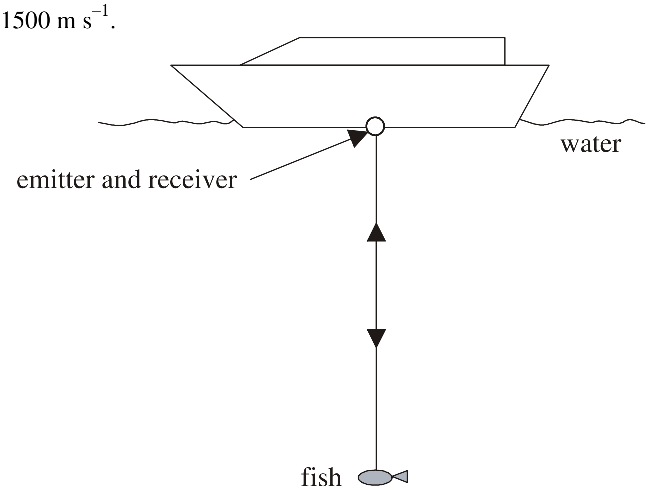
(b) Estimate the distance between the two sources.

(3)
(Total 5 marks)

8. The properties of sound waves

Reflection and Refraction

One method of finding the position of fish beneath a boat is to send out a pulse of sound waves from the bottom of a boat and time how long the pulse takes to return as shown below. The speed of sound waves in water is 1500 m s^{-1}.

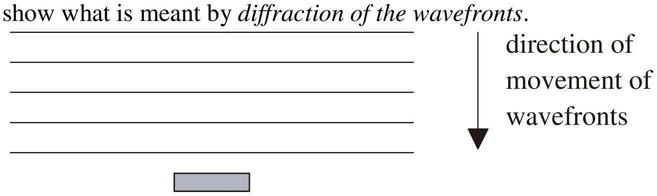


(a) The time between the pulse leaving the emitter and returning to the receiver is 12 ms. Calculate the distance from the bottom of the boat to the fish.

(2)

In order to find fish using this method, the effects of diffraction at the fish need to be minimized.

(b) (i) The diagram below shows plane wavefronts incident on an obstacle. Complete the diagram to show what is meant by *diffraction of the wavefronts*.



(2)

(ii) Explain why you would expect the effects of diffraction to be negligible when sound of frequency 60 kHz is incident on a large fish.

(2)

The Doppler effect can be used to determine the speed of an object.

(c) (i) Explain what is meant by the *Doppler effect*.

(2)

(ii) A train approaches and then passes by a stationary observer. The train is moving with constant velocity and emits a sound of constant frequency. The observer hears the frequency change from 490 Hz to 410 Hz. The speed of sound in air is 340 m s^{-1}. Estimate the speed of the train.

(4)
(Total 12 marks)

9. A student looks at two distant point sources of light. The wavelength of each source is 590 nm. The angular separation between these two sources is 3.6×10^{-4} radians subtended at the eye. At the eye, images of the two sources are formed by the eye on the retina.

(a) State the Rayleigh criterion for the two images on the retina to be just resolved.

(2)

(b) Estimate the diameter of the circular aperture of the eye.

(1)

(c) Use your estimate in (b) to determine whether the student can resolve these two sources. Explain your answer.

(2)
(Total 5 marks)

Note: for single slit diffraction review – see the unit packet

Topic 14 – Mark Scheme

1. B
2. B
3. A
4. B
5. B

6. Wave properties

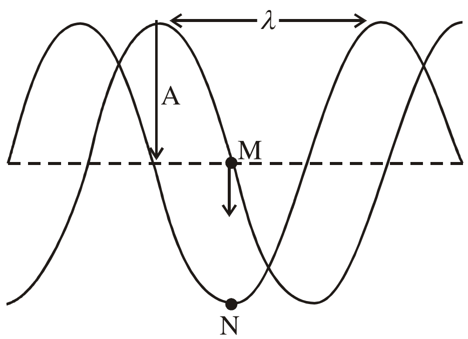
(a) (i)

1

(ii)

1

(b)



(i) downwards; 1
(ii) correct marking of A; 1
(iii) correct marking of λ; 1
(iv) +ve sine curve;
correct position of N; 2

Watch for ecf from (i).

(c) (i) $f = \dfrac{v}{\lambda}$ to give 2.0 Hz; 1

(ii) $T = 0.5$ s;

$s = \dfrac{vT}{4} = 1.25\ (1.3)$ cm;

or

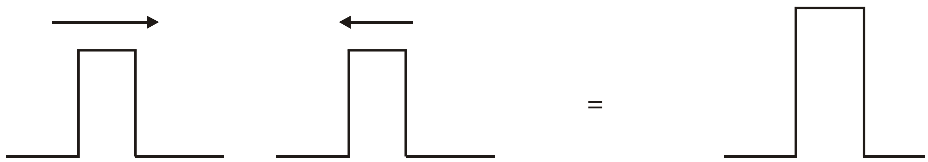
in $\dfrac{T}{4}$ wave moves forward $\frac{1}{4}\lambda$;

$= \dfrac{5}{4} = 1.25\ (1.3)$ cm; 2 max

(d) *Principle of superposition*:
when two or more waves overlap, the resultant displacement at any point;
is the sum of the displacements due to each wave separately / *OWTTE*;

*Award **[2 max]** for an answer that shows a clear understanding of the principle, **[1]** for a reasonable understanding and **[0]** for a weak answer.*

Explanation:

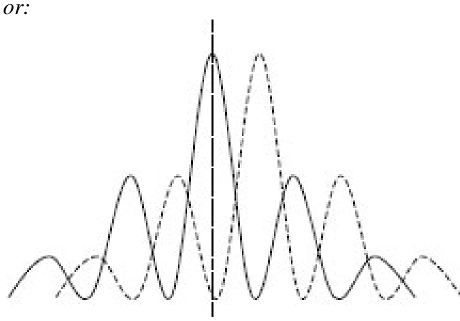


suitable diagram;
when two +ve pulses (or two wave crests) overlap, they reinforce / OWTTE; 4

Any situation where resultant displacement looks as though it is the sum of the individual displacements. Mark the description of the principle and the description of constructive interference together.

[14]

7. (a) *Award **[2]** for a clear statement or **[2]** for a clear diagram.*
the maximum of one diffraction pattern is coincident with the first minimum of the other;
or:



2

(b) $\theta_{\min} = 1.22\dfrac{\lambda}{d}$

(with small angle approximation), $\theta = \dfrac{s}{150\,\text{m}}$;

equate $\theta = 1.22\dfrac{\lambda}{D} = 1.22\dfrac{590\times10^{-9}}{5.0\times10^{-3}}$;

to get s = 2.2 cm; 3

*Award **[2 max]** if 1.22 factor is omitted.*

[5]

8. The properties of sound waves

(a) substitution into speed = distance / time to get
distance =1500 × 0.012 = 18m;
therefore, depth = 18 ÷ 2 = 9m; 2

(b) (i) appropriate wavefronts shown in geometric shadow region;
of constant wavelength; 2

(ii) substitution of correct values into $v = f\lambda$
to get λ = 0.025m;
so obstacle (fish) significantly larger than wavelength hence diffraction effect small / *OWTTE*; 2
<u>or</u> the wavelength is very small;
so diffraction will be small for any reasonably sized fish;

(c) (i) change in received frequency of sound (wave);
as a result of relative motion of source and observer; 2
*Accept other general descriptions but award **[1 max]** for an answer that just gives an example of the Doppler effect.*

(ii) $$490 = \frac{f}{1 - \frac{v}{340}};$$

$$410 = \frac{f}{1 + \frac{v}{340}};$$

$$\frac{490}{410} = \frac{340 + v}{340 - v};$$

to get $v = 30\text{ms}^{-1}$;
or:

$$490 = \frac{f}{1 - \frac{v}{340}};$$

with $f = 450\text{Hz}$;
justification of $f = 450\text{Hz}$;
to get $v = 28\text{ms}^{-1}$;
or:

$$410 = \frac{f}{1 + \frac{v}{340}};$$

with $f = 450\text{Hz}$;
justification of $f = 450\text{Hz}$;
to get $v = 33\text{ms}^{-1}$; 4

[12]

9. (a) the diffraction pattern of one point source has its central maximum on the first minimum of the diffraction pattern of the other point source / *OWTTE*; 2
Full marks can be awarded for a clearly drawn and fully labelled diagram.
Partial credit is for answers that have some idea but lack precision.

(b) 3 (± 2) mm; 1

(c) correct calculation of Rayleigh criteria angle;
eg $\theta = 1.22 \frac{\lambda}{d} = 1.22 \times 590 \times 10^{-9} / 0.003 = 2.4 \times 10^{-4}$ *radians*.
Accept answers that miss the factor of 1.2 to get 2.0×10^{-4} *radians.*
correct comparison and answer; 2 max
eg this will be resolved as minimum angle is less than the separation of the point sources.
Watch for ecf – this angle may or may not be resolved depending on the estimation of the diameter of the aperture.

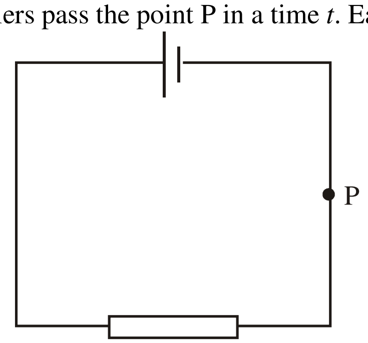
[5]

Topic 5 – Electric Currents

1. Which **one** of the following is a correct definition of electric potential difference between two points?

A. The power to move a small positive charge between the two points.
B. The work done to move a small positive charge between the two points.
C. The power per unit charge to move a small positive charge between the two points.
D. The work done per unit charge to move a small positive charge between the two points.

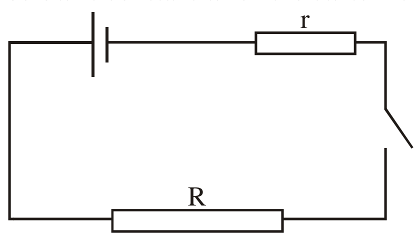
2. In the circuit below, n charge carriers pass the point P in a time t. Each charge carrier has charge q.



The current in the circuit is given by the expression

A. $\frac{q}{t}$.
B. $\frac{nq}{t}$.
C. $\frac{qt}{n}$.
D. nqt.

3. The current in the circuit shown below is constant when the switch is closed.



The energy transfer in the internal resistance r of the battery is 15 J when a charge of 40 C passes through it. For the same amount of charge, 45 J of energy is transferred in the resistor R.

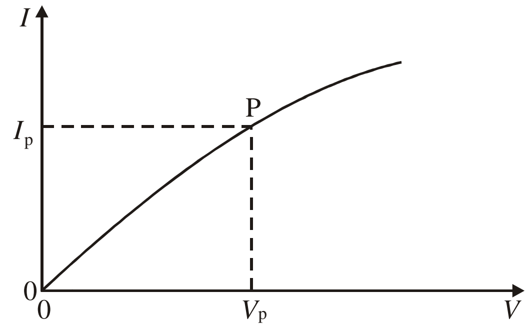
Which of the following gives the emf of the battery?

A. $\frac{15}{40}$ V
B. $\frac{30}{40}$ V
C. $\frac{45}{40}$ V
D. $\frac{60}{40}$ V

4. The drift velocity of the electrons in a copper wire in which there is an electric current is

A. equal to the speed of light.
B. close to that of the speed of light.
C. of the order of a few kilometres per second.
D. of the order of a few millimetres per second.

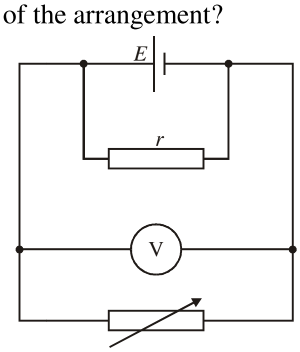
5. The variation with potential difference V of the current I in an electric lamp is shown below.

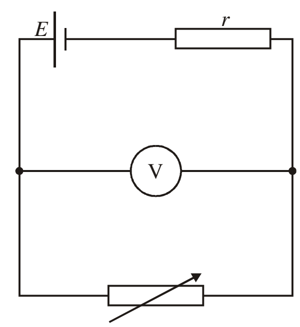


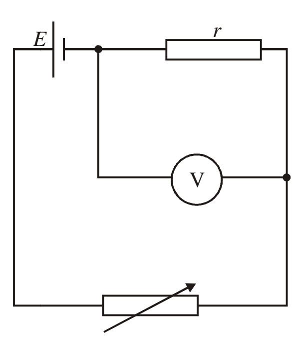
At point P, the current is I_p, the potential difference is V_p and the gradient of the tangent to the curve is G. What is the resistance of the lamp at point P?

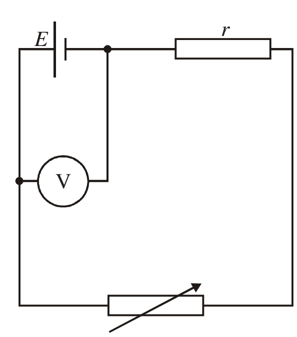
A. $\frac{1}{G}$
B. G
C. $\frac{I_p}{V_p}$
D. $\frac{V_p}{I_p}$

6. A cell of emf E and internal resistance r is connected to a variable resistor. A voltmeter is connected so as to measure the potential difference across the terminals of the cell. Which **one** of the following is the correct circuit diagram of the arrangement?

A.


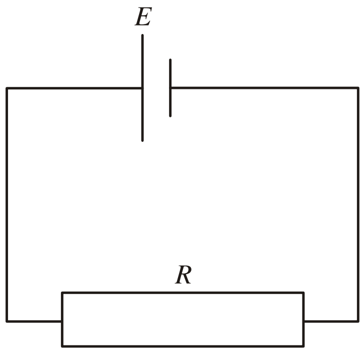
B.


C.


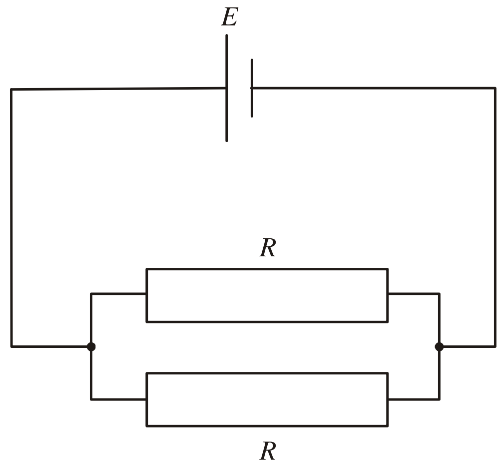
D.


7. In the two circuits X and Y below, each cell has an emf E and negligible internal resistance. Each resistor has a resistance R.

circuit X



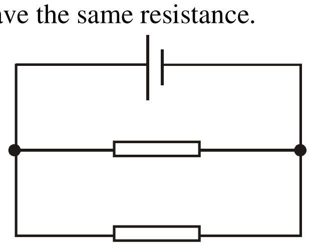
circuit Y



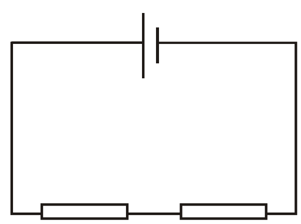
The power dissipated in circuit X is P.
The best estimate for the power dissipated in circuit Y is

A. $\frac{P}{4}$.
B. $\frac{P}{2}$.
C. $2P$.
D. $4P$.

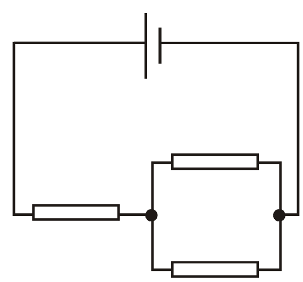
8. In the circuits below, the cells each have the same emf and zero internal resistance. All the resistors have the same resistance.



Circuit X



Circuit Y



Circuit Z

Which of the following gives the current through the cells in order of increasing magnitude?

	Lowest current	→	Highest current
A.	X	Y	Z
B.	Z	X	Y
C.	Y	Z	X
D.	Y	X	Z

9. This question compares the electrical properties of two 12 V filament lamps.
A lamp is designed to operate at normal brightness with a potential difference of 12 V across its filament. The current in the filament is 0.50 A.

(a) For the lamp at normal brightness, calculate

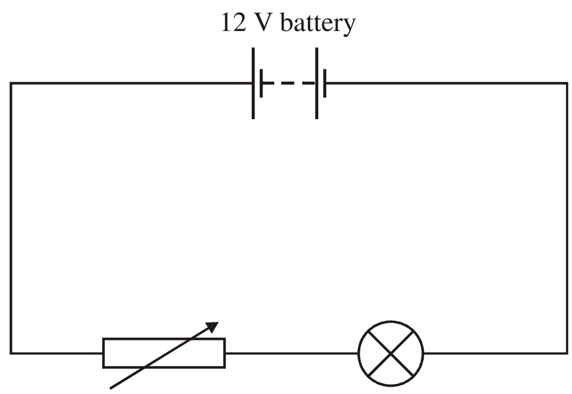
(i) the power dissipated in the filament.

(1)

(ii) the resistance of the filament.

(1)

In order to measure the voltage-current (*V-I)* characteristics of a lamp, a student sets up the following electrical circuit.



(b) On the circuit above, add circuit symbols showing the correct positions of an ideal ammeter **and** an ideal voltmeter that would allow the *V-I* characteristics of this lamp to be measured.

(2)

The voltmeter and the ammeter are connected correctly in the previous circuit.

(c) Explain why the potential difference across the lamp

(i) cannot be increased to 12 V.

(2)

(ii) cannot be reduced to zero.

(2)

An alternative circuit for measuring the *V-I* characteristic uses a *potential divider*.

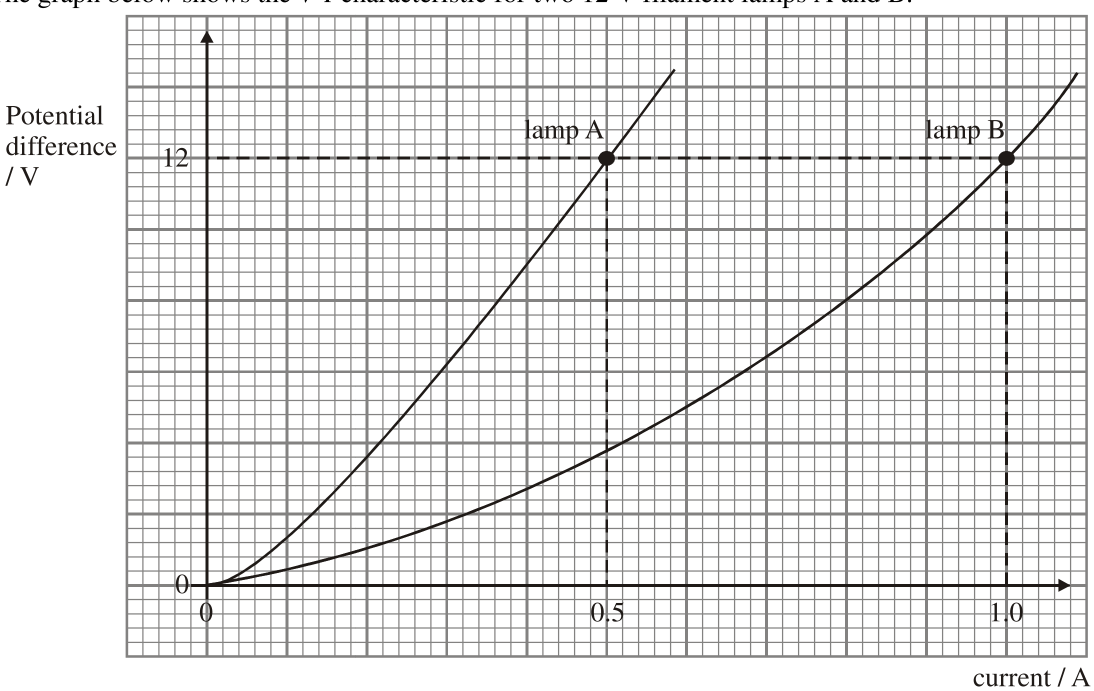
(d) (i) Draw a circuit that uses a potential divider to enable the *V-I* characteristics of the filament to be found.

(3)

(ii) Explain why this circuit enables the potential difference across the lamp to be reduced to zero volts.

(2)

The graph below shows the *V-I* characteristic for two 12 V filament lamps A and B.



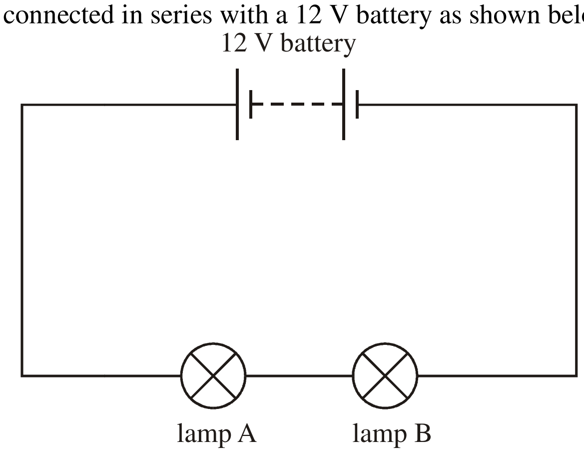
(e) (i) Explain why these lamps do not obey Ohm's law.

(2)

(ii) State and explain which lamp has the greater power dissipation for a potential difference of 12 V.

(3)

The two lamps are now connected in series with a 12 V battery as shown below.



(f) (i) State how the current in lamp A compares with that in lamp B.

(1)

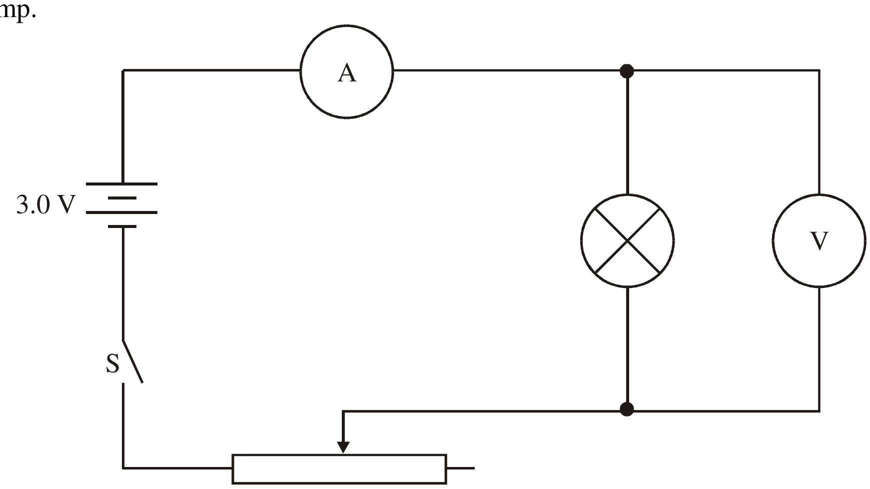
(ii) Use the *V*-*I* characteristics of the lamps to deduce the total current from the battery.

(4)

(iii) Compare the power dissipated by the two lamps.

(2)
(Total 25 marks)

10. This question is about electric circuits.
Susan sets up the circuit below in order to measure the current-voltage (*I*-*V*) characteristic of a small filament lamp.



The supply is a battery that has an emf of 3.0 V and the ammeter and voltmeter are considered to be ideal. The lamp is labelled by the manufacturer as "3 Volts, 0.6 Watts".

(a) (i) Explain what information this labeling provides about the normal operation of the lamp.

(2)

(ii) Calculate the current in the filament of the lamp when it is operating at normal brightness.

