

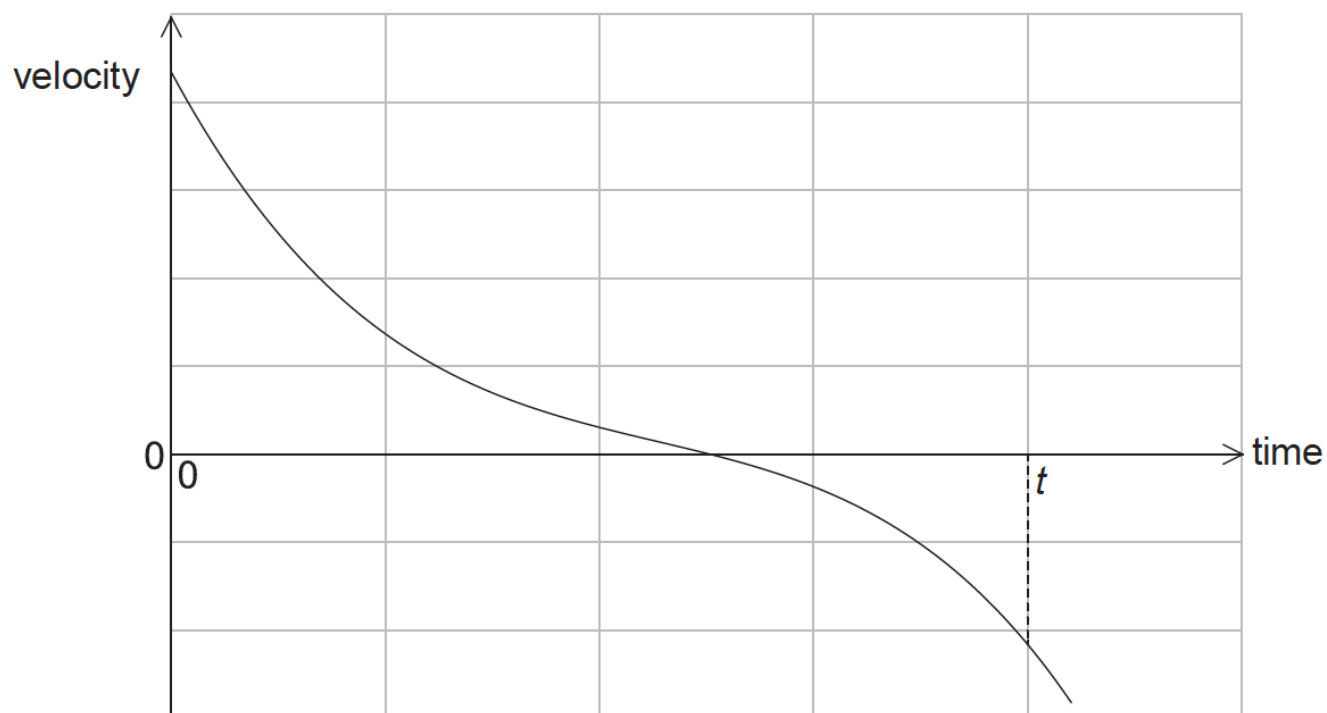
Mechanics motion SL 2 [218 marks]

1. A body moves in a straight line. In order for the equations for uniformly accelerated motion to be applied, which condition **must** be true? [1 mark]
- A. A constant net force acts on the body of fixed mass.
 - B. A constant net force acts on the body.
 - C. The body falls towards the surface of a planet.
 - D. The body has an initial velocity of zero.

Markscheme

A

2. The graph shows the variation with time of the velocity of a truck of fixed mass. [1 mark]



What can be deduced from the graph?

- A. The truck is always accelerating.
- B. The truck is always moving.
- C. The truck is always moving in one direction.
- D. The displacement of the truck after time t is zero.