(2)

Susan sets the variable resistor to its maximum value of resistance. She then closes the switch S and records the following readings.

Ammeter reading = 0.18 A	Voltmeter reading = 0.60 V

She then sets the variable resistor to its zero value of resistance and records the following readings.

Ammeter reading = 0.20 A	Voltmeter reading = 2.6 V

(b) (i) Explain why, by changing the value of the resistance of the variable resistance, the potential difference across the lamp cannot be reduced to zero or be increased to 3.0 V.

(2)

(ii) Determine the internal resistance of the battery.

(3)

(c) Calculate the resistance of the filament when the reading on the voltmeter is
(i) 0.60 V.

(1)

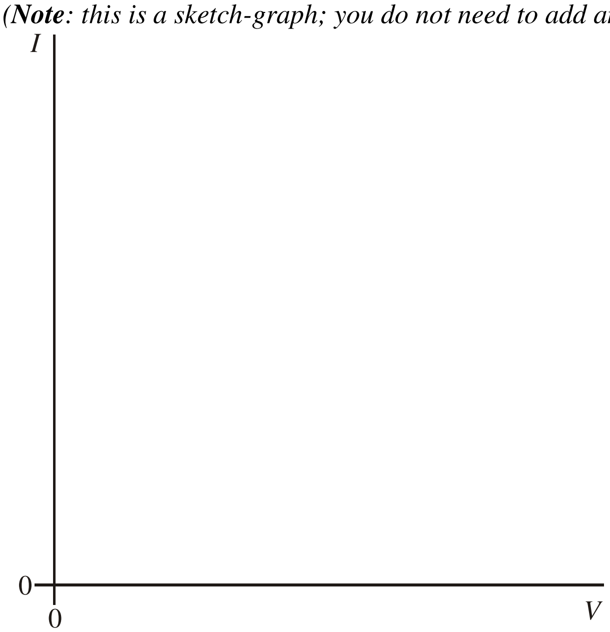
(ii) 2.6 V.

(1)

(d) Explain why there is a difference between your answers to (c)(i) and (c)(ii).

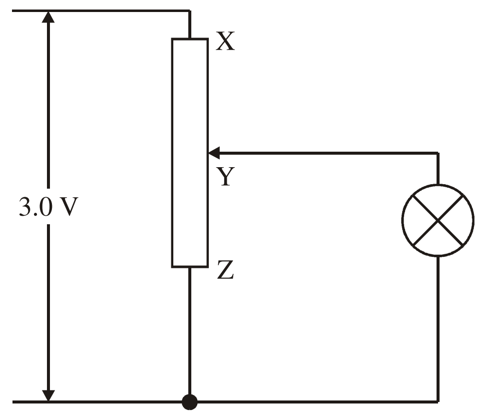
(2)

(e) Using the axes below, draw a sketch-graph of the I-V characteristic of the filament of the lamp. *(**Note**: this is a sketch-graph; you do not need to add any values to the axes.)*



(1)

The diagram below shows an alternative circuit for varying the potential difference across the lamp.

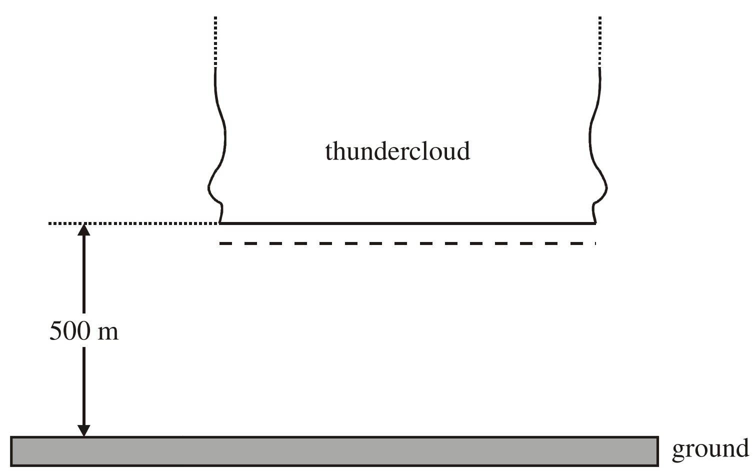


The potential divider XZ has a potential of 3.0 V across it. When the contact is at the position Y, the resistance of XY equals the resistance of YZ which equals 12 Ω. The resistance of the lamp is 4 Ω.

(f) Calculate the potential difference across the lamp.

(4)
(Total 18 marks)

11. This question is about the physics of a lightning strike.
In a simple model of a thundercloud, a negative charge is built up on the base of the cloud by the process of *charge separation*. The resulting *electric field* between the cloud and the ground is approximately the same as that between two infinite parallel charged plates. When the charge on the base of the cloud reaches a certain value, a lightning strike occurs between the ground and the base of the cloud.



(a) Explain what is meant by the term *charge separation*.

(2)

(b) Define *electric field strength*.

(2)

(c) On the above diagram, draw the electric field pattern between the ground and the base of the cloud.

(3)

The electric field strength E between two infinite, parallel charged plates is given by

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

where σ is the charge on an area of 1 m^2 of one plate.
Just before a lightning strike, a particular thundercloud carries a charge of 20 C spread over its base. The area of the base of the cloud is 7×10^6 m^2.

(d) (i) Show that the magnitude of the electric field between the base of the cloud and the ground is approximately 3×10^5 Vm^{-1}.

(3)

(ii) State **two** assumptions made when applying this formula.

(2)

(e) The base of the cloud is at an average height of 500 m. Calculate the potential difference between the ground and the cloud base just before the lightning strike.

(2)

When a lightning strike occurs between the ground and the base of this thundercloud, the cloud completely discharges in a time of 20 ms.

(f) (i) Calculate the average current in the lightning strike.

(1)

(ii) Estimate the energy released during the lightning strike.

(3)
(Total 18 marks)

12. Electrical circuits
Andrew is set the task of measuring the current-voltage (I-V) characteristics of a filament lamp. The following equipment and information are available.

	Information
Battery	emf = 3.0 V, negligible internal resistance
Filament lamp	marked "3 V, 0.2 A"
Voltmeter	resistance = 30 kΩ, reads values between 0.0 and 3.0 V
Ammeter	resistance = 0.1 Ω, reads values between 0.0 and 0.5 A
Potentiometer	resistance = 100 Ω

(a) For the filament lamp operating at normal brightness, calculate

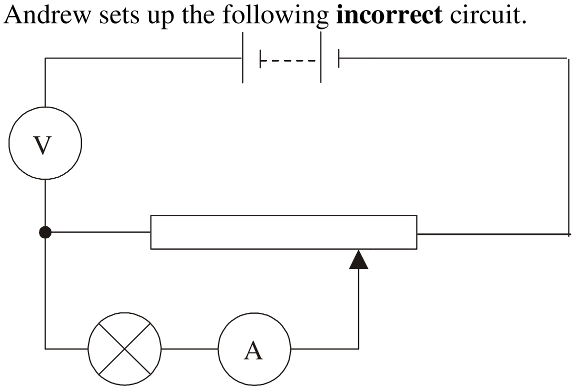
(i) its resistance;

(1)

(ii) its power dissipation.

(1)

Andrew sets up the following **incorrect** circuit.



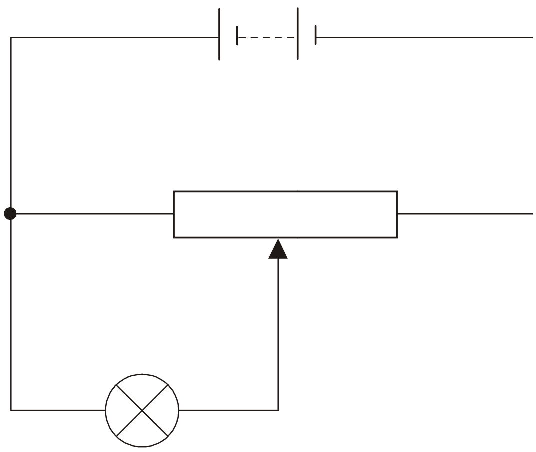
(b) (i) Explain why the lamp will not light.

(2)

(ii) State the approximate reading on the voltmeter. Explain your answer.

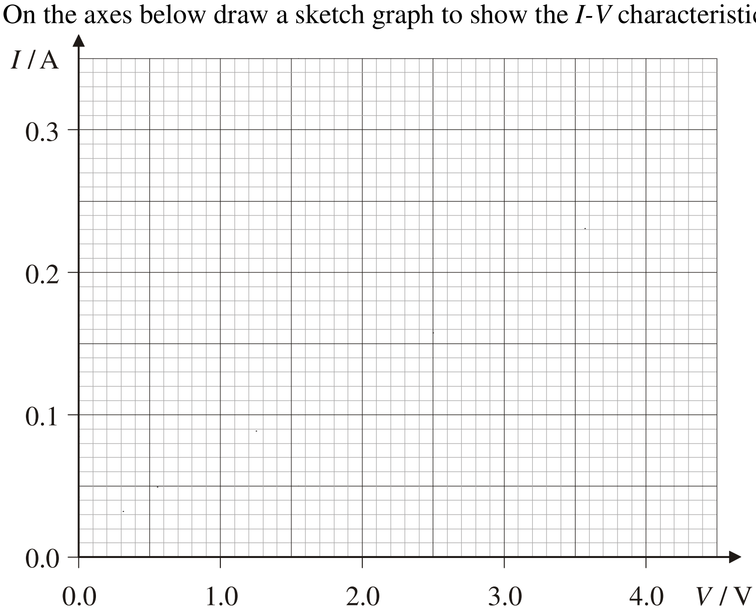
(2)

(c) On the circuit diagram below, add circuit symbols to show the correct position of the ammeter and of the voltmeter in order to measure the *I*-*V* characteristics of the lamp.



(2)

(d) On the axes below draw a sketch graph to show the *I*-*V* characteristics for this filament lamp.



(4)

(e) Explain the shape of the graph that you have drawn in (d).

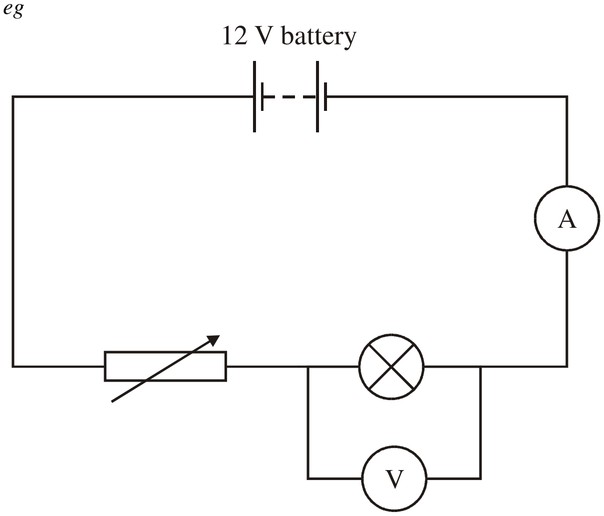
(2)
(Total 14 marks)

Topic 5 – Mark Scheme

1. D
2. B
3. D
4. D
5. D
6. B
7. C
8. C
9. (a) (i) correct substitution into power = p.d. × current
to give power = 12 × 0.5 = 6 W; 1 max

(ii) correct substitution into $V = I \times R$
to give $R = \dfrac{12}{0.5} = 24\Omega$; 1 max

(b) correct positioning of ammeter;
correct positioning of voltmeter;
eg

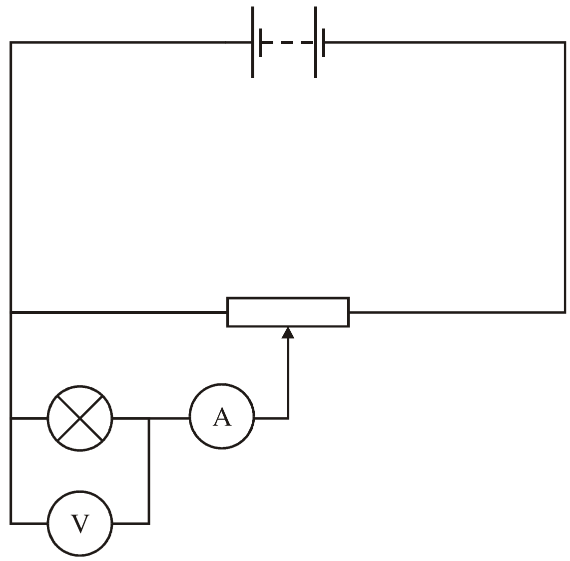


2 max

(c) (i) the battery (**or** the ammeter **or** the wires) must have some resistance;
some p.d. is "used up" so less "available" / *OWTTE*; 2 max

(ii) low voltage requires low current and thus large resistance;
max resistance of variable resistor not infinite / *OWTTE*; 2 max

(d) (i) any circuit involving potentiometer or equivalent;
that correctly controls the p.d. across the bulb;
with meters still correctly connected;



3 max

(ii) *[1] for each relevant point eg*
the 12 V is "shared" by the two halves of the resistor;
if the LH half is zero resistance, the p.d. will be zero / *OWTTE*; 2 max

(e) (i) appropriate statement of Ohm's law;
eg p.d. proportional to current of constant temperature.
temperature is not constant as current varies / *OWTTE*; 2 max

(ii) lamp B must have greater power dissipation;
since it has a greater current for the same p.d. / *OWTTE*;
so power dissipation (= $V \times$ I) is greater; 3 max

(f) (i) current lamp A equals the current in lamp B / *OWTTE*; 1 max

(ii) any answer that is less than 0.5 A but above 0.3 A;
realization (seen or implied) that each lamp does not have the same p.d.;
explanation (or evidence from the graph) of trying to find the current when the individual p.d.s sum to 12 V;
to give 0.4 A (± 0.1); 4 max

(iii) lamp A will have greater power dissipation;
since current the same, but it takes greater share of p.d.; 2 max

[25]

10. (a) (i) when connected to a 3 V supply, the lamp will be at normal brightness;
and energy is produced in the filament at the rate of 0.60 W;
Look for the idea that 3 V is the operating voltage and the idea of energy transformation.
or
when connected to a 3 V supply, the lamp will be at normal brightness;
and the resistance of the filament is 15 Ω / the current in the filament is 0.20 A; 2 max

(ii) $I = \dfrac{P}{V}$;
to give $I = 0.20$ A; 2

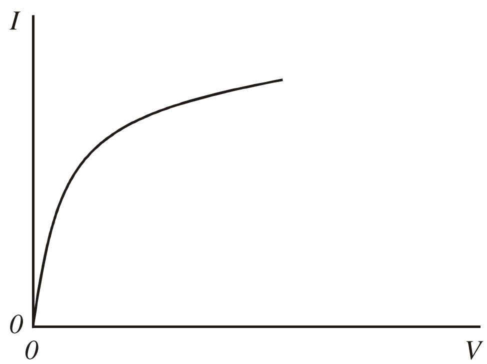
(b) (i) at maximum value, the supply voltage divides between the resistance of the variable resistor, internal resistance and the resistance of the filament;
ie response must show the idea of the voltage dividing between the various resistances in the circuit. Do not penalise if responses do not mention internal resistance here.
at zero resistance, the supply voltage is now divided between the filament resistance and the internal resistance of the supply; 2

(ii) when resistance of variable resistor is zero, e.m.f. = $Ir + V_{lamp}$;
$3.0 = 0.2\,r + 2.6$;
to give $r = 2.0\ \Omega$; 3

(c) (i) $3.3\ \Omega$; 1
(ii) $13\ \Omega$; 1

(d) at the higher pd, greater current and therefore hotter; the resistance of a metal increases with increasing temperature; *OWTTE*; 2 max

(e)



correct approximate shape (*ie* showing decreasing gradient with increasing *V*); 1

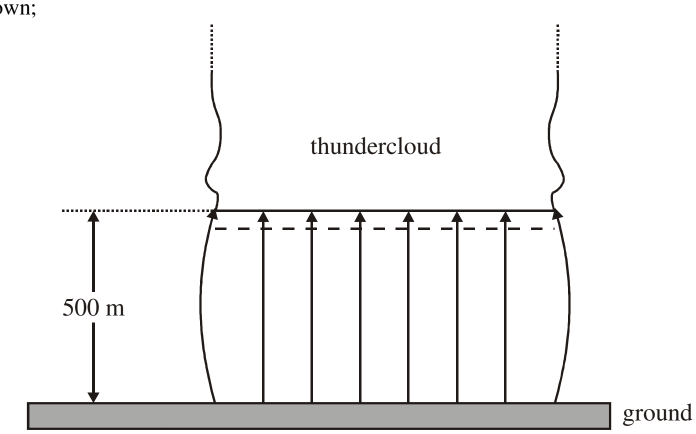
(f) parallel resistance of lamp and YZ is calculated from $\frac{1}{R} = \frac{1}{4} + \frac{1}{12}$;
to give $R = 3.0\ \Omega$;
3.0 V therefore divides between $3.0\ \Omega$ and $12.0\ \Omega$;
to give pd across the lamp = 0.60 V;
Give relevant credit if answers go via the currents ie
calculation of total resistance = $15.0\ \Omega$;
total current = 0.20 A;
current in lamp = 0.15 A; 4
pd across lamp = $0.15 \times 4 = 0.60$ V

[18]

11. (a) there are two types of charge: positive and negative;
if they are moved apart, this is charge separation / *OWTTE*; 2 max

(b) electric field strength is the force per unit charge;
felt by a positive test charge placed in the field / *OWTTE*; 2 max
Accept mathematical definitions, but do not award any marks for just copying the formula from the data booklet. Answers need to define the terms to receive credit.

(c) straight lines from Earth to negative;
equally spaced;
edge effect shown;



3 max

(d) (e) correct substitution to calculate σ (= 2.86×10^{-6} C m^{-2});
$E = 20 / (8.85 \times 10^{-12} \times 7 \times 10^{6})$ V m^{-1};
= 3.2×10^{5} V m^{-1};
= 3×10^{5} V m^{-1}; 3 max

(ii) ***[1]** for each appropriate and sensible assumption eg*
edge of cloud parallel to ground;
cloud and ground effectively infinite length;
permittivity of air the same as vacuum;
ground and cloud surface both flat, *etc*; 2 max

(e) potential difference = $3.2 \times 10^{5} \times 500$ V;
= 1.6×10^{8} V; 2 max
Accept 1.5×10^{8} V.

(f) (i) average current = 20 C / 20 ms
= 1000 A; 1

(ii) average p.d. = 1.6×10^{8} V / 2 = 0.8×10^{8} V;
energy released = average p.d × charge = $0.8 \times 10^{8} \times 20$;
= 1.6×10^{9} J; 3 max
[2] if maximum p.d. used to get 3.2×10^{9} J.

[18]

12. Electrical circuits

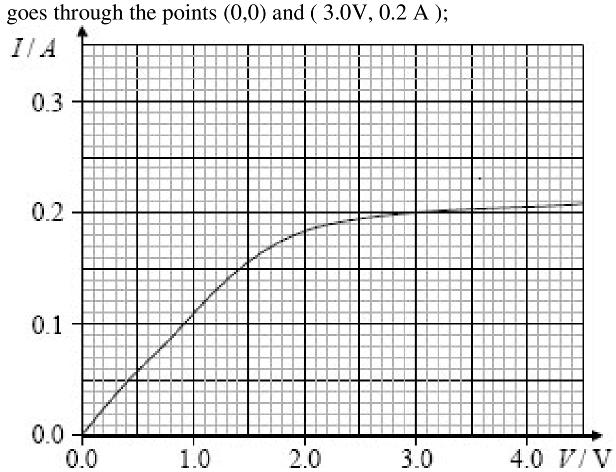
(a) (i) resistance = 15Ω; 1
(ii) power = 0.6W; 1

(b) (i) resistance of circuit too high;
identification of high resistance component / other appropriate and relevant comment; 2
*Reject answers that do not explain why the lamp does not light eg award **[0]** for "the voltmeter should be in parallel" as this is not sufficient.*

(ii) voltmeter reads 3V; (*accept just below 3V*)
because most of the pd is across the voltmeter / resistance is too high / there is no current in the circuit; 2
*Award **[1 max]** if candidate attempts to calculate the precise value of the pd using the total resistance of the circuit.*

(c) correct location of ammeter in series with bulb;
correct location of voltmeter in parallel with bulb; 2

(d) line is initially practically straight;
and then curves;
in the right direction;
goes through the points (0,0) and (3.0V, 0.2 A); 4



*Award **[2 max]** for a straight-line if it goes through (3.0V, 0.2 A). Omit part of the graph from 3.0 volts but do not penalize if there.*

(e) resistance of filament increases as temperature increases;
so $\frac{I}{V}$ decreases with increasing *V / OWTTE*; 2

Allow ecf for a straight-line in (d) only if followed by "temperature is constant" so "I is proportional to V / so ohm's law is obeyed".

[14]

Topic 6 – Fields and Forces

1. Gravitational field strength at a point may be defined as
A. the force on a small mass placed at the point.
B. the force per unit mass on a small mass placed at the point.
C. the work done to move unit mass from infinity to the point.
D. the work done per unit mass to move a small mass from infinity to the point.

2. The Earth is distance R_M from the Moon and distance R_S from the Sun. The ratio

$$\frac{\text{gravitational field strength at the Earth due to the Moon}}{\text{gravitational field strength at the Earth due to the Sun}}$$

is proportional to which of the following?

A. $\frac{R_M{}^2}{R_S{}^2}$

B. $\frac{R_M}{R_S}$

C. $\frac{R_S{}^2}{R_M{}^2}$

D. $\frac{R_S}{R_M}$

3. The acceleration of free fall of a small sphere of mass 5.0×10^{-3} kg when close to the surface of Jupiter is 25 ms^{-2}. The gravitational field strength at the surface of Jupiter is
A. 2.0×10^{-4} N kg^{-1}.
B. 1.3×10^{-1} N kg^{-1}.
C. 25 N kg^{-1}.
D. 5.0×10^{3} N kg^{-1}.

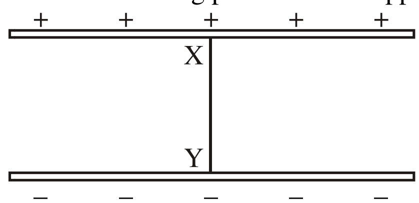
4. Planet X has radius R and mass M. Planet Y has radius $2R$ and mass $8M$.
Which **one** of the following is the correct value of the ratio

$$\frac{\text{gravitational field strength at surface of planet X}}{\text{gravitational field strength at surface of planet Y}}?$$

A. 4
B. 2
C. $\frac{1}{2}$
D. $\frac{1}{4}$

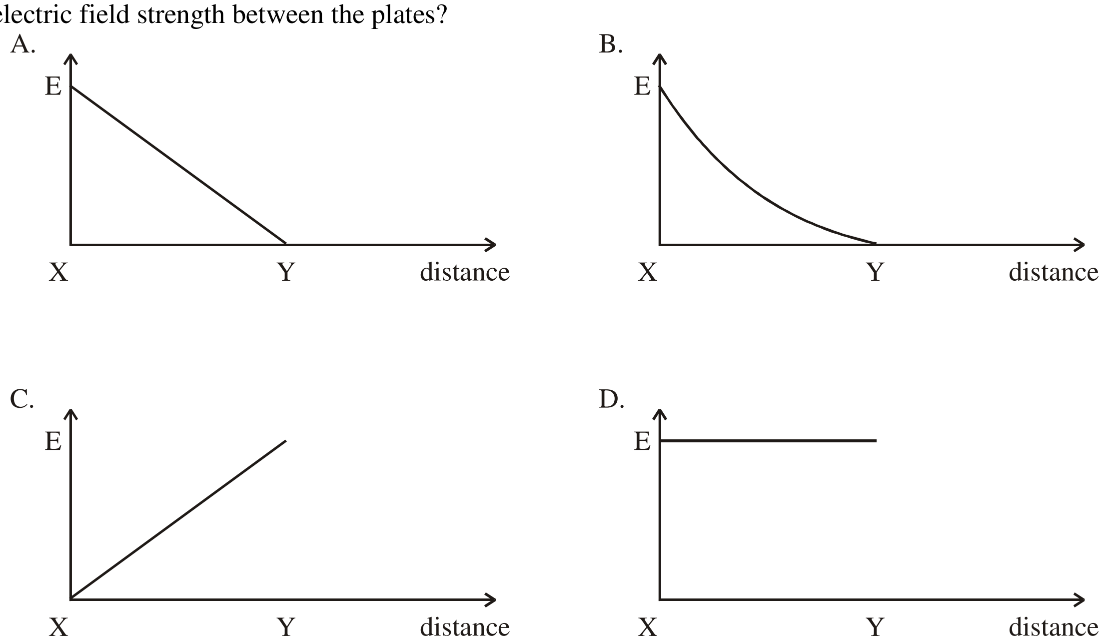
5. The electric field strength at a point may be defined as
A. the force exerted on unit positive charge placed at that point.
B. the force per unit positive charge on a small test charge placed at that point.
C. the work done on unit positive charge to move the charge to that point from infinity.
D. the work done per unit positive charge to move a small test charge to that point from infinity.