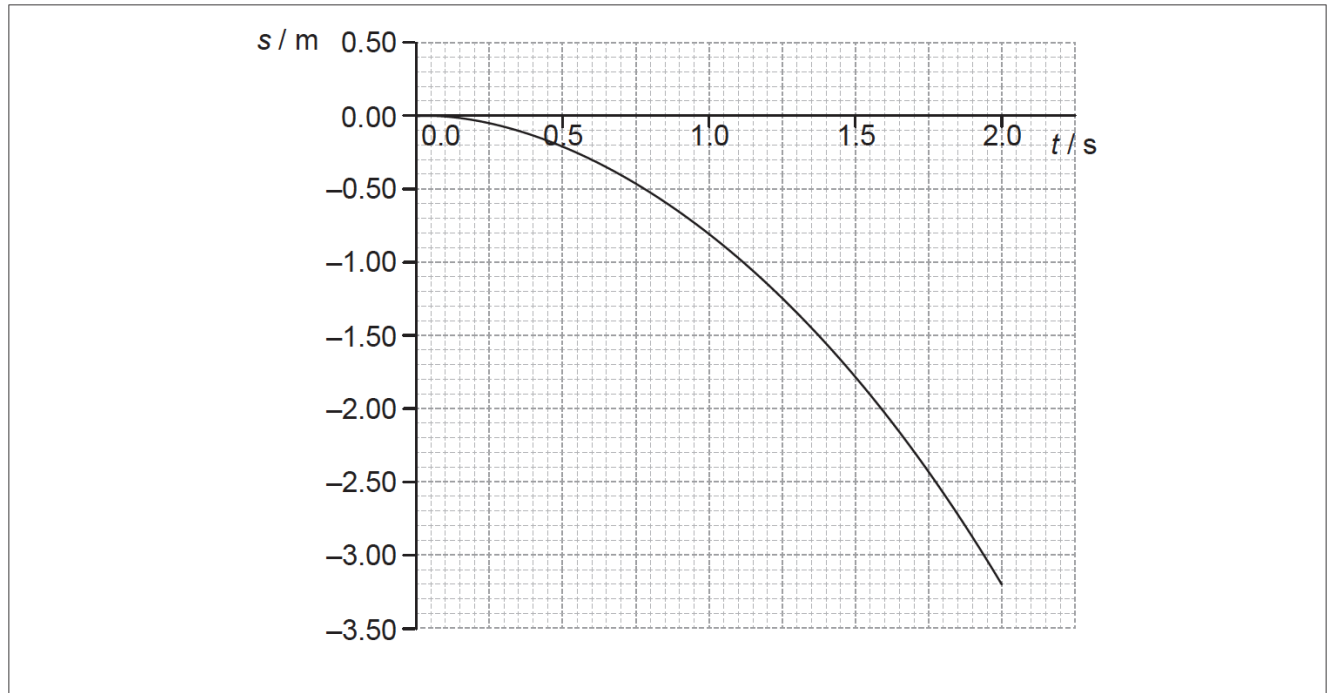
Markscheme

A

This question is in **two** parts. **Part 1** is about kinematics and gravitation. **Part 2** is about radioactivity.

Part 1 Kinematics and gravitation

A ball is released near the surface of the Moon at time $t=0$. The point of release is on a straight line between the centre of Earth and the centre of the Moon. The graph below shows the variation with time t of the displacement s of the ball from the point of release.



3a. State the significance of the negative values of s .

[1
mark]

Markscheme

upwards (or away from the Moon) is taken as positive / downwards (or towards the Moon) is taken as negative / towards the Earth is positive;

3b. Use the graph to

[6 marks]

(i) estimate the velocity of the ball at $t = 0.80$ s.

(ii) calculate a value for the acceleration of free fall close to the surface of the Moon.

Markscheme

(i) tangent drawn to curve at 0.80s;

correct calculation of gradient of tangent drawn;

$-1.3 \pm 0.1 \text{ m s}^{-1}$ or $1.3 \pm 0.1 \text{ m s}^{-1}$ downwards;

or

correct coordinates used from the graph; substitution into a correct equation;

$-1.3 \pm 0.1 \text{ m s}^{-1}$ or $1.3 \pm 0.1 \text{ m s}^{-1}$ downwards;

(ii) any correct method used;

correct reading from graph;

1.6 to 1.7 m s^{-2} ;

3c. The following data are available.

[4 marks]

Mass of the ball = 0.20 kg

Mean radius of the Moon = $1.74 \times 10^6 \text{ m}$

Mean orbital radius of the Moon about the centre of Earth = $3.84 \times 10^8 \text{ m}$

Mass of Earth = $5.97 \times 10^{24} \text{ kg}$

Show that Earth has no significant effect on the acceleration of the ball.

Markscheme

values for masses, distance and correct G substituted into Newton's law;

see subtraction (ie r value = $3.84 \times 10^8 - 1.74 \times 10^6 = 3.82 \times 10^8 \text{ m}$);

$F = 5.4 \text{ to } 5.5 \times 10^{-4} \text{ N}$ / $a = 2.7 \times 10^{-3} \text{ m s}^{-2}$;

comment that it's insignificant compared with ($0.2 \times 1.63 =$) 0.32 to 0.33 N / 1.63 m s^{-2} ;

3d. Calculate the speed of an identical ball when it falls 3.0 m from rest close to the surface of Earth. Ignore air resistance. [1 mark]

Markscheme

7.7 m s^{-1} ;

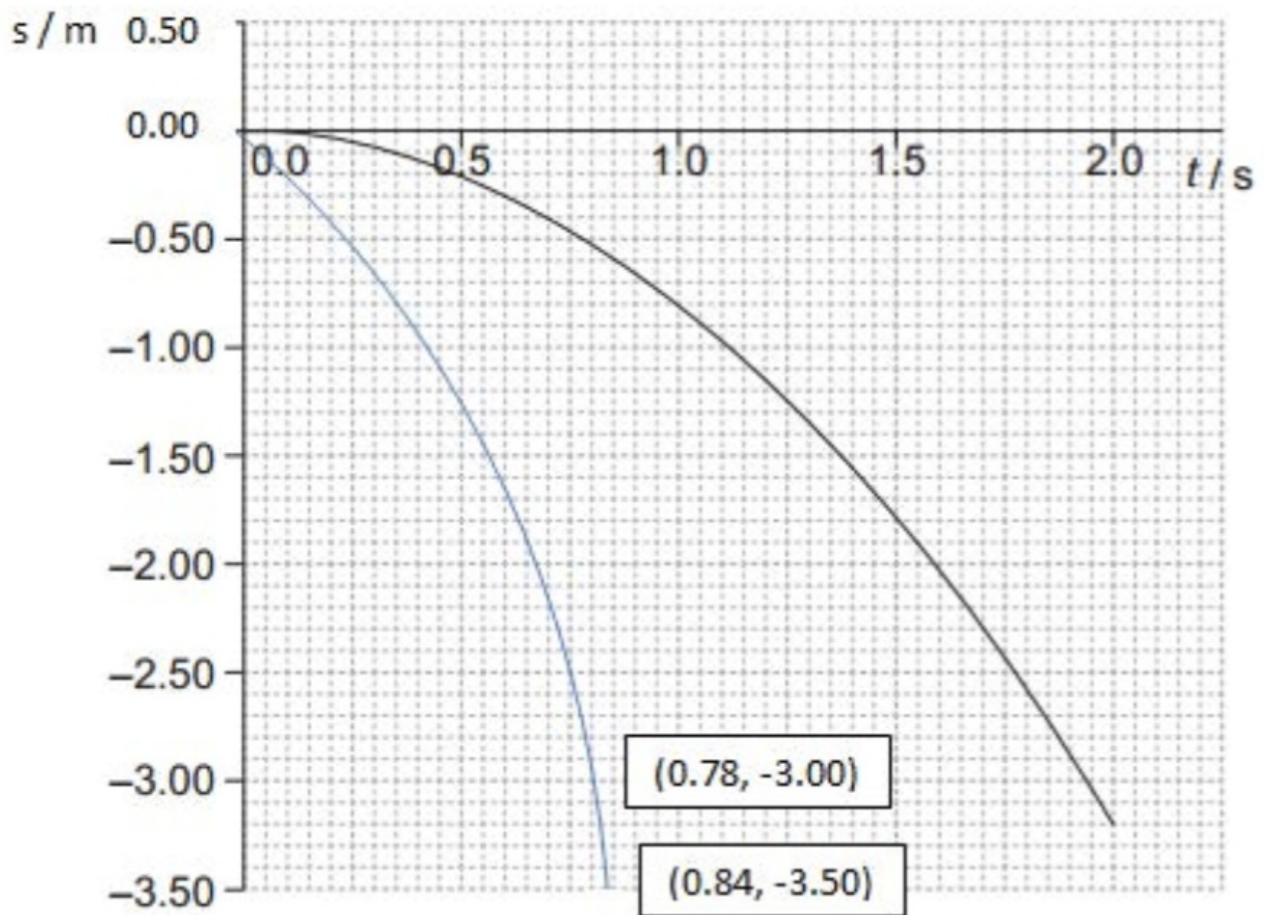
- 3e. Sketch, on the graph, the variation with time t of the displacement s from [3 marks]
the point of release of the ball when the ball is dropped close to the
surface of Earth. (For this sketch take the direction towards the Earth as being
negative.)