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



The line XY is perpendicular to the plates.

Which of the following diagrams shows the variation along the line XY of the magnitude *E* of the electric field strength between the plates?



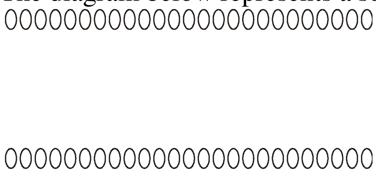
7. X and Y are two identical conducting spheres separated by a distance *d*. X has a charge +6 μC and Y has a charge –2 μC. The electric force between them is + F (*ie* attractive). The spheres are touched together and are then returned to their original separation *d*. The force between them now is

A. $+F$.
B. $-F$.
C. $+\frac{F}{3}$.
D. $-\frac{F}{3}$.

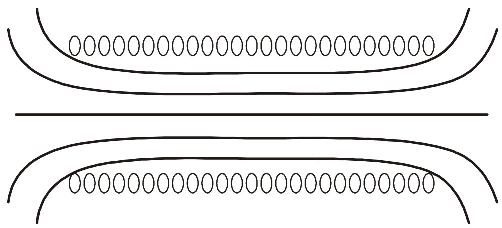
8. The electron volt is **defined** as

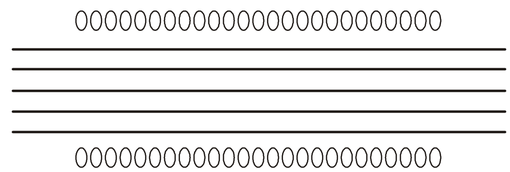
A. a unit of energy exactly equal to 1.6×10^{-19} J.
B. a fraction $\frac{1}{13.6}$ of the ionization energy of atomic hydrogen.
C. the energy gained by an electron when it moves through a potential difference of 1.0 V.
D. the energy transfer when 1.0 C of charge moves through a potential difference of 1.0 V.

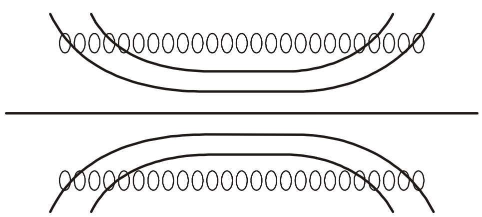
9. The diagram below represents a solenoid in which there is no electric current.

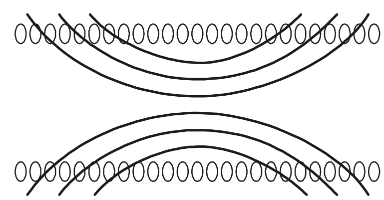


Which **one** of the following best represents the magnetic field pattern due to an electric current in the solenoid?

A.


B.


C.


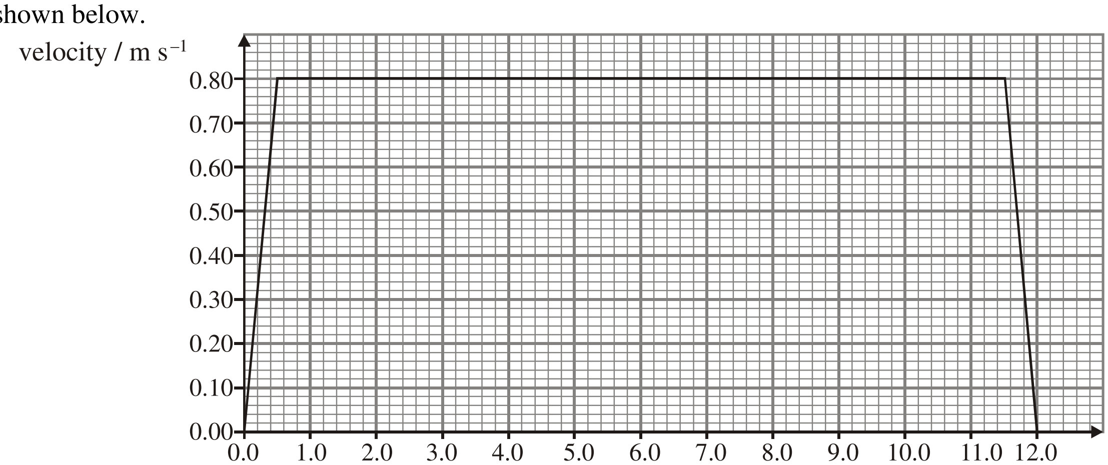
D.


10. This question is about the kinematics of an elevator (lift).

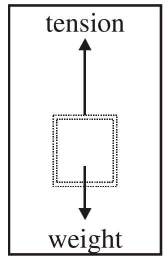
(a) Explain the difference between the gravitational mass and the inertial mass of an object.

(3)

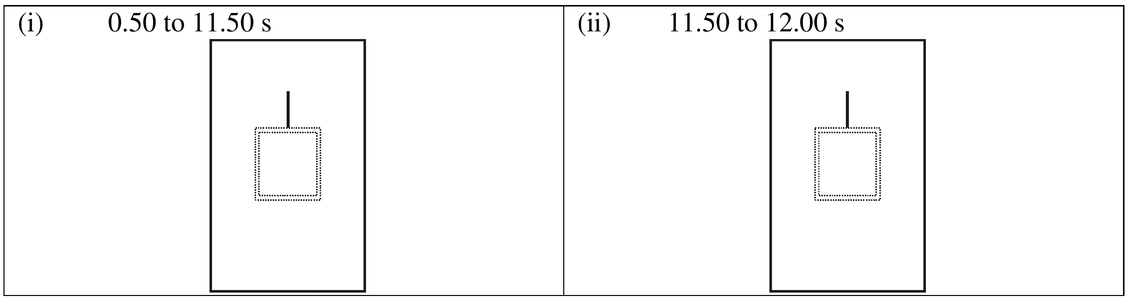
An elevator (lift) starts from rest on the ground floor and comes to rest at a higher floor. Its motion is controlled by an electric motor. A simplified graph of the variation of the elevator's velocity with time is shown below.



The elevator is supported by a cable. The diagram below is a free-body force diagram for when the elevator is moving upwards during the first 0.50 s.



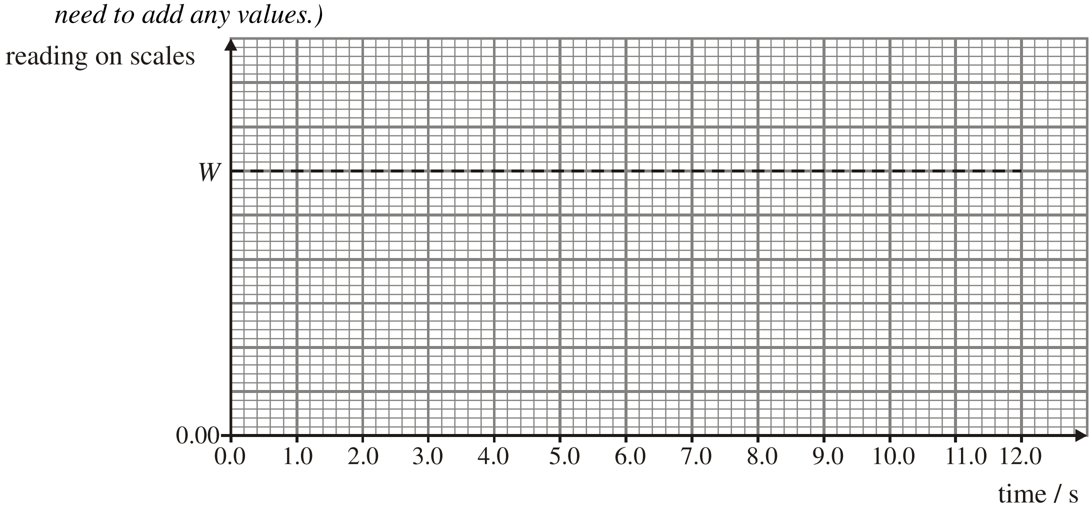
(b) In the space below, draw free-body force diagrams for the elevator during the following time intervals.



(3)

A person is standing on weighing scales in the elevator. Before the elevator rises, the reading on the scales is *W*.

(c) On the axes below, sketch a graph to show how the reading on the scales varies during the whole 12.00 s upward journey of the elevator. *(Note that this is a sketch graph – you do not need to add any values.)*



(3)

(d) The elevator now returns to the ground floor where it comes to rest. Describe and explain the energy changes that take place during the whole up and down journey.

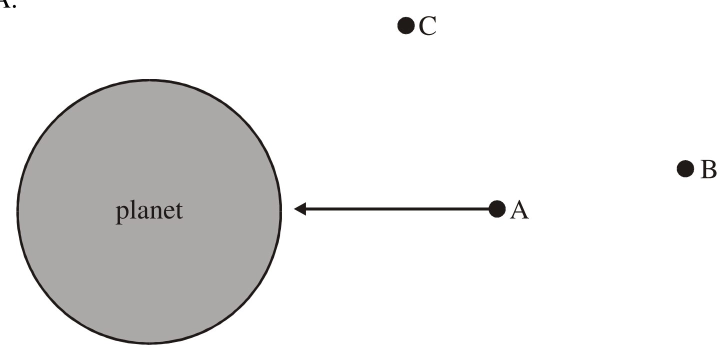
(4)
(Total 13 marks)

11. This question is about gravitation and orbital motion.

(a) Define *gravitational field strength* at a point in a gravitational field.

(2)

The diagram below shows three points above a planet. The arrow represents the gravitational field strength at point A.

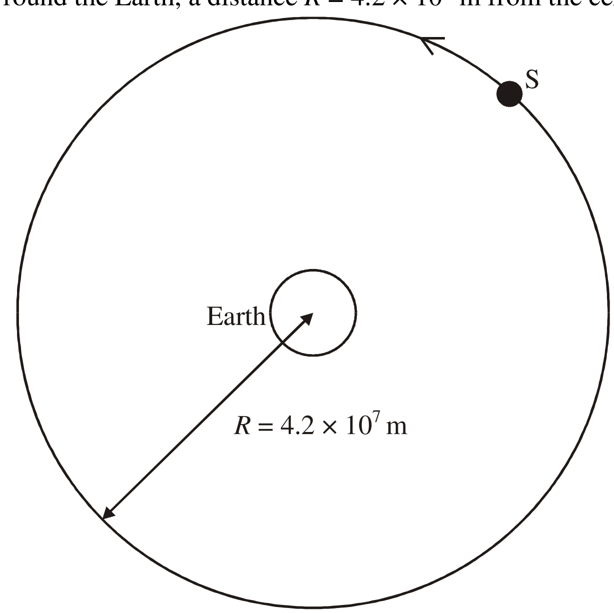


(b) Draw arrows to represent the gravitational field strength at point B and point C.

(2)
(Total 4 marks)

12. This question is about a satellite orbiting the Earth.

A satellite S is in orbit round the Earth, a distance $R = 4.2 \times 10^7$ m from the centre of the Earth.



(a) On the diagram above, for the satellite in the position shown, draw arrow(s) to represent the force(s) acting on the satellite.

(1)

(b) Deduce that the velocity v of the satellite is given by the expression

$$v^2 = \frac{GM}{R}$$

where M is the mass of the Earth.

(1)

(c) Hence deduce that the period of orbit T of the satellite is given by the following expression.

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

(3)

(d) Use the following information to determine that the orbital period of the satellite is about 24 hours.

Acceleration due to gravity at the surface of the Earth $g = \frac{GM}{R_E{}^2} = 10\ \text{ms}^{-2}$, where M is the mass of the Earth and R_E is the radius of the Earth = 6.4×10^6 m.

(2)

(e) The satellite is moved into an orbit that is closer to the Earth. State what happens to its

(i) potential energy.

(1)

(ii) kinetic energy.

(1)
(Total 9 marks)

13. This question is about the force between current-carrying wires.
Diagram 1 below shows two long, parallel vertical wires each carrying equal currents in the same direction. The wires pass through a horizontal sheet of card. Diagram 2 shows a plan view of the wires looking down onto the card.

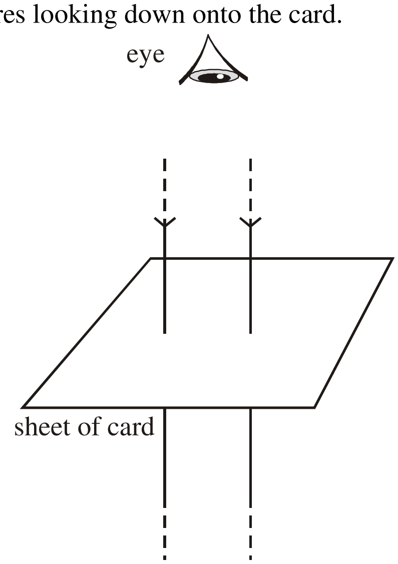


diagram 1

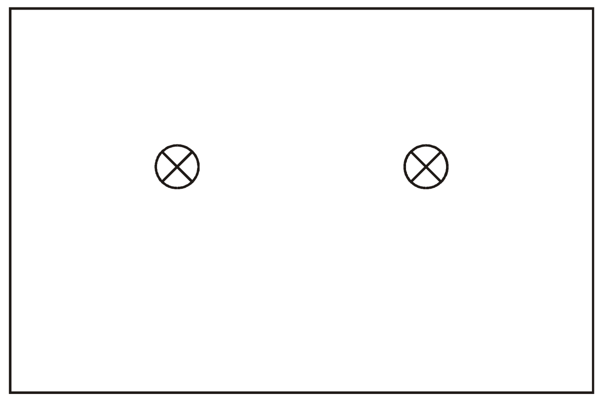


diagram 2

(a) (i) Draw on diagram 1 the direction of the force acting on each wire.

(1)

(ii) Draw on diagram 2 the magnetic field pattern due to the currents in the wire.

(3)

(b) The card is removed and one of the two wires is free to move. Describe and explain the changes in the velocity and in acceleration of the moveable wire.

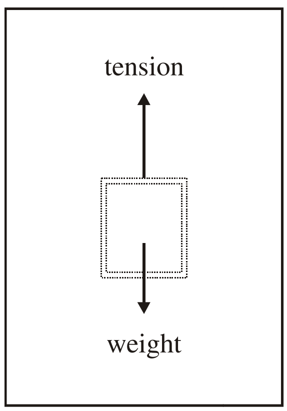
(3)
(Total 7 marks)

Topic 6 – Mark Scheme

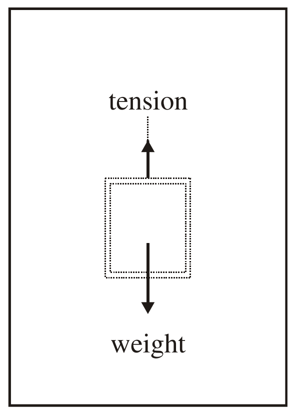
1. B
2. C
3. C
4. C
5. B
6. D
7. D
8. C
9. A
10. (a) statement that gravitational mass and inertial mass have the same numerical value;
understanding of what gravitational mass means;
eg "a quantity that determines the gravitational force on the object"
understanding of what inertial mass means;
eg "a quantity that determines the acceleration of the object" 3 max

(b) *Mark part (i) and (ii) together.*
weight arrow the same in both diagrams;
magnitude of tension (size of arrow) **equal to** weight in (i);
magnitude of tension (size of arrow) **less than** weight in (ii); 3 max

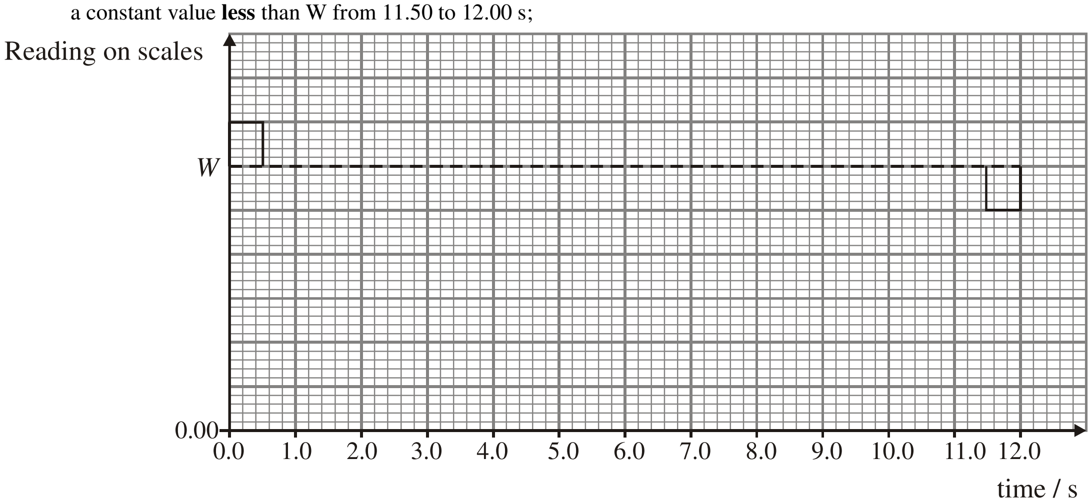
(i) 0.50 to 11.50 s



(ii) 11.50 to 12.00 s



(c) a constant value **greater** than W from 0.00 to 0.50 s;
a constant value **equal** to W from 0.50 to 11.50 s;
a constant value **less** than W from 11.50 to 12.00 s;



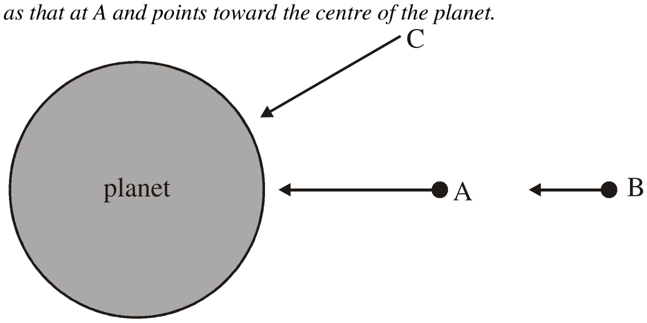
3 max

(d) *[1] for each appropriate and valid point. Essentially [2] for journey up and [2] for journey down. Some explanation or justification is required for full marks eg*
the law of conservation of energy does apply to round trip;
energy is all dissipated into heat and sound;
on the way up, most electrical energy converted into g.PE, initially some electrical energy is converted into K.E;
on the way down electrical energy does work "breaking" lift some (not all) g.PE is converted into KE; 4 max
Reject answers that imply that PE converts into KE as lift falls.

[13]

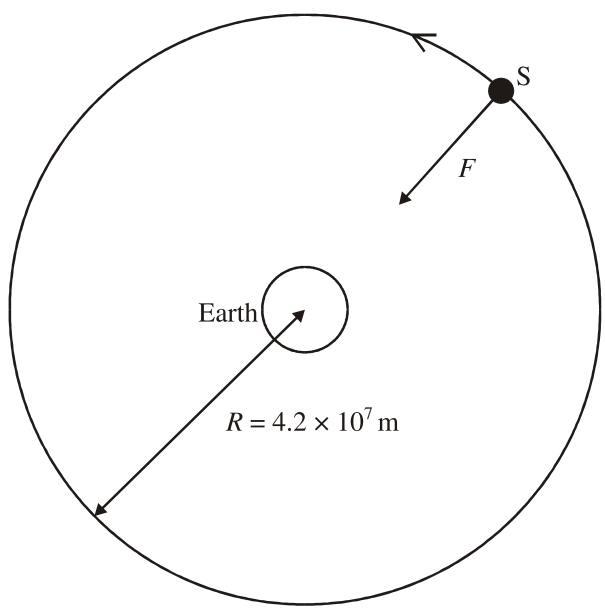
11. (a) $g = \frac{F}{m}$
F is the gravitational force;
exerted on / experienced by a small / point / infinitesimal mass m; 2

(b) *Award [1] for each correct arrow. The one at B points in the same direction as that at A and is shorter. The one at C has the same length as that at A and points toward the centre of the planet.* 2



[4]

12. (a)



F – towards centre of Earth; 1 max
Award [0] if any other forces are drawn.

(b) (i) $\dfrac{GM}{R^2} = \dfrac{v^2}{R}$

so $v^2 = \dfrac{GM}{R}$; 1 max

(c) $v = \dfrac{2\pi R}{T}$;

so $v^2 = \dfrac{4\pi^2 R^2}{T^2} = \dfrac{GM}{R}$;

so $T^2 = \dfrac{4\pi^2 R^3}{GM}$; 3 max

(d) $T^2 = \dfrac{4\pi^2 R^3}{g_0 {R_E}^2}$;

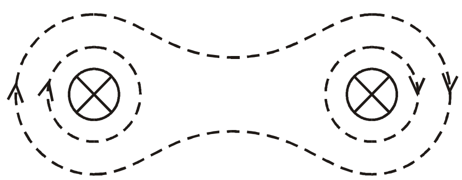
to give $T \approx 85000$ s ≈ 24 hours; 2 max

(e) (i) decreases; 1 max
(ii) increases; 1 max

[9]

13. (a) (i) $\rightarrow \leftarrow$; 1

(ii)



general shape: at least one circle around each wire and one loop around both wires;
appropriate spacing of lines: increasing separation with distance from wires;
correct direction of field; 3

(b) velocity increases;
acceleration increases;
because the force is getting larger the closer the wires get together; 3

Watch for ecf if force is drawn in wrong direction in (a) (i) ie velocity increases, acceleration decreases, force gets smaller.

[7]

Topics 7 & 13 – Atomic and Nuclear Physics

1. Which **one** of the following provides direct evidence for the existence of discrete energy levels in an atom?

A. The continuous spectrum of the light emitted by a white-hot metal.
B. The line emission spectrum of a gas at low pressure.
C. The emission of gamma radiation from radioactive atoms.
D. The ionization of gas atoms when bombarded by alpha particles.