Markscheme

curve permanently below Moon curve;

smooth parabola; (judge by eye)

line passing through $s = -3.00 \text{ m}$, $t = 0.78 \text{ s}$ or $s = -3.50 \text{ m}$, $t = 0.84 \text{ s}$
($\pm 1 \text{ mm}$);



Part 2 Radioactivity

Two isotopes of calcium are calcium-40 ($^{40}_{20}\text{Ca}$) and calcium-47 ($^{47}_{20}\text{Ca}$). Calcium-40 is stable and calcium-47 is radioactive with a half-life of 4.5 days.

- 3f. Calculate the percentage of a sample of calcium-47 that decays in 27 days. [3 marks]

Markscheme

six half-lives occurred;

$\left(\left(\frac{1}{2}\right)^6 =\right) 1.6\%$ remaining;

98.4 / 98% decayed;

- 3g. The nuclear equation for the decay of calcium-47 into scandium-47 ($^{47}_{21}\text{Sc}$) [4 marks] is given by



(i) Identify X.

(ii) The following data are available.

Mass of calcium-47 nucleus = 46.95455 u

Mass of scandium-47 nucleus = 46.95241 u

Using the data, determine the maximum kinetic energy, in MeV, of the products in the decay of calcium-47.

(iii) State why the kinetic energy will be less than your value in (h)(ii).