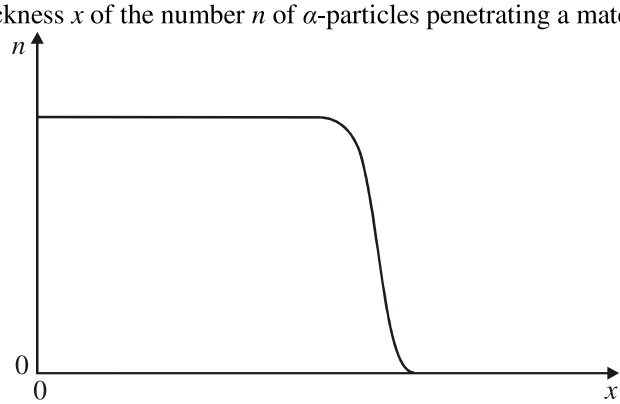
2. A sample of material initially contains atoms of only one radioactive isotope. Which **one** of the following quantities is reduced to one half of its initial value during a time equal to the half-life of the radioactive isotope?

A. Total mass of the sample
B. Total number of atoms in the sample
C. Total number of nuclei in the sample
D. Activity of the radioactive isotope in the sample

3. In a fission chain reaction,

A. energy from one fission reaction causes further fission reactions.
B. nuclei produced in one fission reaction cause further fission reactions.
C. neutrons from one fission reaction cause further fission reactions.
D. gamma radiation produced in one fission reaction causes further fission reactions.

4. The variation with thickness x of the number n of α-particles penetrating a material is shown below.



What can be deduced from the graph about the α-particles?

A. The α-particles have approximately the same initial energy.
B. The range is independent of the initial energy.
C. The α-particles produce high levels of ionization.
D. The α-particles have a large mass.

5. K-capture is a process that occurs when a nucleus captures an electron from the innermost shell of electrons surrounding the nucleus.

When K-capture occurs in iron-55 (${}^{55}_{26}\text{Fe}$), the nucleus is changed into a manganese (Mn) nucleus.

Which equation represents this change?

A. $({}^{55}_{26}\text{Fe}) + {}^{0}_{1}\text{e} \rightarrow {}^{55}_{27}\text{Mn}$
B. $({}^{55}_{26}\text{Fe}) + {}^{1}_{1}\text{e} \rightarrow {}^{56}_{27}\text{Mn}$
C. $({}^{55}_{26}\text{Fe}) + {}^{0}_{-1}\text{e} \rightarrow {}^{55}_{25}\text{Mn}$
D. $({}^{55}_{26}\text{Fe}) + {}^{1}_{-1}\text{e} \rightarrow {}^{56}_{25}\text{Mn}$

6. When the isotope aluminium-27 is bombarded with alpha particles, the following nuclear reaction can take place.

$$^{4}_{2}\mathrm{HE} + ^{27}_{13}\mathrm{Al} \rightarrow \mathrm{X} + \mathrm{neutron}$$

Which **one** of the following correctly gives the atomic (proton) number and mass (nucleon) number of the nucleus X?

	Proton number	Nucleon number
A.	15	30
B.	16	31
C.	30	15
D.	31	16

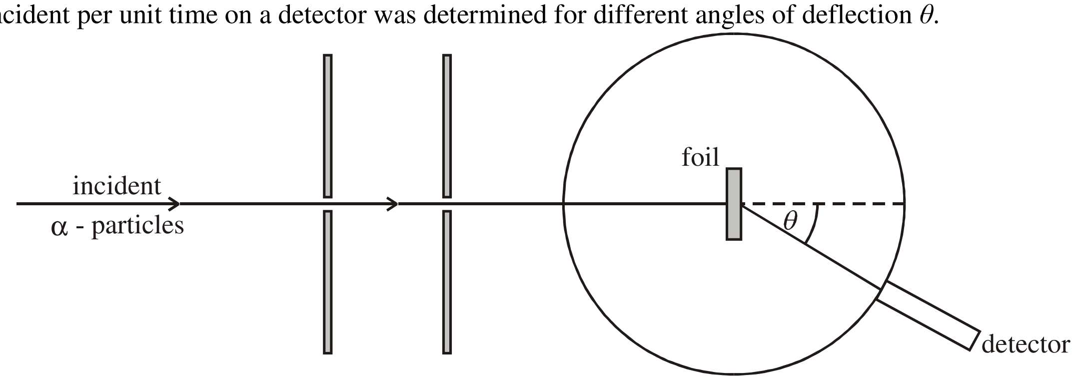
7. When the isotope aluminium-27 is bombarded with alpha particles, the following nuclear reaction can take place

$$^{4}_{2}\mathrm{He} + ^{27}_{13}\mathrm{Al} + \rightarrow \mathrm{X} + \mathrm{neutron}.$$

Which **one** of the following correctly gives the atomic (proton) number and mass (nucleon) number of the nucleus X?

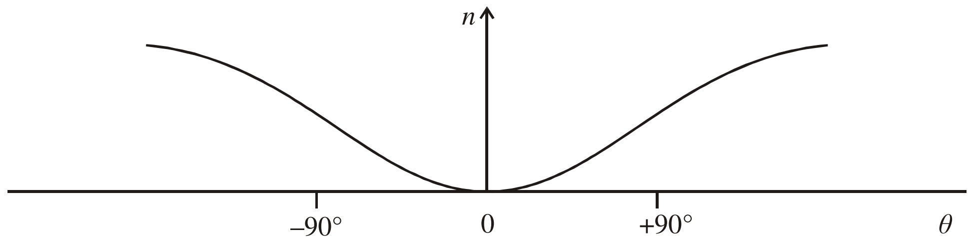
	Proton number	Nucleon number
A.	15	30
B.	16	31
C.	30	15
D.	31	16

8. In an α-particle scattering experiment (Geiger-Marsden experiment), the number n of particles incident per unit time on a detector was determined for different angles of deflection θ.

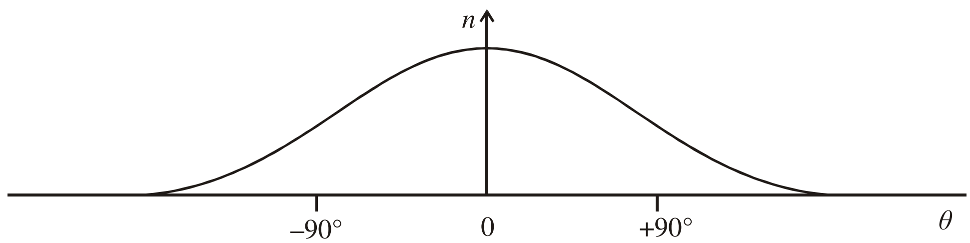


Which of the following graphs best shows the variation with θ of n?

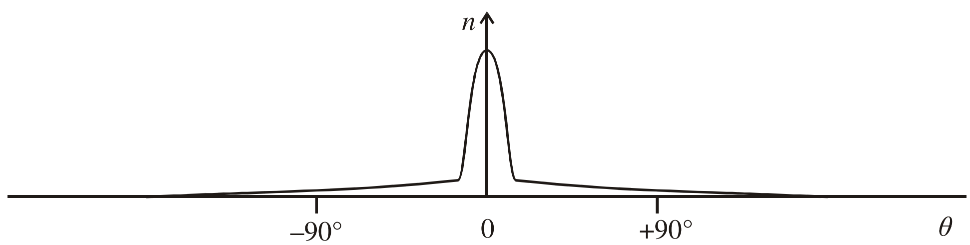
A.



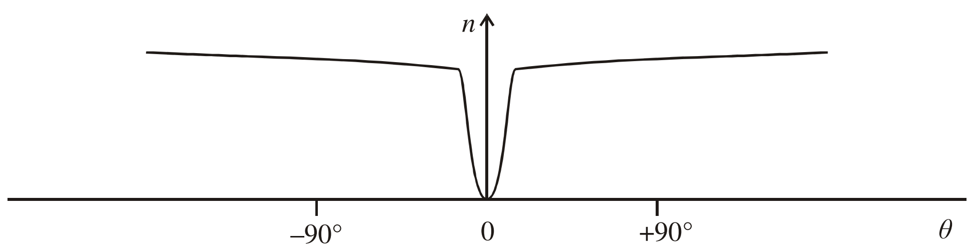
B.



C.



D.



9. The existence of isotopes provides evidence for the presence of

A. electrons in atomic energy levels.
B. electrons in the nuclei of atoms.
C. neutrons in the nuclei of atoms.
D. protons in the nuclei of atoms.

10. When a high-energy α-particle collides with an aluminium-27 ($^{27}_{13}\text{Al}$) nucleus, a nucleus of phosphorus may be produced. Which of the following equations correctly shows this transmutation?

A. $^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{n}$
B. $^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{p}$
C. $^{27}_{13}\text{Al} + {}^{2}_{1}\text{He} \rightarrow {}^{28}_{14}\text{P} + {}^{1}_{0}\text{p}$
D. $^{27}_{13}\text{Al} + {}^{2}_{1}\text{He} \rightarrow {}^{28}_{14}\text{P} + {}^{1}_{0}\text{n}$

11. Which **one** of the following provides evidence for a nuclear model of the atom?
A. Natural radioactive decay
B. The ionizing properties of radiation
C. The stability of certain elements
D. The scattering of alpha particles by gold foil

12. The main source of the Sun's energy is
A. chemical reaction.
B. natural radioactivity.
C. nuclear fusion.
D. nuclear fission.

14. This question is about atomic and nuclear structure and fundamental forces.
In a nuclear model of the atom, most of the atom is regarded as empty space. A tiny nucleus is surrounded by a number of electrons.

(a) Outline **one** piece of experimental evidence that supports this **nuclear** model of the atom.

(3)

(b) Explain why the protons in a nucleus do not fly apart from each other.

(2)

(c) In total, there are approximately 10^{29} electrons in the atoms making up a person. Estimate the electrostatic force of repulsion between two people standing 100 m apart as a result of these electrons.

(4)

(d) Estimate the gravitational force of attraction between two people standing 100 m apart.

(2)

(e) Explain why two people standing 100 m apart would not feel either of the forces that you have calculated in parts (c) and (d).

(2)
(Total 13 marks)

15. This question considers some aspects of the atomic and nuclear physics associated with isotopes of the element helium.

Atomic aspects

(a) The element helium was first identified from the *absorption spectrum* of the Sun.

(i) Explain what is meant by the term *absorption spectrum*.

(2)

(ii) Outline how this spectrum may be experimentally observed.

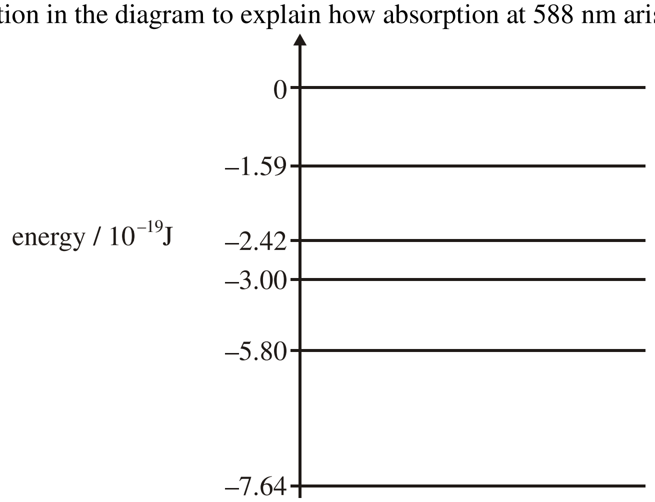
(2)

(b) One of the wavelengths in the absorption spectrum of helium occurs at 588 nm.

(i) Show that the energy of a photon of wavelength 588 nm is 3.38×10^{-19} J.

(2)

(ii) The diagram below represents some of the energy levels of the helium atom. Use the information in the diagram to explain how absorption at 588 nm arises.



(3)

Two different models have been developed to explain the existence of **atomic** energy levels. The **Bohr model** and the **Schrödinger model** are both able to predict the principal wavelengths present in the spectrum of atomic hydrogen.

(c) Outline
 (i) the Bohr model, and
 (ii) the Schrödinger model.

(6)

Nuclear aspects

(d) The helium in the Sun is produced as a result of a nuclear reaction. Explain whether this reaction is burning, fission or fusion.

(2)

At a later stage in the development of the Sun, other nuclear reactions are expected to take place. One such overall reaction is given below.

$$^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \rightarrow \mathrm{C} + \gamma + \gamma$$

(e) (i) Identify the atomic number **and** the mass number of the isotope of carbon C that has been formed.
Atomic number: …………………………………...
Mass number: ……………………………………...

(2)

 (ii) Use the information below to calculate the energy released in the reaction.
Atomic mass of helium = $6.648\ 325 \times 10^{-27}$ kg
Atomic mass of carbon = $1.993\ 200 \times 10^{-26}$ kg

(3)

Another isotope of helium ${}^{6}_{2}\text{He}$ decays by emitting a β^{-}-particle.

(f) (i) State the name of the other particle that is emitted during this decay.

(1)

(ii) Explain why a sample of ${}^{6}_{2}\text{He}$ emits β^{-}-particles with a **range of energies**.

(2)

(iii) The half-life for this decay is 0.82 s. Determine the percentage of a sample of ${}^{6}_{2}\text{He}$ that remains after a time of 10 s.

(3)

(iv) Describe the process of β^{-} decay in terms of quarks.

(2)
(Total 30 marks)

16. This question is about the Bohr model of the hydrogen atom and the Heisenberg uncertainty principle.

(a) A postulate of the Bohr model of the hydrogen atom is that the electron revolves about the proton in stable, circular orbits. State **two** other postulates of the Bohr model.

1 ....

....

2 ....

....

(2)

In the n^{th} energy state, the hydrogen atom has energy E_n and the electron orbits with speed v_n in an orbit of radius r_n. E_n, r_n and v_n are given by the following relationships.

$$E_n = -\frac{13.606}{n^2}\ \text{eV}$$

$$r_n = 0.0529n^2\ \text{nm}$$

$$v_n = \frac{2.19\times10^6}{n}\ \text{m s}^{-1}$$

(b) Apply the expressions above, to hydrogen in its ground state, to determine the ground state energy, the radius of the electron orbit and the electron speed.

(2)

(c) According to the Schrödinger model, the position and the speed of an electron are not well defined. It can be assumed that the uncertainty in the position of the electron in a hydrogen atom is equal to the radius of the electron orbit in the $n = 1$ state.

(i) Apply the Heisenberg uncertainty principle to hydrogen in this state to show that the **uncertainty** in the speed of the electron is approximately equal to the electron speed as calculated in (b).

(3)

(ii) Explain why the result in (i) above suggests that the idea of electron orbits, as used in the Bohr model, is a poor one.

(3)
(Total 10 marks)

17. This question is about radioactivity and nuclear energy.

(a) Define the following terms,

(i) *Isotope*

....
....

(1)

(ii) *Radioactive half-life*

....
....

(1)

Thorium-227 (Th-227) results from the decay of the isotope actinium-227.

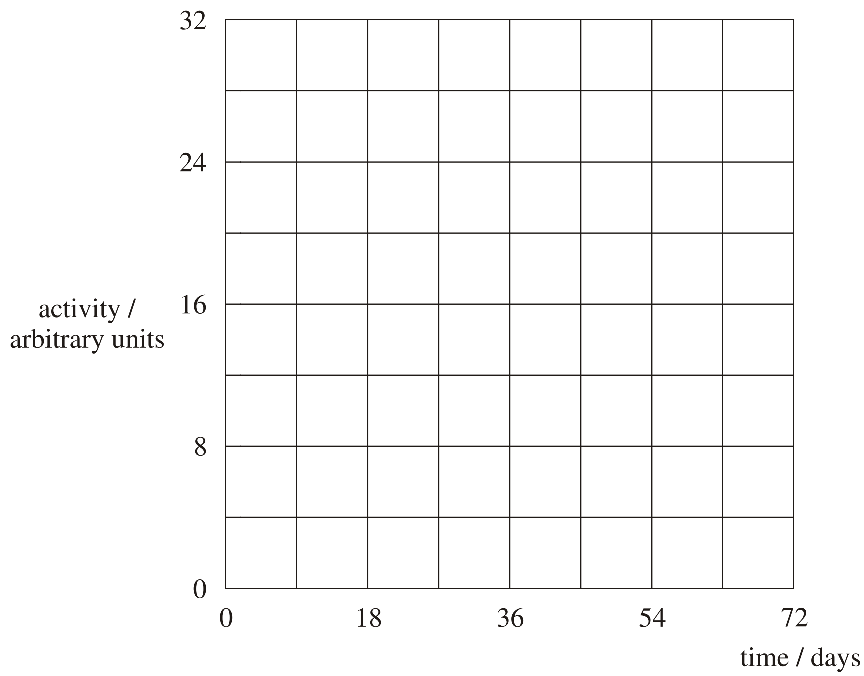
(b) (i) Complete the following reaction equation.

$${}^{227}_{89}\text{Ac} \rightarrow {}^{227}_{90}\text{Th} +$$

(1)

Th-227 has a half-life of 18 days and undergoes α-decay to the isotope Ra-223 (Ra-223). A sample of Th-227 has an initial activity of 32 arbitrary units.

(ii) Using the axes below, draw a graph to show the variation with time t (for $t = 0$ to $t = 72$ days) of the activity A of Th-227.



(2)

(iii) Determine from your graph, the activity of thorium after 50 days.

....

(1)

(iv) Outline the experimental procedure to measure the activity of Th-227.

(2)

In the decay of a Th-227 nucleus, a γ-ray photon is also emitted.

(c) Use the following data to deduce that the energy of the γ-ray photon is 0.667 MeV.

mass of Th-227 nucleus = 227.0278 u
mass of Ra-223 nucleus = 223.0186 u
mass of helium nucleus = 4.0026 u
energy of α-particle emitted = 5.481 MeV
unified atomic mass unit (u) = 931.5 MeV c^{-2}

You may assume that the Th-227 nucleus is stationary before decay and that the Ra-223 nucleus has negligible kinetic energy.

(3)

(Total 11 marks)

18. This question is about wave-particle duality.

(a) Describe the de Broglie hypothesis.

(2)

(b) An electron is accelerated from rest through a potential difference of 1250 V. Determine the associated de Broglie wavelength of the accelerated electron.

(4)
(Total 6 marks)

19. This question is about line spectra.

(a) Light is emitted from a gas discharge tube. Outline briefly how the visible line spectrum of this light may be obtained.

....
....
....

(2)

The table below gives information relating to three of the wavelengths in the line spectrum of atomic hydrogen.

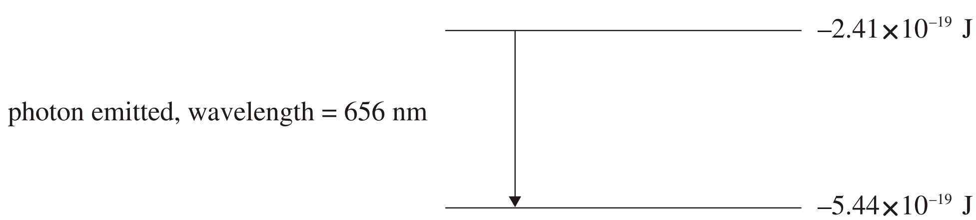
Wavelength / $\times 10^{-9}$ m	**Photon energy / $\times 10^{-19}$ J**
1880	1.06
656	3.03
486	4.09

(b) Deduce that the photon energy for the wavelength of 486×10^{-9} m is 4.09×10^{-19} J.

....
....
....

(2)

The diagram below shows two of the energy levels of the hydrogen atom, using data from the table above. An electron transition between these levels is also shown.



(c) (i) On the diagram above, construct the other energy level needed to produce the energy changes shown in the table above.

(1)

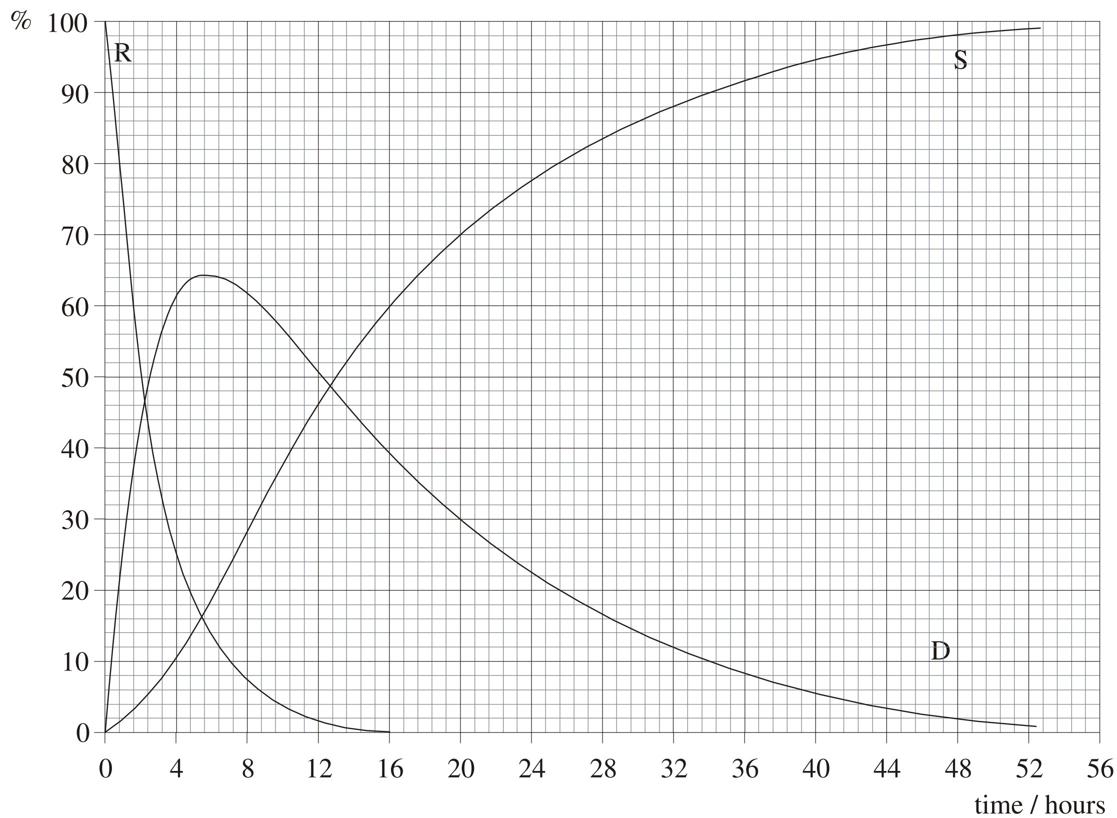
(ii) Draw arrows to represent the energy changes for the two other wavelengths shown in the table above.

(1)

(Total 6 marks)

20. This question is about radioactive decay.

A nuclide R undergoes radioactive decay to form a daughter nuclide D which is also radioactive. The daughter nuclide D decays to form a stable nuclide S. The graph below shows the variation with time *t* of the percentage number of atoms of each of the nuclides R, D and S.



(a) Use data from the graph to determine the decay constant λ for the nuclide R.

(2)

The graph for daughter nuclide D shows a maximum value.

(b) (i) State and explain the relation between the rates of decay of R and of D at this maximum.

(2)

Measurement of the percentage of R, D and S in a sample that initially contained 100% of R may be used to determine the age of the sample.

(ii) Suggest why such measurements of percentage composition would **not** provide a reliable result for samples that are about 50 hours old.

(1)
(Total 5 marks)

21. This question is about nuclear binding energy and nuclear decay.

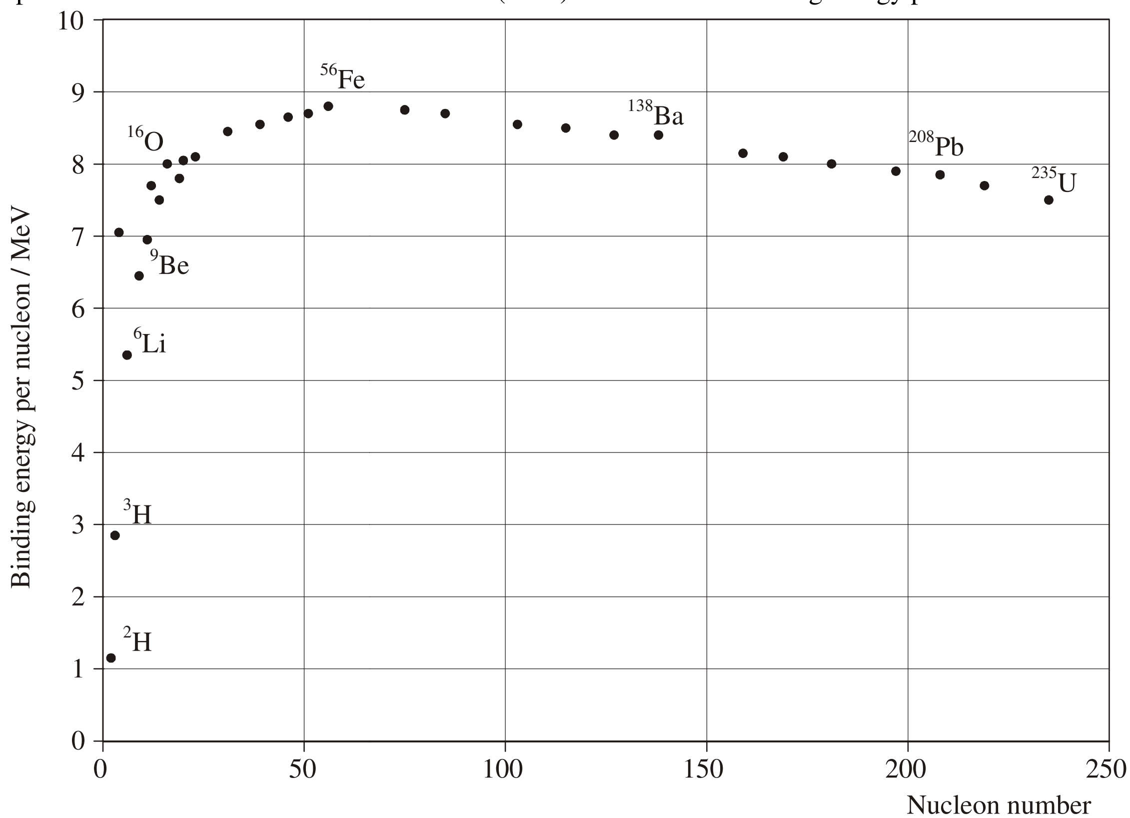
(a) State what is meant by a *nucleon*.

(1)

(b) Define what is meant by the *binding energy* of a nucleus.

(1)

The graph below shows the variation with nucleon (mass) number of the binding energy per nucleon.



(c) Use the graph to explain why energy can be released in both the fission and the fusion processes.

(3)

(d) Carbon-11, ${}^{11}_{6}\text{C}$, undergoes β^{+} decay with a half-life of 20.5 minutes to form an isotope of boron.

(i) Write down the nuclear equation for this decay.

(2)

(ii) Deduce that a sample of Carbon-11 of mass 1.0×10^{-15} kg contain 5.5×10^{10} atoms.

(2)

(iii) Calculate the initial activity of the sample in (d) (ii).

(2)
(Total 11 marks)

Topics 7 & 13 – Mark Scheme

1. B
2. D
3. C
4. A
5. C
6. A
7. A
8. C
9. C
10. A
11. D
12. C

[1]

14. (a) *[1] for any valid and relevant point eg*
Geiger-Marsden experiment involved bombardment of gold foil by alpha particles;
most passed straight through / were deviated through small angles, but some deflected through large angles;
these alpha particles were heading towards central nucleus; 3 max

(b) ***[1 max]*** *for any valid and relevant point eg*
protons in nucleus repel each other (seen or implied);
but are held together by the strong nuclear force / or neutrons are involved keeping it bound together / *OWTTE*; 2 max

(c) attempted use of $F = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r^2}$;
with $q_1 = q_2 = 10^{29}\ e = 1.6 \times 10^{-10}$ C;
and $r = 100$ m;
to get $F = 2.3 \times 10^{26}$ N $\approx 10^{26}$ N; 4 max

(d) substitution into $F = \dfrac{Gm_1 m_2}{r^2}$
with $m_1 = m_2 = 70$ kg;
Accept any sensible estimate, say 30 kg → 110 kg
and $r = 100$ m
to get $F = 3.3 \times 10^{-11}$ N $\approx 3 \times 10^{-11}$ N;
above range gives 6×10^{-12} *N* $\rightarrow 8 \times 10^{-11}$ *N* 2 max

(e) people are overall electrically neutral / equal numbers of positive charges mean that overall the electrical force is zero / *OWTTE*;
the gravitational force of attraction is too small to notice; 2 max

[13]

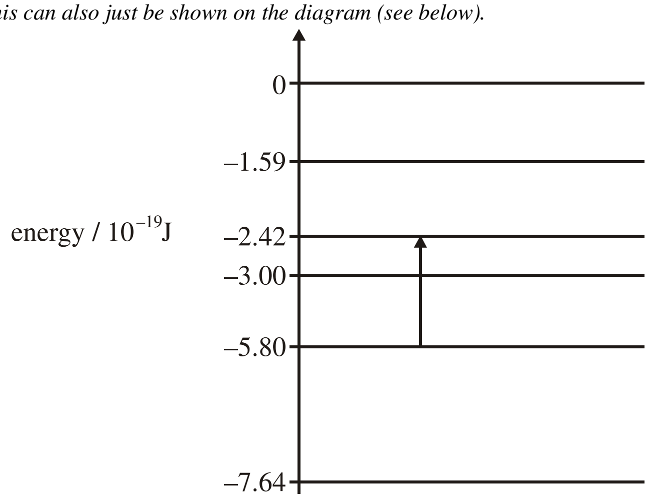
15. (a) (i) *Answer to include*:
missing frequencies / wavelengths;
in otherwise continuous spectrum; 2 max

(ii) *Answer to include*:
light from Sun is split into its component wavelengths;
using prism / grating; 2 max

(b) (i) correct substitution into $E = hf$ *and* $c = f\lambda$ to give $E = \dfrac{hc}{\lambda}$;
$E = 6.63 \times 10^{-34} \times 3 \times 10^{8} / 5.88 \times 10^{-7}$;
$= 3.38 \times 10^{-19}$ J 2 max

(ii) transition is an absorption so involves electron being "promoted" up between two levels;
energy of gap must be exactly = 3.38×10^{-19} J;
this is between (-5.80×10^{-19} J) and (-2.42×10^{-19} J) levels; 3 max

__[2 max]__ can be given for other relevant information concerning, for example, the existence of photons with different energies in sunlight / the immediate re-radiation in random directions. The final mark is for identifying the energy levels concerned. This can also just be shown on the diagram (see below).



(c) *Mark (i) and (ii) together. __[1]__ for each relevant point eg*
Bohr assumed electrons were in circular orbits around nucleus;
of fixed angular momentum that;
were stable (did not radiate) and thus the energy can be calculated;
Schrödinger considers electron "probability" waves;
only some standing waves fit the boundary conditions;
and these fix the available energies for the electron; 6 max

__NB [4 max]__ for any one of the models.

(d) a **fusion** reaction;
since Hydrogen nuclei are joining to create helium / any other relevant further detail / explanation; 2 max

(e) (i) atomic number: 6;
mass number: 12; 2 max

__NB__ if 6 and 12 are reversed, __[1 max]__.

(ii) mass before $= 3 \times (6.648325 \times 10^{-27}\text{ kg})$
$= 1.994497\,5 \times 10^{-26}$ kg
mass of Carbon $= 1.9932000 \times 10^{-26}$ kg
so mass defect $= 1.9944975 \times 10^{-26} - 1.993\,2000 \times 10^{-26}$ kg
$= 0.0012975 \times 10^{-26}$ kg ;
correct substitution into $E = mc^2$;
energy released $= 0.0012975 \times 10^{-26} \times 9.00 \times 10^{-16}$ J
$= 1.16775 \times 10^{-12}$ J
$\approx 1.17 \times 10^{-12}$ J ; 3 max

(f) (i) an (electron-) antineutrino; 1

Reject "neutrino".

(ii) idea that there is a fixed total energy of decay;
total energy shared between the (three) resulting particles / *OWTTE*; 2 max

(iii) correct calculation of decay constant λ;
$\lambda = ln\ 2 / 0.82 = 0.845$
correct substitution into $N = N_0 e^{-\lambda t}$;
to give $N = N_0 e^{-8.45}$ therefore $\frac{N}{N_0} = e^{-8.45} = 0.000213 = 0.02\%$; 3 max
*NB Award attempts without full equation **[1 max]**.*

(iv) an up quark changes into a down quark;
any other relevant detail; 2 max
eg this involves the weak interaction / statement of quark content of proton (UUD) or neutron (UDD).

[30]

16. (a) *Any two of:*
radiation is only emitted when the atom (electron) makes a transition from a higher to a lower energy state;
the difference in energy between the two states, $\Delta E = hf$;
the angular momentum of the electron is quantized in units of $\frac{h}{2\pi}$; 2 max

$$\left(mvr = \frac{h}{2\pi}\right)$$

*Award **[0]** for orbiting electrons do not radiate (electromagnetic waves).*

(b) in the ground state $n = 1$, so;
$E_1 = -13.6$ eV $r_1 = 0.0529$ nm $v_1 = 2.19 \times 10^6$ m s^{-1}; 2 max
All three must be correct for the second mark. Allow ECF but not if n = 0.

(c) (i) $\Delta x = 0.0529$ nm, hence $\Delta p = \frac{\left(\frac{h}{2\pi}\right)}{0.529} \times 10^9$;
$= m\,\Delta v$;
hence $\Delta v = \frac{\left(\frac{h}{2\pi}\right)}{0.529} \times 10^9$ m $= 2.2 \times 10^6$ m s^{-1}; 3 max

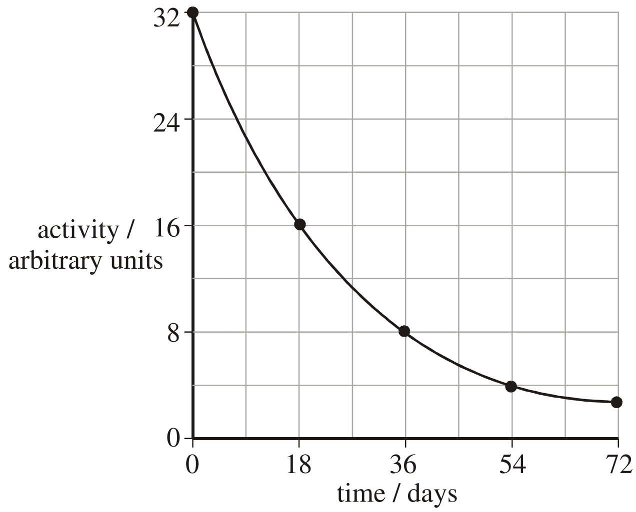
(ii) the bare statement that there is a (relatively) large uncertainty in the position **and/or** the momentum/velocity of the electron;
some discussion that this situation cannot be "improved upon"; *up to **[2]***
eg if the position uncertainty is made smaller (to better define the radius), the speed uncertainty gets even bigger and vice versa;
hence the picture of well defined "orbits" is inappropriate / *OWTTE*; 3 max

[10]

17. (a) (i) isotope: nuclei of elements with different number of neutrons; 1
Accept same Z different A / OWTTE.
(ii) time for the activity to halve in value / time for the number of nuclei to transmute to nuclei of another element / *OWTTE*; 1

(b) (i) ${}^{227}_{86}\text{Ac} \rightarrow {}^{227}_{90}\text{Th} + \beta^-\ (e^-)$; 1

(ii)



correct data points;
sensible attempt at line of best fit; 2

(iii) 5.0 (±1); 1

(iv) Geiger tube plus counter;
count for given time and divide count by time to get activity; 2
*Or if candidates use Geiger tube plus ratemeter, **[1]** then some other detail is needed such as source must be placed close to the GM tube **[1]**.*

(c) mass defect = 227.0278 – (223.0186 + 4.0026) = 0.0066 u;
= 6.148 MeV c^{-2};
therefore energy of γ = 6.148 – 5.481 = 0.667 MeV; 3

[11]

18. (a) all particles have a wavelength associated with them;
given by $\lambda = \dfrac{h}{p}$, with h and p explained; 2

(b) kinetic energy of electron = qV;
= 2.00×10^{-16} J;
$E_K = \dfrac{P^2}{2m}$ *or* $v^2 = \dfrac{2E}{m}$ and $p = mv$ ($v = 2.1 \times 10^7\ ms^{-1}$)
$p = 1.91 \times 10^{-23}$ Ns;
$\lambda = \dfrac{h}{p}$
= 3.47×10^{-11} m; *(allow 2 significant digits)* 4

[6]

19. (a) use of diffraction grating / prism and screen / telescope;
observe <u>diffracted</u> / <u>refracted</u> light <u>or</u> first / second orders; 2

(b) $E = \dfrac{hc}{\lambda}$ or $E = hf$ and $c = f\lambda$;
correct substitution into relevant formula clear; 2
to give energy = 4.09×10^{-19} J *Award **[0]** for answer alone.*

(c) (i) ______________________ -1.35×10^{-19} J
______________________ -2.41×10^{-19} J
______________________ -5.44×10^{-19} J
level shown in "reasonable" position (spacing of lines not important); 1
To receive the mark answers must quote -1.35×10^{-19} J.

(ii) transition $-1.35 \times 10^{-19} \rightarrow -5.44 \times 10^{-19}$ (and labelled 486 nm)
transition $-1.35 \times 10^{-19} \rightarrow -2.41 \times 10^{-19}$ (and labelled 1880 nm); 1

[6]

20. (a) $T_{\frac{1}{2}} = 2.0$ hours; *(accept exact answers only)*

$$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}} = 0.35\,\text{hr}^{-1};$$ 2

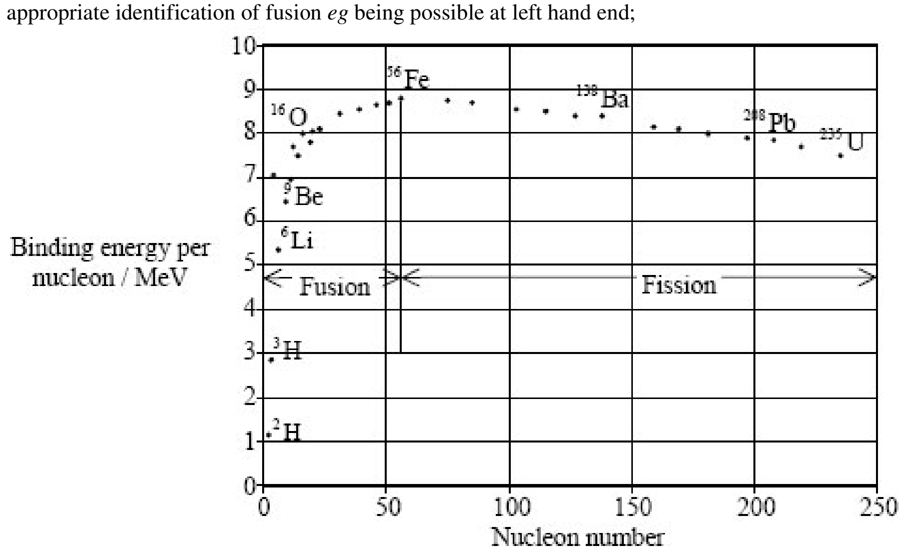
(b) (i) rate of decay of R = rate of production of D;
at maximum, rate of decay of D = rate of production of D; 2
(ii) *eg* percentage composition varies very slowly with time; 1

[5]

21. (a) (a nucleon is either) a proton or a neutron / *OWTTE*; 1

(b) appropriate definition; 1
eg energy released when a nucleus is formed from its constituent nucleons / (minimum) energy needed to break a nucleus up into its constituent nucleons

(c) appropriate identification of fission *eg* being possible at right hand end of the graph;
appropriate identification of fusion *eg* being possible at left hand end;



discussion in terms of energy release being possible as products have higher (average) binding energy per nucleon; 3

(d) (i) proton and nucleon numbers correct for boron;
Ignore mistakes in chemical symbol used for boron.
inclusion of neutrino; 2
Reject antineutrino.

$${}^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{1}\beta^{+} + \nu$$

(ii) number of moles = $\dfrac{1.0\times10^{-15}}{0.011} = 9.09\times10^{-14}$;

therefore, number of nuclei $N_0 = 9.09 \times 10^{-14} \times 6.02 \times 10^{23}$;

$= 5.47 \times 10^{10} \approx 5.5 \times 10^{10}$ 2

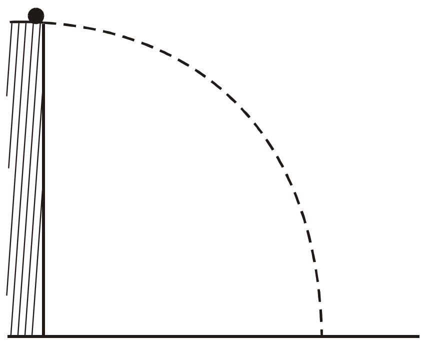
(iii) decay constant $\lambda = \dfrac{\ln 2}{1230} = 5.64\times10^{-4}\ \mathrm{s}^{-1}$;

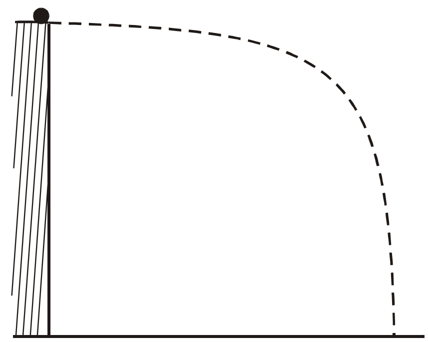
therefore, activity = $\lambda N_0 = 3.1 \times 10^{7}$ Bq; 2

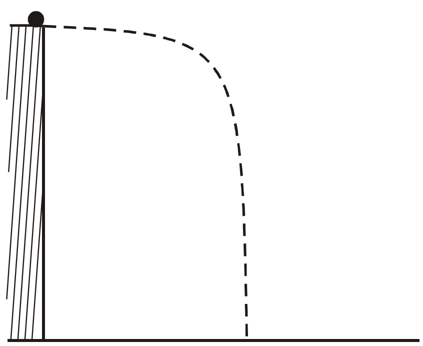
[11]

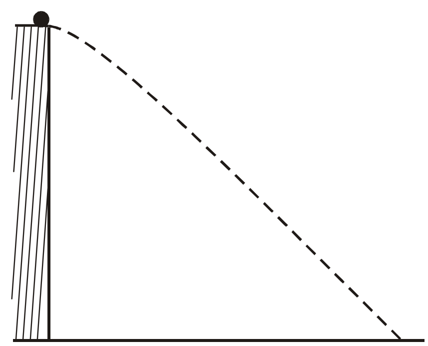
Topic 9 – Motion in Fields

1. A ball is thrown horizontally from the top of a cliff. Air resistance is negligible. Which of the following diagrams best represents the subsequent path of the ball?

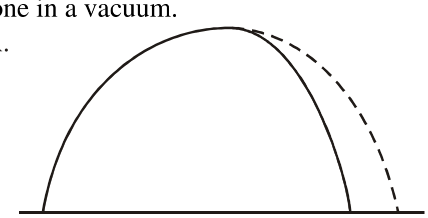
A.


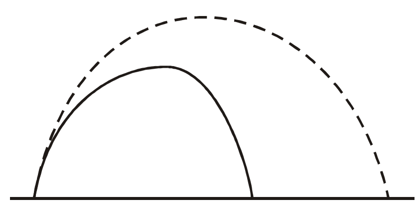
B.


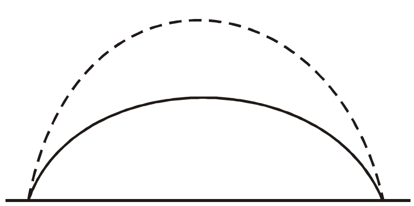
C.


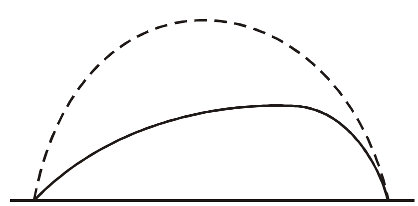
D.


2. A stone is thrown from O at an angle to the horizontal. Which sketch below best shows the path of the stone when air resistance is **not** neglected? On each sketch, the broken line shows the path for the same stone in a vacuum.

A.

O

B.

O

C.

O

D.

O

3. A stone is projected horizontally from the top of a cliff. Neglecting air resistance, which *one* of the following correctly describes what happens to the horizontal component of velocity and to the vertical component of velocity?

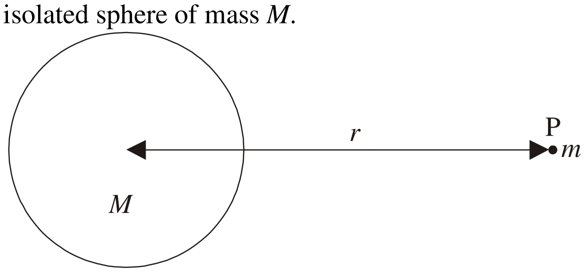
	Horizontal component of velocity	Vertical component of velocity
A.	Decreases	Increases
B.	Decreases	Constant
C.	Constant	Constant
D.	Constant	Increases

4. The gravitational potential at point X due to the Earth is –7 kJ kg^{-1}. At point Y, the gravitational potential is –3 kJ kg^{-1}.

The change in gravitational potential energy of a mass of 4 kg when it is moved from point X to point Y is

A. 4 kJ.
B. 10 kJ.
C. 16 kJ.
D. 40 kJ.

5. A point object of mass *m* is brought from infinity to the point P, a distance *r* from the centre of an isolated sphere of mass *M*.



The work done by the gravitational force in bringing the point object from infinity to point P is

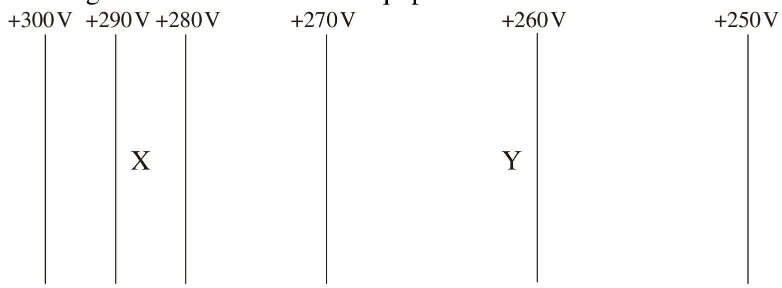
A. $G\frac{M}{r}$.

B. $G\frac{Mm}{r}$.

C. $-G\frac{M}{r}$.

D. $-G\frac{Mm}{r}$.

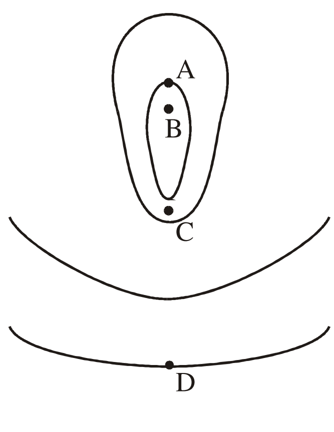
6. The diagram below shows some equipotential lines in an electric field.



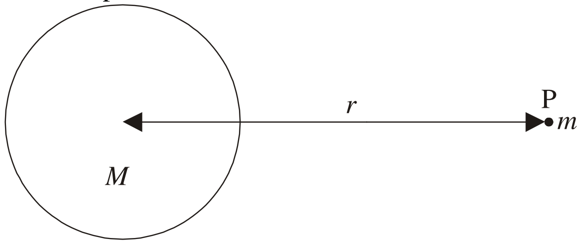
The magnitude of the electric field strength at X is E_X and at Y is E_Y.
Which **one** of the following correctly compares E_X and E_Y and gives the correct direction of the electric field?

	Magnitude of field strengths	Direction of field
A.	$E_X > E_Y$	$X \rightarrow Y$
B.	$E_X > E_Y$	$Y \rightarrow X$
C.	$E_X < E_Y$	$X \rightarrow Y$
D.	$E_X < E_Y$	$Y \rightarrow X$

7. The diagram below shows lines of electric equipotential. The change in potential on moving from one line to the next is always the same. At which point does the electric field strength have its greatest magnitude?



8. A point object of mass m is brought from infinity to the point P, a distance r from the centre of an isolated sphere of mass M.



The work done by the gravitational force in bringing the point object from infinity to point P is

A. $G\dfrac{M}{r}$.

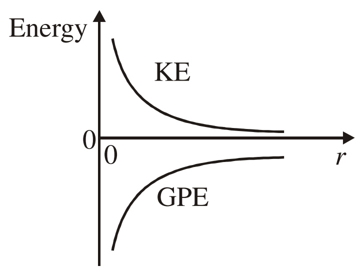
B. $G\dfrac{Mm}{r}$.

C. $-G\dfrac{M}{r}$.

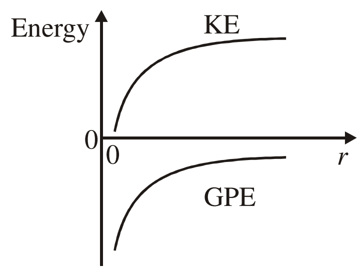
D. $-G\dfrac{Mm}{r}$.

9. Which **one** of the following graphs best represents the variation of the kinetic energy, KE, and of the gravitational potential energy, GPE, of an orbiting satellite with its distance r from the centre of the Earth?

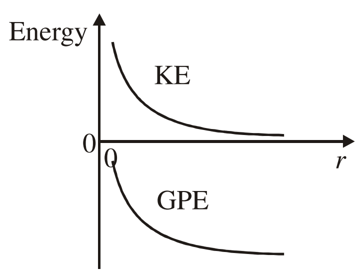
A.



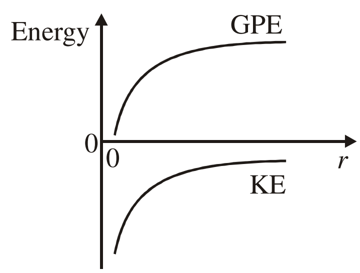
B.



C.



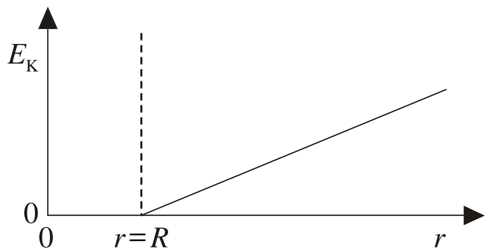
D.



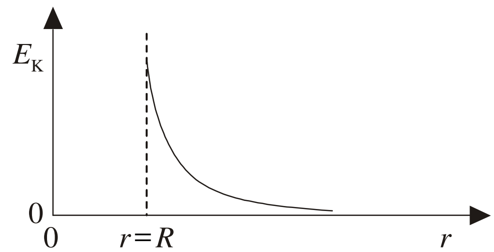
10. The kinetic energy E_K of a satellite in orbit varies with its distance r from the centre of a planet of radius R.

Which **one** of the following graphs best shows the variation of E_K with r?

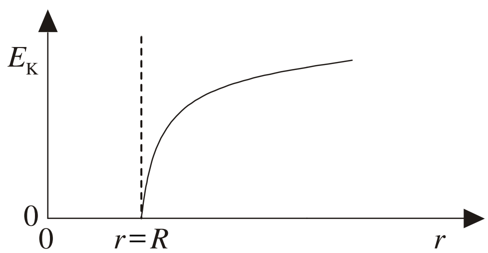
A.



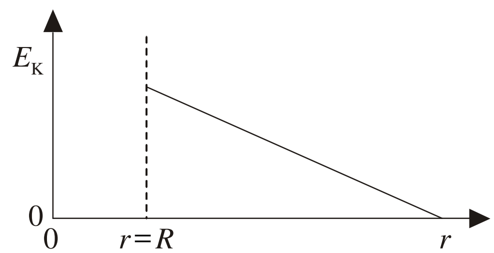
B.



C.



D.



11. Which of the following expressions correctly relates the radius R of the circular orbit of a planet round a star to the period T of the orbit?

A. $R^3 \propto T^2$

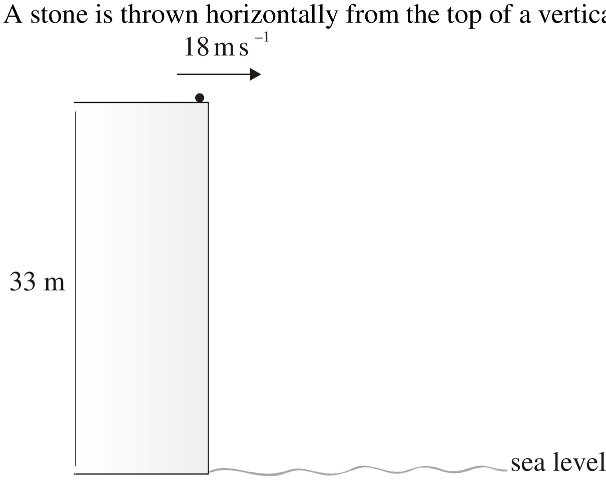
B. $\frac{1}{R^3} \propto T^2$

C. $R^2 \propto T^3$

D. $\frac{1}{R^2} \propto T^3$

12. This question is about projectile motion.

A stone is thrown horizontally from the top of a vertical cliff of height 33 m as shown below.



The initial horizontal velocity of the stone is 18 m s^{-1} and air resistance may be assumed to be negligible.

(a) State values for the horizontal and for the vertical acceleration of the stone.
Horizontal acceleration:

Vertical acceleration:

(2)

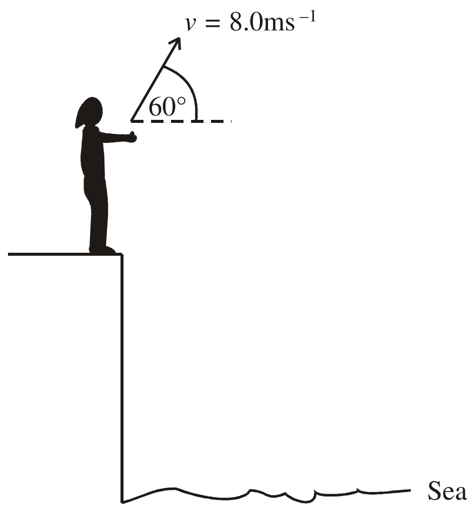
(b) Determine the time taken for the stone to reach sea level.

(2)

(c) Calculate the distance of the stone from the base of the cliff when it reaches sea level.

(1)
(Total 5 marks)

13. This question is about trajectory motion.
Antonia stands at the edge of a vertical cliff and throws a stone upwards at an angle of 60° to the horizontal.



The stone leaves Antonia's hand with a speed $v = 8.0$ m s^{-1}. The time between the stone leaving Antonia's hand and hitting the sea is 3.0 s.
The acceleration of free fall g is 10 m s^{-2} and all distance measurements are taken from the point where the stone leaves Antonia's hand.
Ignoring air resistance calculate
(a) the maximum height reached by the stone.

(3)

(b) the horizontal distance travelled by the stone.

(2)
(Total 5 marks)

14. This question is about gravitation.

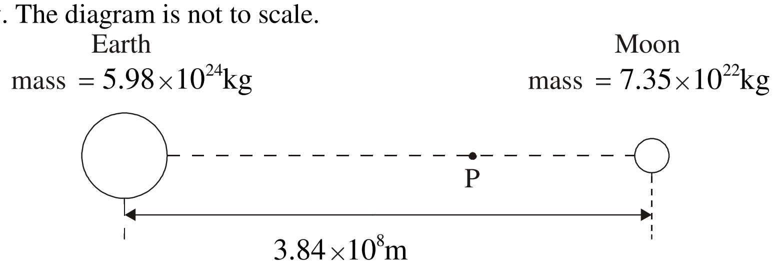
(a) (i) Define *gravitational potential* at a point in a gravitational field.

(2)

(ii) Explain why values of gravitational potential have negative values.

(2)

The Earth and the Moon may be considered to be two isolated point masses. The masses of the Earth and the Moon are 5.98×10^{24}kg and 7.35×10^{22} kg respectively and their separation is 3.84×10^{8} m, as shown below. The diagram is not to scale.



(b) (i) Deduce that, at point P, 3.46×10^{8}m from Earth, the gravitational field strength is approximately zero.

(3)

(ii) The gravitational potential at P is -1.28×10^{6} J kg^{-1}. Calculate the minimum speed of a space probe at P so that it can escape from the attraction of the Earth and the Moon.

(3)
(Total 10 marks)

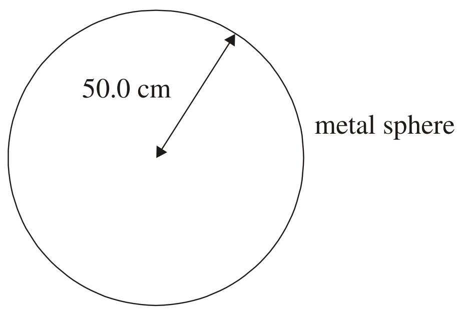
15. Fields and potential

Electric fields and potential

(a) Define *electric potential*.

(2)

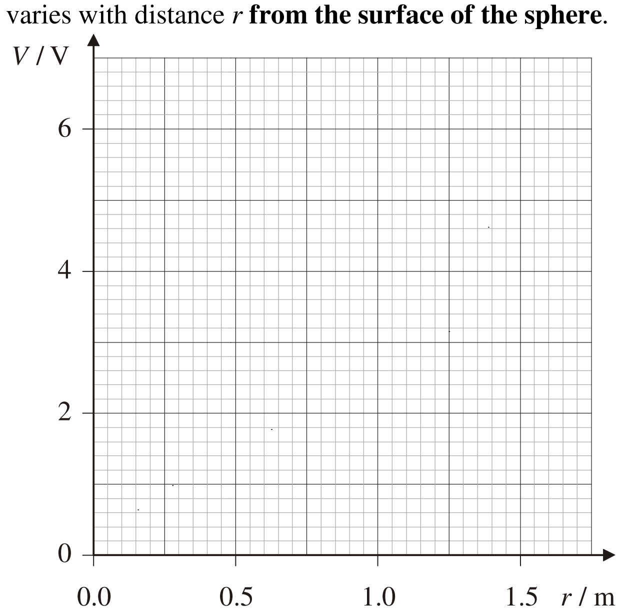
An isolated metal sphere of radius 50.0 cm has a positive charge. The electric potential at the surface of the sphere is 6.0 V.



(b) (i) On the diagram above, draw a line to represent an equipotential surface outside the sphere.

(1)

(ii) On the axes below, draw a sketch graph to show how the potential V outside the sphere varies with distance r **from the surface of the sphere**.

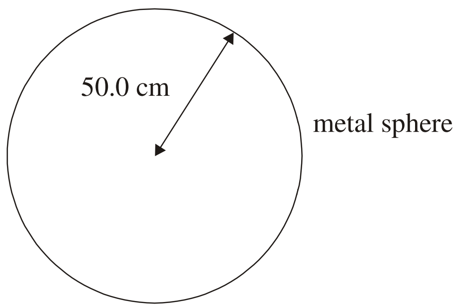


(4)

(iii) Explain how the graph drawn in (b) (ii) can be used to determine the magnitude of the electric field strength at the surface of the sphere.

(2)

(c) On the diagram below draw lines to represent the electric field outside the sphere.



(2)

Gravitational fields and potential

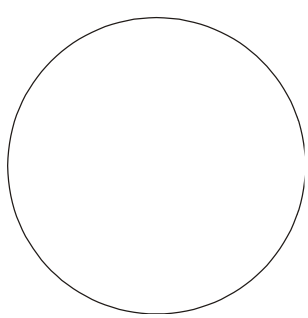
(d) Derive an expression for the gravitational field strength as a function of distance away from a point mass *M*.

(3)

(e) The radius of the Earth is 6400 km and the gravitational field strength at its surface is 9.8 N kg^{-1}. Calculate a value for the mass of the Earth.

(2)

(f) On the diagram below draw lines to represent the gravitational field outside the Earth.



(2)

(g) A satellite that orbits the Earth is in the gravitational field of the Earth. Discuss why an astronaut inside the satellite feels weightless.

(3)

(h) The gravitational potential outside the Earth and the electric potential outside the sphere both vary with distance. Compare these variations.

(2)
(Total 23 marks)

16. This question is about gravitation.
A space probe is launched from the equator in the direction of the north pole of the Earth. During the launch, the energy E given to the space probe of mass m is

$$E = \frac{3GMm}{4R_e}$$

where G is the Gravitational constant and M and R_e are, respectively, the mass and radius of the Earth. Work done in overcoming frictional forces is not to be considered.

(a) (i) Explain what is meant by *escape speed*.

(2)

(ii) Deduce that the space probe will not be able to travel into deep space.

(3)

The space probe is launched into a circular polar orbit of radius R.

(b) Derive expressions, in terms of G, M, R_e, m and R, for

(i) the change in gravitational potential energy of the space probe as a result of travelling from the Earth's surface to its orbit.

(1)

(ii) the kinetic energy of the space probe when in its orbit.

(2)

(c) Using your answers in (b) and the total energy supplied to the space probe as given in (a), determine the height of the orbit above the Earth's surface.

(4)

A space probe in a low orbit round the Earth will experience friction due to the Earth's atmosphere.

(d) (i) Describe how friction with the air reduces the energy of the space probe.

(2)

(ii) Suggest why the rate of loss of energy of the space probe depends on the density of the air and also the speed of the space probe.

(2)

(iii) State what will happen to the height of the space probe above the Earth's surface and to its speed as air resistance gradually reduces the total energy of the space probe.

(2)

(Total 18 marks)

Topic 9 – Mark Scheme

1. A
2. B
3. D
4. C
5. B
6. A
7. C
8. B
9. A
10. B
11. A

12. (a) *horizontally* : zero;
vertically: 9.8(1)ms^{-2} (downwards); 2

N. B. *Part (b) and part (c) to be marked independently of part (a).*

*Deduct **[1]** if answer uses g = 10 ms^{-2}, but only once in **either** part (a) **or** part (b) but not both.*

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

$33 = \frac{1}{2} \times 9.8 \times t^2$;

$t = 2.6$s; 2

(c) $s = ut$

$= 18 \times 2.6 = 47$ (46.8) m; 1

[5]

13. (a) $v_V = 8.0 \sin 60 = 6.9$ m s^{-1};

$h = \dfrac{v^2}{2g}$;

to give $h = 2.4$ m ; 3

*Award **[1]** if $v = 8.0$ m s^{-1} to get $h = 3.2$ m is used.*

(b) $v_H = 8.0 \cos 60$;

range $= v_H t = 8.0 \cos 60 \times 3 = 12$ m; 2

*Award **[1]** if $v = 8.0$ m s^{-1} to get $R = 2.4$ m is used.*

[5]

14. (a) (i) work done per unit mass;
in moving (small mass) from infinity to that point; 2

(ii) gravitational forces are always attractive;
work got out when moving from infinity;
work done against field is negative; 2

(b) (i) $\frac{M_{\mathrm{E}}}{M_{\mathrm{M}}}=81.4$; (*ratio idea is essential*)

$$\frac{\left(3.46\times10^{8}\right)^{2}}{\left(3.84\times10^{8}-3.46\times10^{8}\right)^{2}}=82.9;$$

some comment *eg* $\frac{M}{R^2}$ should be same so QED;

or:

$$F_{\mathrm{Earth}}=\frac{\left(G\times5.98\times10^{24}\right)}{\left(3.46\times10^{8}\right)^{2}}=5.00\times10^{7}\,G;$$ *(ratio idea is essential)*

$$F_{\mathrm{Moon}}=\frac{\left(G\times7.35\times10^{22}\right)}{\left(0.38\times10^{8}\right)^{2}}=5.09\times10^{7}\,G;$$

some comment *eg* about same so QED;

or:

$$\frac{GM_{\mathrm{E}}}{r^{2}}=\frac{GM_{\mathrm{M}}}{\left(3.84\times10^{8}-r\right)^{2}};$$ *(ratio idea is essential)*

$$81.4=\frac{r^{2}}{\left(3.84\times10^{8}-r\right)^{2}};$$

$r = 3.45\times10^{8}$ m; 3

(ii) indicates in some way that ΔGPE is change in kinetic energy;

gravitational potential = $\frac{1}{2}v^{2}$;

$v = 1.6\times10^{3}\ \mathrm{ms}^{-1}$; 3

Award ***[2 max]*** *if the answers use m = 1kg.*

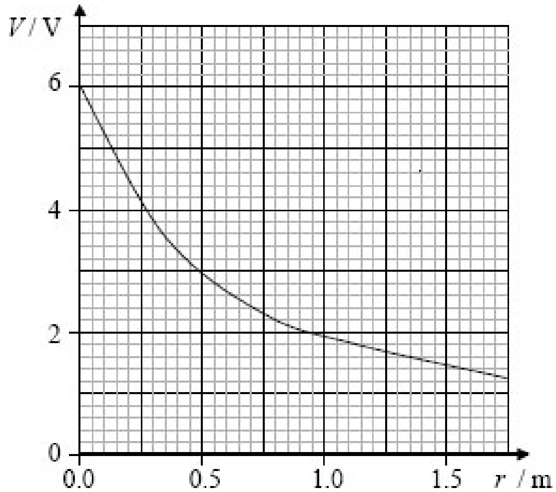
[10]

15. Fields and potential

(a) energy / work per unit charge;
in bringing a small <u>positive</u> test charge / <u>positive</u> point charge from infinity / <u>positive</u> test charge; 2
Award ***[0]*** *for quoting formula without definition of symbols.*

(b) (i) any roughly drawn circle drawn concentric to the sphere; 1
Ignore any shape inside the sphere. Award ***[0]*** *if other lines also shown.*

(ii) curve starting from 6.0V;
curves downwards;
asymptotically to zero potential at infinity;
going through the point (0.5m, 3.0V); 4



(iii) idea that $E = (-)$ potential gradient seen / implied;
so draw tangent at $r = 0$ and find gradient; 2

(c) at least four radial lines evenly spaced around the sphere;
with arrows away from centre; 2
*Award **[1 max]** if any line inside sphere.*

(d) use of $F = \frac{GMm}{R^2}$ and $g = \frac{F}{m}$;
working to get $g = \frac{GM}{R^2}$;
m and R defined / identified / implied; 3
Ignore inclusion, or not, of negative (minus) signs.
*Award **[0]** for a bald answer* $g = \frac{GM}{R^2}$.

(e) rearrangement to get $M = \frac{gR^2}{G}$;
substitution to give $M = \frac{9.8 \times (6.40 \times 10^6)^2}{6.67 \times 10^{-11}} = 6.0 \times 10^{24}$ kg; 2

(f) at least four radial lines evenly spaced around the Earth;
with arrows in towards the centre; 2
Ignore any line inside sphere.

(g) each sensible and relevant comment;
eg astronaut has a resultant force towards the Earth;
which provides centripetal force to stay in orbit / acceleration of astronaut and satellite are identical / both in free fall together;
hence no contact force between the two *ie* apparently weightless / *OWTTE*; 3

(h) each sensible and relevant comment;
eg both vary inversely proportional to distance;
gravitational potential increases with distance whereas in this setup, electric potential decreases with distance / *OWTTE*;
in both, the field is (negative) potential gradient; 2
Reject answers that do not mention potential.

[23]

16. (a) (i) speed of object at Earth's surface;
so that it will escape from the gravitational field / travel to infinity; 2

(ii) gravitational potential energy at Earth's surface = $(-)\dfrac{GMm}{R_e}$;
this must be provided for probe to escape;
energy is less than this <u>hence</u> not escape; 3

(b) (i) change = $GMm\left(\dfrac{1}{R_e}-\dfrac{1}{R}\right)$; 1

Accept $GMm\left(\dfrac{1}{R}-\dfrac{1}{R_e}\right)$.

(ii) in orbit, $\dfrac{mv^2}{r}=\dfrac{GMm}{r^2}$;

$\frac{1}{2}mv^2=\dfrac{GMm}{2R}$; 2

(c) idea of equating energies;

$$\frac{3GMm}{4R_e}=\frac{GMm}{2R}+\frac{GMm}{R_e}-\frac{GMm}{R}$$

$$\frac{1}{4R_e}=\frac{1}{2R}$$

$R = 2R_e$;
height above surface = R_e; 4 max

(d) (i) probe collides with air molecules;
giving them kinetic energy and so losing energy itself; 2
Accept answers in terms of frictional forces.

(ii) greater density, more molecules of air with which to collide;
higher speed, higher rebound speed for air molecules; 2
Accept answers in terms of magnitude of frictional force.

(iii) height becomes less;
and speed increases; 2

[18]

Topic 10 – Thermodynamics

1. The specific latent heat of vaporization of a substance is greater than its specific latent heat of fusion because
A. boiling takes place at a higher temperature than melting.
B. thermal energy is required to raise the temperature from the melting point to the boiling point.
C. the volume of the substance decreases on freezing but increases when boiling.
D. the increase in potential energy of the molecules is greater on boiling than on melting.

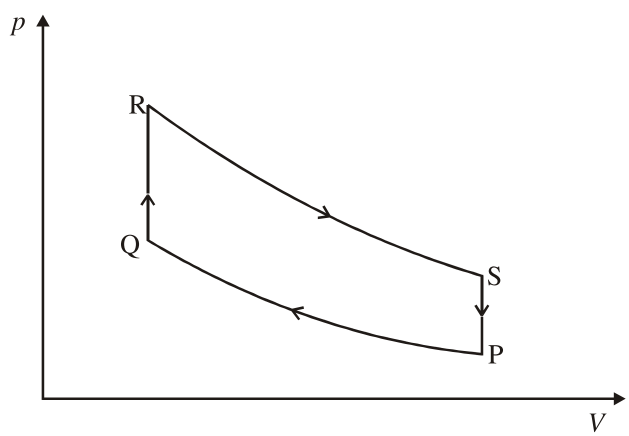
2. A substance changes from solid to liquid at its normal melting temperature. What change, if any, occurs in the average kinetic energy and the average potential energy of its molecules?

	Average kinetic energy	Average potential energy
A.	constant	constant
B.	increases	constant
C.	increases	decreases
D.	constant	increases

3. Which of the following is the internal energy of a system?
A. The total thermal energy gained by the system during melting and boiling.
B. The sum of the potential and the kinetic energies of the particles of the system.
C. The total external work done on the system during melting and boiling.
D. The change in the potential energy of the system that occurs during melting and boiling.

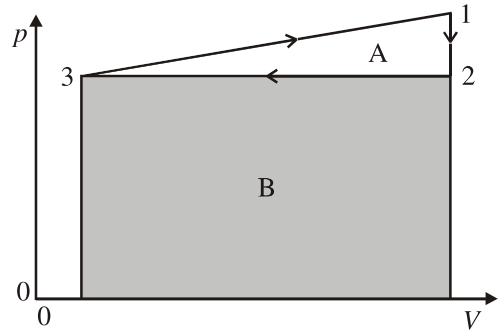
4. When a gas in a thermally insulated cylinder is suddenly compressed, the change of state is
A. adiabatic.
B. isothermal.
C. isobaric.
D. isochoric.

5. The graph below shows the variation with volume V of the pressure p of a gas during one cycle of an engine.



During which operations, PQ, QR, RS and SP does the gas do external work?
A. PQ only
B. RS only
C. QR and RS only
D. PQ and RS only

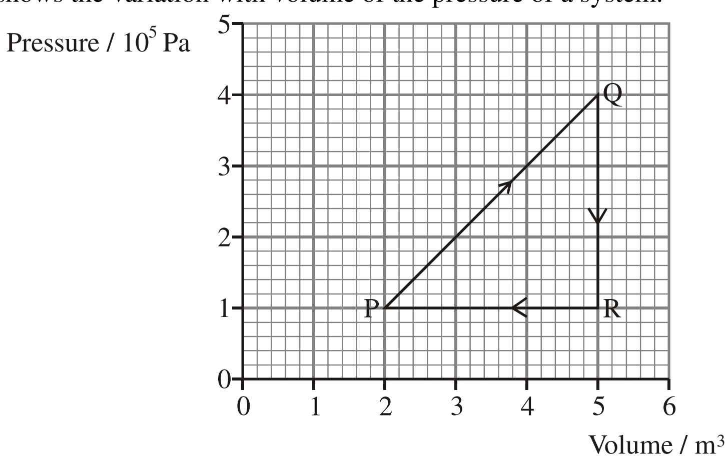
6. The diagram shows the variation with volume V of pressure p during one complete cycle of a heat engine.



The work done is represented by the area

A. A.
B. B.
C. (B + A).
D. (B – A).

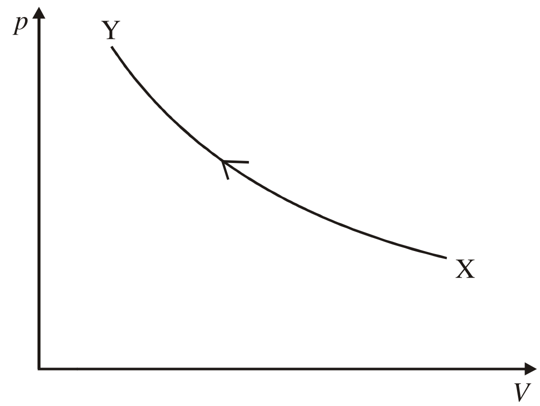
7. The graph below shows the variation with volume of the pressure of a system.



The work done in compressing the gas from R to P is

A. 5.0×10^5 J.
B. 4.5×10^5 J.
C. 3.0×10^5 J.
D. 0.

8. A sample of an ideal gas is held in an insulated container and it undergoes an adiabatic change. The graph below shows the change in pressure p with change in volume V as the gas changes from X to Y.



Which of the following describes correctly the work done and the change in the internal energy of the gas?

	Work done	Internal energy
A.	on the gas	increases
B.	on the gas	decreases
C.	by the gas	decreases
D.	by the gas	increases

9. Which **one** of the following is a correct statement of the second law of thermodynamics?

A. When the state of a system changes its entropy increases.
B. When the state of a system changes its entropy decreases.
C. The total entropy of the universe is increasing with time.
D. The total entropy of the universe is decreasing with time.

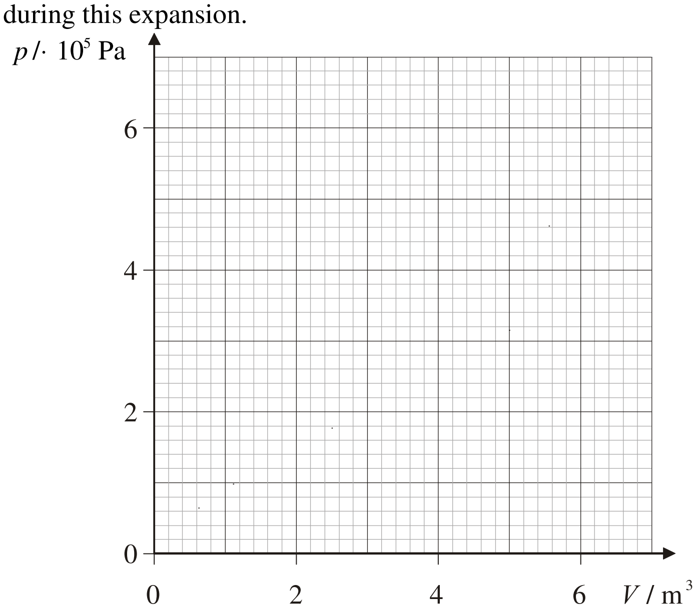
10. Expansion of a gas

An ideal gas at an initial pressure of 4.0×10^5 Pa is expanded isothermally from a volume of 3.0 m^3 to a volume of 5.0 m^3.

(a) Calculate the final pressure of the gas.

(1)

(b) On the axes below draw a sketch graph to show the variation with volume V of the pressure p during this expansion.



(3)

(c) Use the sketch graph in (b) to

(i) estimate the work done by the gas during this process;

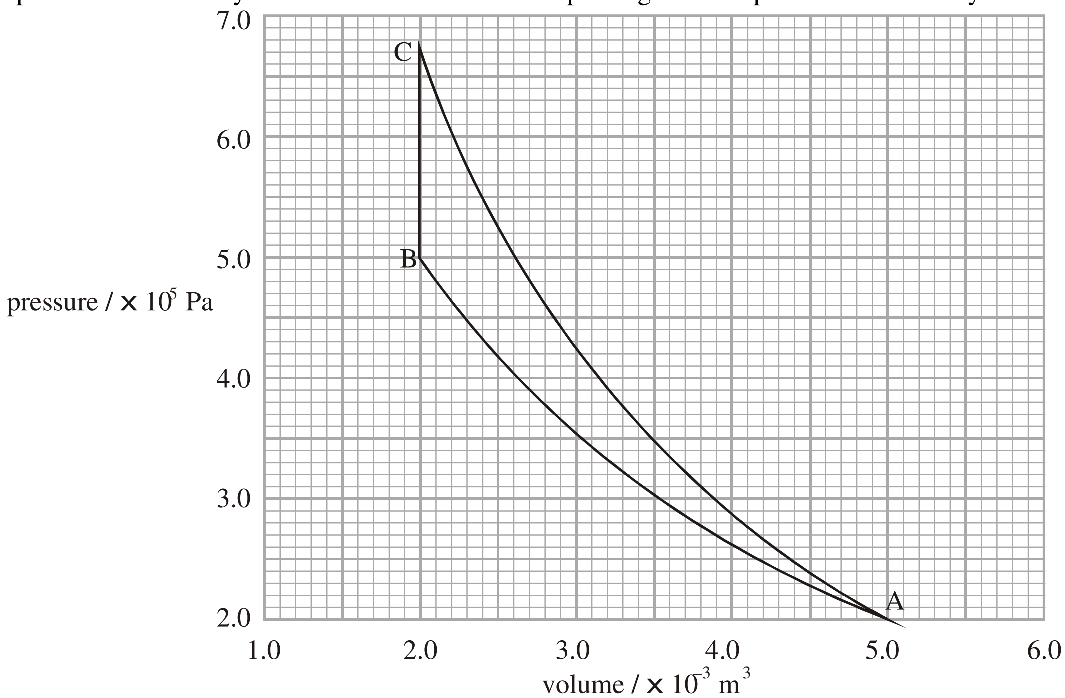
(2)

(ii) explain why less work would be done if the gas were to expand adiabatically from the same initial state to the same final volume.

(1)

(Total 7 marks)

11. This question is about *p–V* diagrams.
The graph below shows the variation with volume of the pressure of a fixed mass of gas when it is compressed adiabatically and also when the same sample of gas is compressed isothermally.



(a) State and explain which line AB or AC represents the isothermal compression.

(2)

(b) On the graph, shade the area that represents the difference in work done in the adiabatic change and in the isothermal change.

(1)

(c) Determine the difference in work done, as identified in (b).

(3)

(d) Use the first law of thermodynamics to explain the change in temperature during the adiabatic compression.

(3)
(Total 9 marks)

12. This question is about entropy changes.

(a) State what is meant by an *increase in entropy* of a system.

(1)

(b) State, in terms of entropy, the second law of thermodynamics.

(2)

(c) When a chicken develops inside an egg, the entropy of the egg and its contents decreases. Explain how this observation is consistent with the second law of thermodynamics.

(2)
(Total 5 marks)

13. This question is about estimating the area of solar panels and the diameter of a wind turbine.
It is suggested that a combination of solar power and wind power be used to provide the hot water system in a house.
An active solar heater is to provide the energy to heat the water. A wind turbine is to provide the energy to pump the water.

Solar heater

The following data are available:

volume of hot water tank	$= 1.2\ \text{m}^3$
density of water	$= 1.0 \times 10^3\ \text{kg m}^{-3}$
initial temperature of the water	= 10°C
final temperature of the water	= 40°C
specific heat capacity of water	$= 4.2 \times 10^3\ \text{J kg}^{-1}\text{K}^{-1}$
average power per unit area from the Sun	$= 0.80\ \text{kW m}^{-2}$
time required to heat the water	= 2.0 hours

(a) Using the above data,

(i) deduce that 1.5×10^8 J of energy is required to heat the volume of water in the tank from 10°C to 40°C.

(2)

(ii) estimate the minimum area of the solar panel needed to provide 1.5×10^8 J of energy in 2.0 hours.

(2)

(iii) discuss whether, in this situation, using a solar panel to heat the water is a sensible method.

(2)

Wind turbine

The following data are available:

power of solar heater pump	= 0.4 kW
average local wind speed	= 6.0 m s^{-1}
average density of air	= 1.0 kg m^{-3}

(b) (i) Using the above data, estimate the minimum radius of the wind turbine needed to provide the power required to drive the solar heater pump.

(3)

(ii) Discuss whether, in this situation, using a wind turbine to pump the water is a sensible method.

(1)
(Total 10 marks)

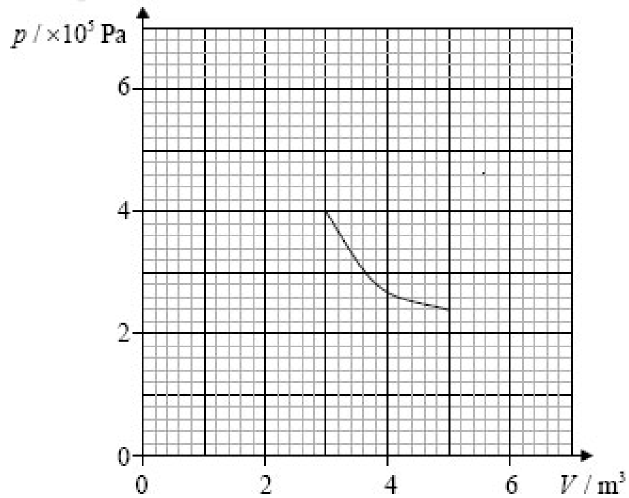
Topic 10 – Mark Scheme

1. D
2. D
3. B
4. A
5. B
6. A
7. C
8. A
9. C

10. Expansion of a gas

(a) 2.4×10^5 Pa; 1

(b) any line through (3.0, 4.0) and (5.0, 2.4);
that is a smooth curve in correct direction;
that starts and ends on the above points;



3

(c) (i) work done = area under line / curve / graph;
to get 6.1×10^5 J; 2
Accept $5.5 \rightarrow 6.7 \times 10^5$ *J.*

(ii) work done would be less as adiabatic line is steeper than isothermal line / *OWTTE*;
or:
no energy / heat has to be transferred to the surroundings to maintain constant temperature / *OWTTE*; 1

[7]

11. (a) pV constant for isothermal / adiabatic always steeper;
hence AB; 2

(b) area between lines AB and AC shaded; 1

(c) area is 150 (±15) small squares;
(allow ecf from (b))
work done = $1.5 \times 1 \times 10^{-3} \times 1 \times 10^5$;
= 150 J; 3

*For any reasonable approximate area outside the range 150 (±15) squares award **[2 max]** for the calculation of energy from the area.*

(d) no thermal energy enters or leaves / $\Delta Q = 0$;
so work done seen as increase in internal energy;
hence temperature rises; 3

*Award **[0]** for a mere quote of the 1st law.*

[9]

12. (a) increase in the degree of disorder (in the system); 1
(b) total entropy (of the universe); is increasing; 2
(c) entropy of surroundings increases by a greater factor;
because process gives off thermal energy / other appropriate statement; 2

[5]

13. (a) (i) mass of water = 1.2×10^3 kg;
energy required = $1.2 \times 10^3 \times 4.2 \times 10^3 \times 30 = 1.5 \times 10^8$ J; 2 max

(ii) energy provided in 2 hours = $7\,200 \times 800 \times A$;
therefore, $A = \dfrac{(1.5\times10^8)}{7200\times800)} \approx 26\ \text{m}^2$; 2 max

(iii) this is a large area;
appropriate relevant detail *eg* a lot of space needed; 2 max

Look for a plausible argument for or against eg if the space is available then could be a viable proposition. Or the response may argue that in reality a greater area than this will be needed.

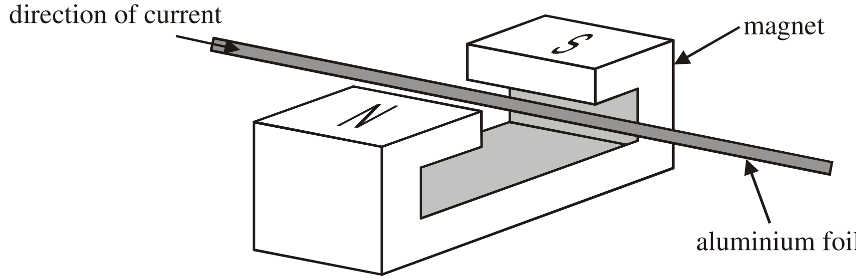
(b) (i) power $P = \frac{1}{2}\rho A v^3 = \frac{1}{2}\rho \pi r^2 v^3$ where r is the blade radius;
therefore, $r = \sqrt{\dfrac{2P}{\pi\rho v^3}}$;
$= \sqrt{\dfrac{800}{3.14\times6^3}} = 1.1$ m; 3 max

(ii) *Look for any sensible reason in support or against.* 1 max

[10]

Topic 12 – Electromagnetic Induction

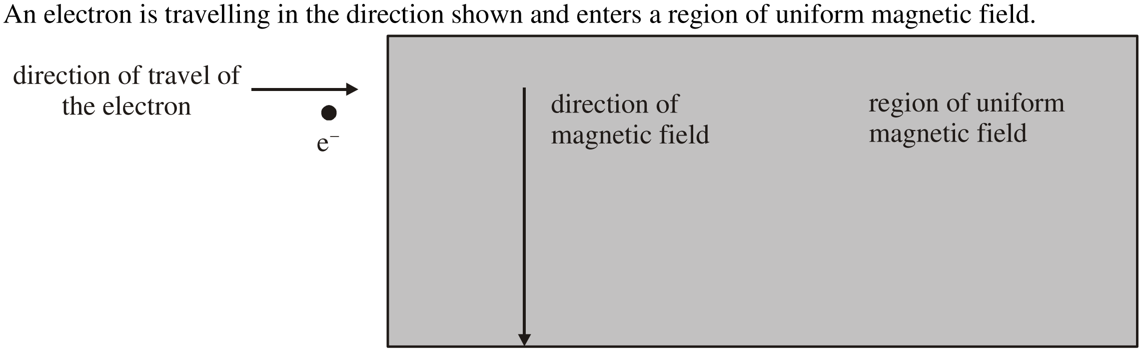
1. A strip of aluminium foil is held between the poles of a strong magnet, as shown below.



When a current is passed through the aluminium foil in the direction shown, the foil is deflected. In which direction is this deflection?

A. Vertically downwards
B. Vertically upwards
C. Towards the North pole of the magnet
D. Towards the South pole of the magnet

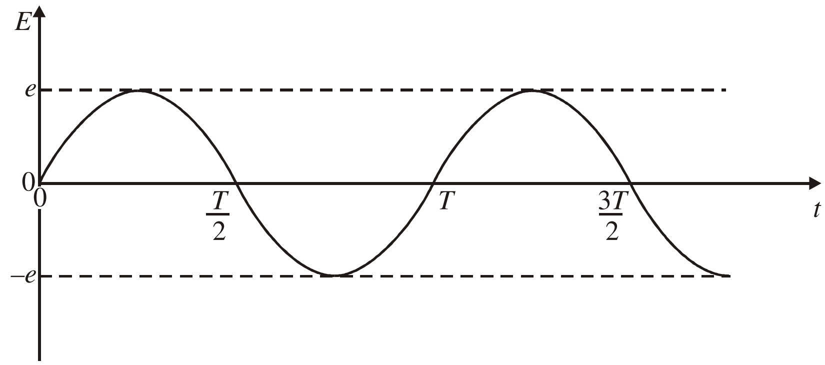
2. An electron is travelling in the direction shown and enters a region of uniform magnetic field.



On entering the field the direction of the force acting on the electron is

A. into the plane of the paper.
B. out of the plane of the paper.
C. towards the top of the page.
D. towards the bottom of the page.

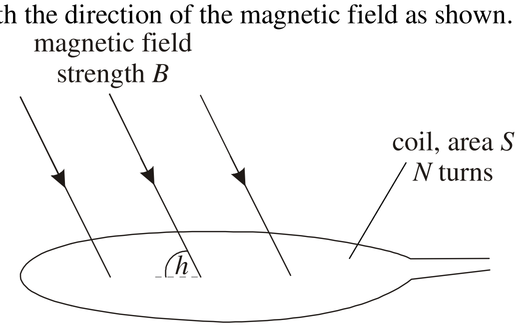
3. The diagram below shows the variation with time t of the emf E generated in a coil rotating in a uniform magnetic field.



What is the root-mean-square value E_{rms} of the emf and also the frequency f of rotation of the coil?

	E_{rms}	f
A.	e	$\frac{2}{T}$
B.	e	$\frac{1}{T}$
C.	$\frac{e}{\sqrt{2}}$	$\frac{2}{T}$
D.	$\frac{e}{\sqrt{2}}$	$\frac{1}{T}$

4. A coil of area S has N turns of wire. It is placed in a uniform magnetic field of strength B so that its plane makes an angle θ with the direction of the magnetic field as shown.

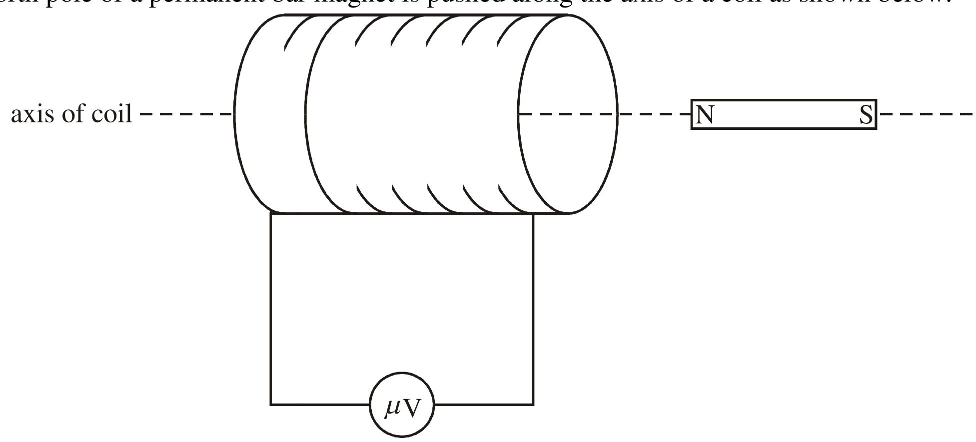


The magnetic flux linkage is

A. $BSN \sin \theta$.
B. $BSN \cos \theta$.
C. $BSN \tan \theta$.
D. BSN.

5. The rms voltages across the primary and secondary coils in an ideal transformer are V_p and V_s respectively. The currents in the primary and secondary coils are I_p and I_s respectively.
Which **one** of the following statements is always true?
A. $V_s = V_p$
B. $I_s = I_p$
C. $V_s I_s = V_p I_p$
D. $\frac{V_s}{V_p} = \frac{I_s}{I_p}$.

6. The north pole of a permanent bar magnet is pushed along the axis of a coil as shown below.

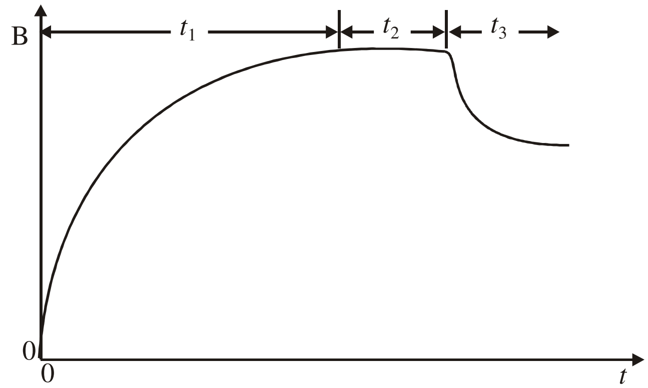


The pointer of the sensitive voltmeter connected to the coil moves to the right and gives a maximum reading of 8 units. The experiment is repeated but on this occasion, the south pole of the magnet enters the coil at twice the previous speed.

Which of the following gives the maximum deflection of the pointer of the voltmeter?
A. 8 units to the right
B. 8 units to the left
C. 16 units to the right
D. 16 units to the left

7. A resistor is connected in series with an alternating current supply of negligible internal resistance. The **peak value** of the supply voltage is V_o and the **peak value** of the current in the resistor is I_0. The **average power** dissipation in the resistor is
A. $\frac{V_0 I_0}{2}$
B. $\frac{V_0 I_0}{\sqrt{2}}$
C. $V_0 I_0$.
D. $2\,V_0 I_0$.

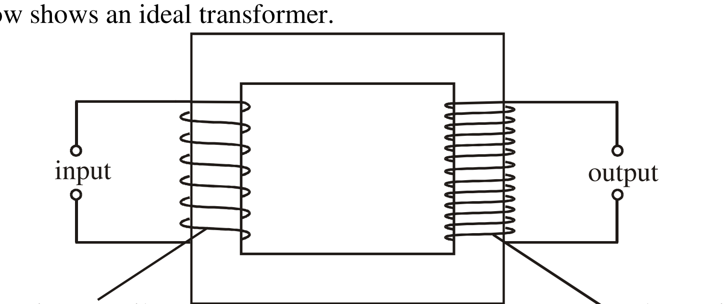
8. A magnetic field links a closed loop of metal wire. The magnetic field strength *B* varies with time *t* as shown.



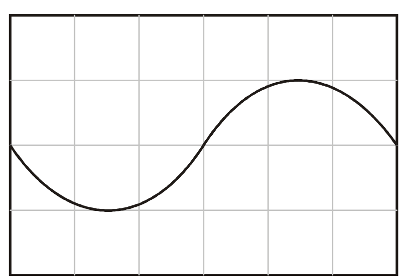
A current is induced in the loop during the time period

A. t_1 only.
B. t_2 only.
C. t_2 and t_3 only.
D. t_1 and t_3 only.

9. The diagram below shows an ideal transformer.

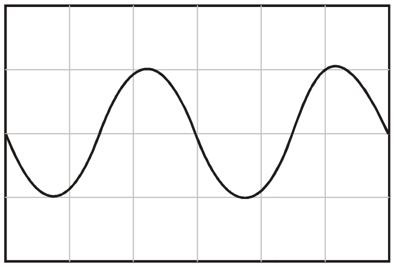


The transformer has *n* turns on the primary coil and 2*n* turns on the secondary coil. The waveform produced on the screen of a cathode-ray oscilloscope (cro), when the cro is connected to the primary coil, is shown below.

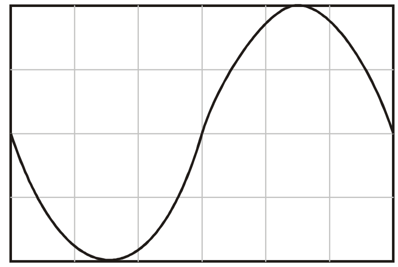


Which of the following diagrams shows the waveform displayed on the cro when it is connected to the secondary coil? The settings of the cro remain unchanged.

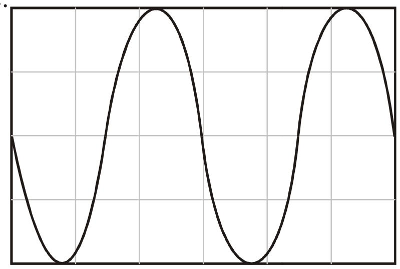
A.



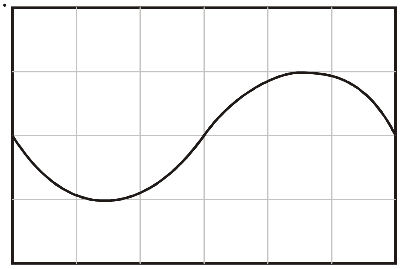
B.



C.



D.



10. A thin copper ring encloses an area S. The area is linked by magnetic flux that is increasing. The rate of change of the magnetic flux from time $t = 0$ to time $t = T$ is R.
The emf induced in the copper ring during the time $t = 0$ to time $t = T$ is

A. R.
B. RS.
C. RST.
D. $\frac{RS}{T}$.

11. The maximum value of a sinusoidal alternating current in a resistor of resistance R is I_0. The maximum current is increased to $2I_0$.
Assuming that the resistance of the resistor remains constant, the **average** power dissipated in the resistor is now

A. $\frac{1}{2}I_0^2R$.
B. I_0^2R.
C. $2I_0^2R$.
D. $4I_0^2R$.

12. This question is about electromagnetic induction.
In 1831 Michael Faraday demonstrated three ways of inducing an electric current in a ring of copper. One way is to move a bar magnet through the stationary copper ring.

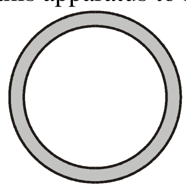
(a) Describe briefly a way that a current may be induced in the copper ring using a **stationary** bar magnet.

....
....

(1)

You are given the following apparatus: copper ring, battery, variable resistor, lengths of insulated copper wire with connecting terminals at each end.

(b) Describe how you would use all of this apparatus to induce a current in the copper ring.



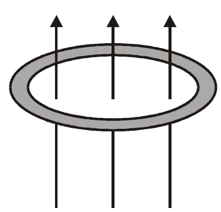
copper ring

....
....
....
....

(4)

In the diagram below, a magnetic field links a circular copper ring. The field is uniform over the area of the ring and its strength is increasing in magnitude at a steady rate.

magnetic field



(c) (i) State Faraday's law of electromagnetic induction as it applies to this situation.

....
....
....

(2)

(ii) Draw on the diagram, an arrow to show the direction of the induced current in the copper ring. Explain how you determined the direction of the induced current.

....
....
....
....

(3)

(iii) The radius of the copper ring is 0.12 m and its resistance is 1.5×10^{-2} Ω. The field strength is increasing at rate of 1.8×10^{-3} T s^{-1}. Calculate the value of the induced current in the copper ring.

....
....
....
....
....

(3)
(Total 13 marks)

13. This question is about the possibility of generating electrical power using a satellite orbiting the Earth.

(a) Define *gravitational field strength*.

....
....
....

(2)

(b) Use the definition of gravitational field strength to deduce that

$$GM = g_0 R^2$$

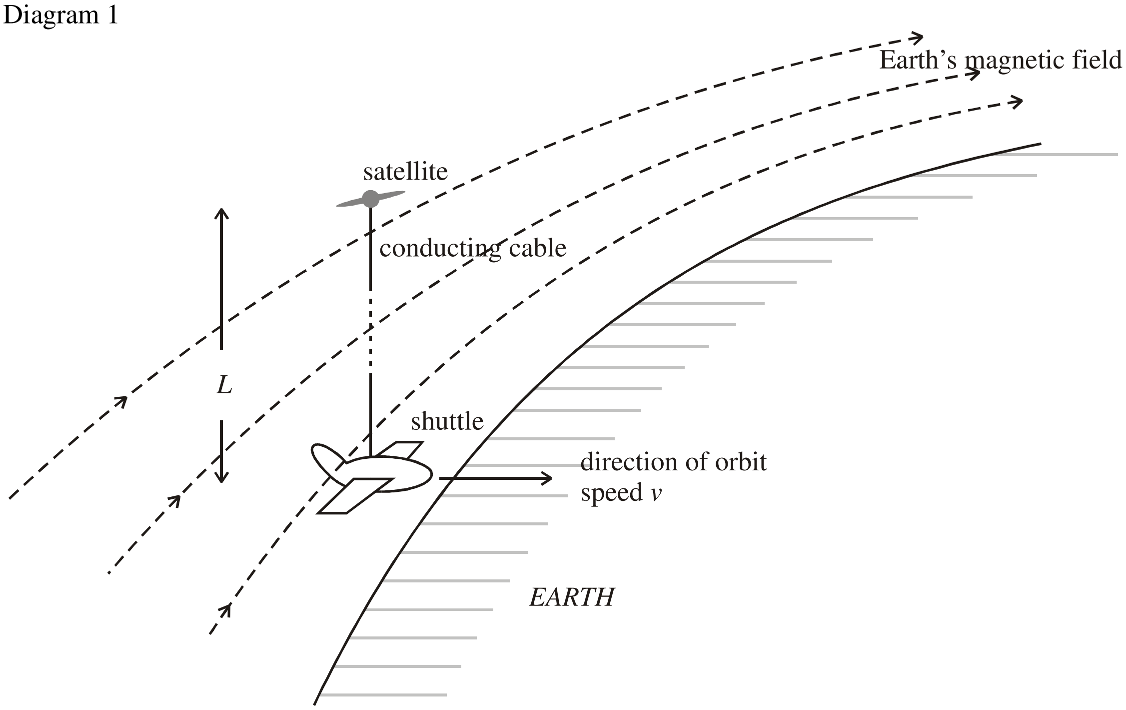
where M is the mass of the Earth, R its radius and g_0 is the gravitational field strength at the surface of the Earth. (You may assume that the Earth is a uniform sphere with its mass concentrated at its centre.)

....
....
....
....

(2)

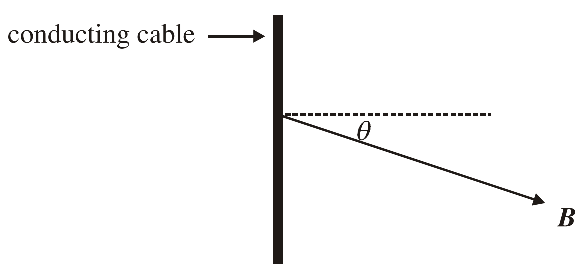
A space shuttle orbits the Earth and a small satellite is launched from the shuttle. The satellite carries a conducting cable connecting the satellite to the shuttle. When the satellite is a distance L from the shuttle, the cable is held straight by motors on the satellite.

Diagram 1



As the shuttle orbits the Earth with speed v, the conducting cable is moving at right angles to the Earth's magnetic field. The magnetic field vector $\boldsymbol{B}$ makes an angle θ to a line perpendicular to the conducting cable as shown in diagram 2. The velocity vector of the shuttle is directed out of the plane of the paper.

Diagram 2



(c) On diagram 2, draw an arrow to show the direction of the magnetic force on an electron in the conducting cable. Label the arrow F.

(1)

(d) State an expression for the force F on the electron in terms of B, v, e and θ, where B is the magnitude of the magnetic field strength and e is the electron charge.

....

(1)

(e) Hence deduce an expression for the emf E induced in the conducting wire.

....

....

....

....

....

(3)

(f) The shuttle is in an orbit that is 300 km above the surface of the Earth. Using the expression

$$GM = g_0 R^2$$

and given that $R = 6.4 \times 10^6$ m and $g_0 = 10$ N kg^{-1}, deduce that the orbital speed v of the satellite is 7.8×10^3 m s^{-1}.

....

....

....

....

....

....

....

(3)

(g) The magnitude of the magnetic field strength is 6.3×10^{-6} T and the angle $\theta = 20°$. Estimate the length L of the cable required in order to generate an emf of 1 kV.

....

....

....

(2)
(Total 14 marks)

Topic 12 – Mark Scheme

1. B
2. B
3. D
4. A
5. C
6. D
7. A
8. D
9. B
10. A
11. C

12. (a) move the ring over the end of the magnet / *OWTTE*; 1
ie magnet stationary, ring moved.

(b)

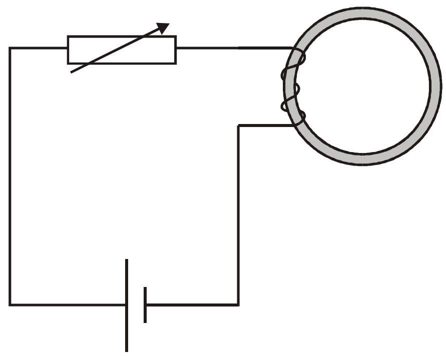
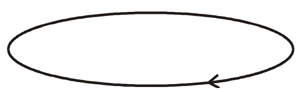


diagram showing wire wrapped around part of the ring;
and appropriate connections to battery and variable resistor;
as the current is changed by altering the value of the resistance;
a current is induced in the ring; 4

Mark diagram and description together – look for any sensible description of the production of transformer induced currents.

(c) (i) the emf induced in the ring;
is equal / proportional to the rate of change of magnetic flux linking the ring; 2

(ii)



clockwise;
Lenz's law: induced current is such as to oppose the change / *OWTTE*;
current in this direction induces a field in the opposite direction to the changing field / *OWTTE*; 3

(iii) area = $3.14 \times (1.2)^2 \times 10^{-2} = 4.5 \times 10^{-2}\ \text{m}^2$;
rate of flux change = $4.5 \times 10^{-2}\ \text{m}^2 \times 1.8 \times 10^{-3}$ = emf = 8.1×10^{-5} V;
current = $\dfrac{(8.1\times10^{-5})}{1.5\times10^{-2}}$ = 5.4 mA; 3

[13]

13. (a) force exerted per unit mass;
on a small / point mass; 2

(b) from the law of gravitation, the field strength $\dfrac{F}{m} = G\dfrac{M}{R^2}$;

$= g_0$ to give $GM = g_0R^2$; 2

***NB** To achieve full marks, candidates need to state that* $\dfrac{F}{m} = g_0$.

(c) downwards; (*accept 90° to B field or down the wire*) 1

(d) $F = Bev\cos\theta$; 1

(e) work done in moving an electron the length of the wire is
$W = FL = BevL\cos\theta$;
emf = work done per unit charge;
therefore, $E = BLv\cos\theta$;
or
electric field = $\dfrac{F}{e} = Bv\cos\theta$;
emf E = electric field × L;
to give $E = BLv\cos\theta$; 3
*Award **[2 max]** if flux linkage argument is used.*

(f) $F = G\dfrac{Mm}{r^2} = \dfrac{mv^2}{r}$;
such that $v^2 = \dfrac{GM}{r} = \dfrac{g_0 R^2}{r}$;
$v^2 = \dfrac{10\times(6.4)^2\times10^{12}}{6.7\times10^6}$ to give $v = 7.8\times10^3\ \mathrm{m\ s^{-1}}$; 3

(g) $L = \dfrac{E}{Bv\cos\theta}$;
$= \dfrac{10^3}{6.3\times10^{-6}\times7.8\times10^3\times0.93} = 2.2\times10^4$ m; 2

[14]

Option H - Relativity

1. This question is about evidence to support the Special Theory of Relativity and relativistic mass increase.

The following is an extract from an article on Relativity.

> *"…The **proper length** of an object and the **proper time** interval between events can never be measured directly by the same **inertial observer**."*

(a) Define the following terms.

(i) *Proper length*

(1)

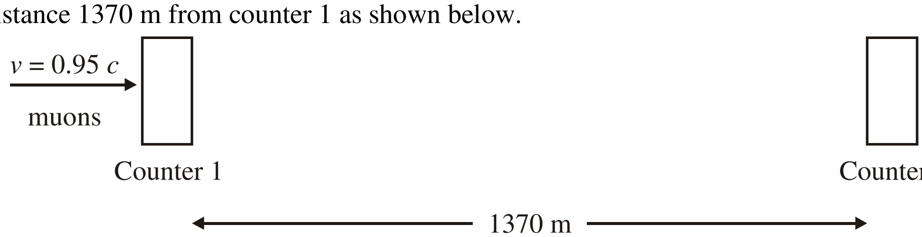
(ii) *Proper time*

(1)

(iii) *Inertial observer*

(1)

An experiment is set-up in which muons are accelerated to a speed of 0.95 c, as measured by a laboratory observer. They are counted by the particle counter 1 and the muons that do not decay are counted by counter 2, a distance 1370 m from counter 1 as shown below.



N muons pass through counter 1 in a given time and $\frac{N}{2}$ pass through counter 2 in the same given time.

(b) Determine

(i) the half-life of the muons as measured by a laboratory observer.

(2)

(ii) the half-life of the muons as measured in the reference frame in which the muons are at rest.

(2)

(iii) the separation of the counters as determined in the reference frame in which the muons are at rest.

(1)

(c) Use your answers in (b) to explain what is meant by the terms *time dilation* and *length contraction*.

(4)
(Total 12 marks)

2. The total energy of a particle is always given by $E = mc^2$. Calculate the speed at which a particle is travelling if its total energy is equal to three times its rest mass energy.

(Total 3 marks)

3. This question is about the postulates of relativity.

(a) State the **two** postulates of special relativity.

(2)

(b) State and explain which postulate can be predicted from Maxwell's electromagnetic theory of light.

(2)

(c) Outline **one** piece of experimental evidence that supports the special theory of relativity.

(3)
(Total 7 marks)

4. This question is about Special Relativity.

(a) Explain what is meant by an *inertial frame of reference*.

(1)

(b) State the **two** postulates of the Special Theory of Relativity.

1.

2.

(2)

An observer in a frame of reference A measures the relativistic mass and the length of an object that is at rest in his frame of reference. He also measures the time interval between two events that take place at one point in his reference frame. The relativistic mass and length of the object, and time interval between the two events, are also measured by a second observer in reference frame B that is moving at constant velocity relative to the observer in frame A.

(c) (i) By crossing out the inappropriate words in the table below, state whether the observer in frame B will measure the quantities as being larger, the same size or smaller than when measured by the observer in frame A.

Quantity	Measured by observer in frame B
mass	larger / the same / smaller
length	larger / the same / smaller
time interval	larger / the same / smaller

(3)

(ii) Use your answers in (c)(i) to suggest how the observer in frame B will consider the density of the object in frame A to be affected.

(3)
(Total 9 marks)

5. This question is about relativistic motion.

The radioactive decay of a nucleus of actinium-228 involves the release of a β-particle that has a **total energy** of 2.51 MeV as measured in the laboratory frame of reference. This total energy is significantly larger than the **rest mass energy** of a β-particle.

(a) Explain the difference between *total energy* and *rest mass energy*.

(2)

(b) Deduce that the Lorentz factor, as measured in the laboratory reference frame, for the β-particle in this decay is 4.91.

(3)

A detector is placed 37 cm from the actinium source, as measured in the laboratory reference frame.

(c) Calculate, for the laboratory reference frame,

(i) the speed of the β-particle.

(2)

(ii) the time taken for the β-particle to reach the detector.

(2)

The events described in (c) can be described in the β-particle's frame of reference.

(d) For this frame,

(i) identify the moving object.

(1)

(ii) state the speed of the moving object.

(1)

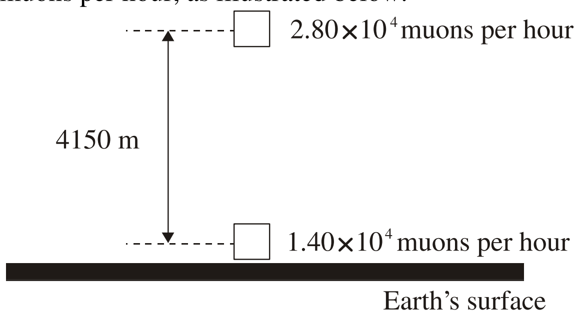
(iii) calculate the distance travelled by the moving object.

(2)
(Total 13 marks)

6. This question is about muon decay.

Muons, created in the upper atmosphere, travel towards the Earth's surface at a speed of 0.994 c relative to an observer at rest on the Earth's surface.

A muon detector at a height above the Earth's surface of 4150 m, as measured by the observer, detects 2.80×10^4 muons per hour. A similar detector on the Earth's surface detects 1.40×10^4 muons per hour, as illustrated below.



The half-life of muons as measured in a reference frame in which the muons are at rest is 1.52 μs.

(a) Calculate the half-life of the muons, as observed by the observer on the Earth's surface.

(2)

(b) Calculate, as measured in the reference frame in which the muons are at rest,

(i) the distance between the detectors;

(1)

(ii) the time it takes for the detectors to pass an undecayed muon.

(1)

(c) Use your answers to (a) and (b) to explain the concepts of

(i) time dilation;

(2)

(ii) length contraction.

(2)

(Total 8 marks)

7. Two electrons are travelling directly towards one another. Each has a speed of $0.80c$ relative to a stationary observer. Calculate the relative velocity of approach, as measured in the frame of reference of one of the electrons.

(Total 3 marks)

8. This question is about relativistic momentum and energy.
A proton is accelerated from rest through a potential difference of 2.0×10^9 V. Calculate the final momentum of the proton in units of MeV c^{-1}.

(Total 3 marks)

Option H Relativity – Mark Scheme

1. (a) (i) *proper length*
the length of an object as measured by an observer at rest with respect to the object / *OWTTE*; 1 max

(ii) *proper time*
the time interval between two events measured in the reference frame in which the two events occur at the same place; 1 max

(iii) *inertial observer*
an observer who is in a reference frame that is moving with constant velocity / in a reference frame in which Newton's 1st law is valid; 1 max

(b) (i) half-life = $\dfrac{1370}{0.95c}$;
$= 4.8 \times 10^{-6}$ s; 2 max

(ii) from $\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}}$, $\gamma = 3.2$;

$T = \dfrac{T_0}{\gamma} = 1.5 \times 10^{-6}$ s;

Alternatively, from length contraction = $\dfrac{1370}{3.2} = 430$ m;

half-life of muons = $\dfrac{430}{9.5c} = 1.5 \times 10^{-6}$ s; 2 max

(iii) $L = \dfrac{L_0}{\gamma} = 430$ m; 1 max

(c) *Mark the answers for* ***time dilation*** *and* ***length contraction*** *together such that a good answer for one can receive* ***[3 max]*** *with* ***[1 max]*** *for the other answer.*
Answers will be open-ended but look for these main points:
the muons regarding themselves at rest measure the proper time for half of them to decay;
to the laboratory observers, the muons will take a longer time to decay;
and this is the time that to them, it takes the muons to travel between the counters;
the laboratory observers measure the proper length since the counters are at rest in their reference frame;
to the muons it will seem that counter 2 is travelling towards them;
and in the time that it takes half of them to decay they will measure counter 2 as having travelled a contracted distance 430 m; 4 max

[12]

2. $E = \gamma mc^2 = 3mc^2$;

$\Rightarrow \gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}} = 3 \Rightarrow \dfrac{v^2}{c^2} = 1 - \dfrac{1}{9}$;

$\Rightarrow v = \dfrac{\sqrt{8}\,c}{3} = 0.94\,c$ ($= 2.8 \times 10^8$ m s^{-1}); 3 max

[3]

3. (a) speed of light <u>in a vacuum</u> is the same for all <u>inertial</u> observers;
laws of physics are the same for all <u>inertial</u> observers; 2
The words underlined are needed for the mark. Award ***[1 max]*** *if both are on the right lines but not precise. Give benefit of the doubt if inertial is only mentioned once.*

(b) constancy of the speed of light / *OWTTE*;
any sensible comment; 2
eg Maxwell's equations predicted a value for the speed of propagation of electromagnetic radiation from constants associated with the medium that was independent of the motion of the source or the observer.

(c) idea or name of appropriate experiment;
eg muon experiments
outline of evidence;
eg number of muons at a given height in the atmosphere in a given time compared with number arriving at the ground. Number at ground seems high given the lifetime of a muon.
link to a prediction; 3 max
eg numbers consistent with time dilation formula.

[7]

4. (a) frame of reference is at rest <u>or</u> moving at constant velocity / reference frame within which Newton's first law is valid; 1

(b) laws of physics are the same in all inertial frames of reference;
speed of light in a vacuum is the same in all inertial frames of reference; 2

(c) (i) larger;
smaller;

larger; 3

(ii) volume decreases and mass increases; *(do not award "heavier")*

$$\text{density} = \frac{\text{mass}}{\text{volume}};$$

density increases; *(award this mark only if the first mark is awarded)* 3

*Award **[0]** for stating "density increases" only.*

[9]

5. (a) rest mass energy is the energy that is needed to create the particle at rest / reference to $E_0 = m_0c^2$;

total energy is the addition of the rest energy and everything else (kinetic *etc*) / reference to mass being greater when in motion / $E = mc^2$; 2 max

(b) realization that betas are electrons;

so $m_e = 0.511$ MeV c^{-2};

$\gamma = \dfrac{2.51}{0.511}$; (= 4.91) 3

Ignore any spurious calculation from Lorentz factor equation here as the use of this equation is rewarded below.

(c) (i) correct substitution into Lorentz factor equation;

to give $v = 0.979c = 2.94 \times 10$ m s^{-1}; 2

(ii) correct substitution into speed = $\dfrac{\text{distance}}{\text{time}}$;

to give time = 1.26 ns; 2

(d) (i) the detector / the laboratory / *OWTTE*; 1

(ii) same answer as (c) (i) = 2.94×10^8 m s^{-1}; 1

(iii) realization that length contraction applies;

distance = $\dfrac{37}{\gamma}$ = 7.5 cm; 2

[13]

6. (a) $\gamma = 9.14$;

$T_{\frac{1}{2}} = 9.14 \times 1.52 = 13.9\,\mu s$; 2

(b) (i) distance = $\dfrac{4150}{9.14} = 454\,\text{m}$; 1

(ii) time = 1.52 μs; 1

(c) (i) observers in different frames of reference measure different times; (discusses times of 1.52μs and 13.9μs wrt frames of reference *eg*) observed time is shortest in rest frame; 2

(ii) observers in different frames of reference measure different lengths; (discusses distances of 4150 m and 454 m wrt frames of reference *eg*) observed distance is shortest in moving frame; 2

[8]

7. $u_x' = \frac{(u_x - v)}{\left(1 - \frac{u_x v}{c^2}\right)}$

identifies u_x as $0.8c$;
identifies v *as* $-0.8c$;
to give answer of $0.98c$;

[3]

8. $E = 2.0 \times 10^9$ eV + 938×10^6 eV = $2.9(38) \times 10^9$ eV;
substitution into $E^2 = p^2\ c^2 + m_0^{\ 2}\ c^4$;
to give $p^2c^2 = (2938\text{MeV})^2 - (938\text{MeV})^2$
$p = 2.8 \times 10^3$ MeVc^{-1};

[3]