Markscheme

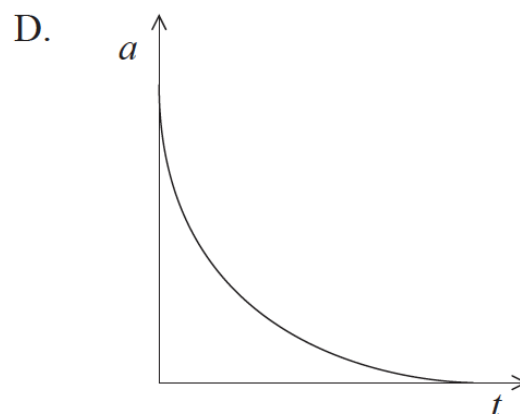
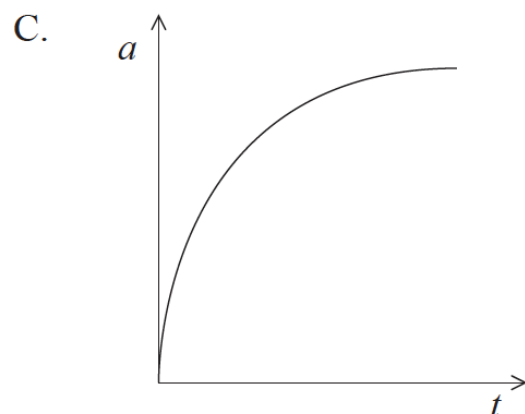
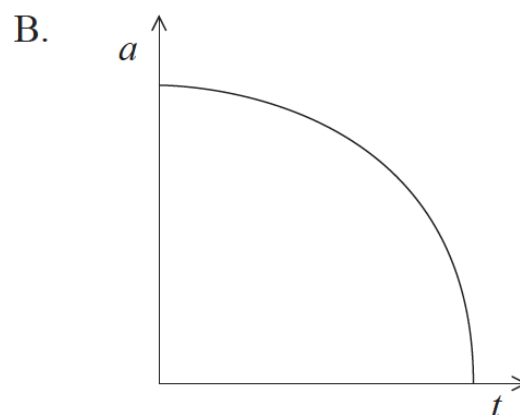
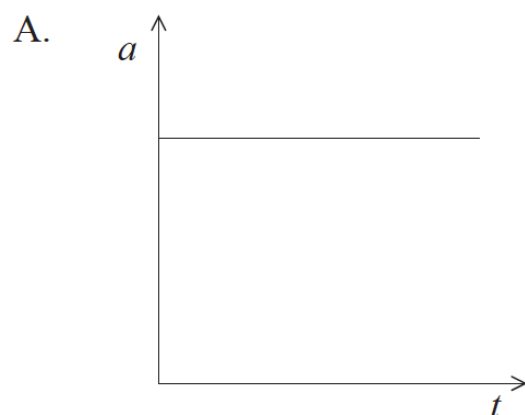
(i)(electron) anti-neutrino / $\bar{\nu}$;

(ii) $46.95455 \text{ u} - (46.95241 \text{ u} + 0.00055 \text{ u}) = 0.00159 \text{ u}$;

1.48 MeV;

(iii) does not account for energy of (anti) neutrino/gamma ray photons;

4. An object is dropped from rest above the Earth's surface. Air resistance acts on the object. What is the variation of acceleration a with time t for the object? [1 mark]



Markscheme

D

This question is in **two** parts. **Part 1** is about the motion of a ship. **Part 2** is about melting ice.

Part 1 Motion of a ship

- 5a. Outline the meaning of work.

[2 marks]

Markscheme

work done = force $\times$ distance moved;
(distance moved) in direction of force;

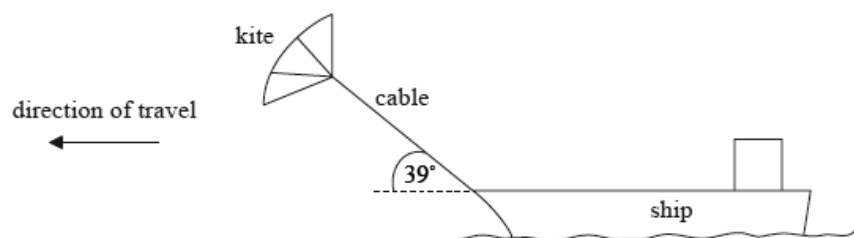
or

energy transferred;
from one location to another;

or

work done = $Fs \cos \theta$;
with each symbol defined;

Some cargo ships use kites working together with the ship's engines to move the vessel.



The tension in the cable that connects the kite to the ship is 250 kN. The kite is pulling the ship at an angle of 39° to the horizontal. The ship travels at a steady speed of 8.5 m s^{-1} when the ship's engines operate with a power output of 2.7 MW.

- 5b. Calculate the work done on the ship by the kite when the ship travels a distance of 1.0 km. [2 marks]

Markscheme

horizontal force = $250\,000 \times \cos 39^\circ (= 1.94 \times 10^5 \text{ N})$;

work done = $1.9 \times 10^8 \text{ J}$;

- 5c. Show that, when the ship is travelling at a speed of 8.5 m s^{-1} , the kite provides about 40% of the total power required by the ship. [4 marks]

Markscheme

power provided by kite = $(1.94 \times 10^5 \times 8.5 =) 1.7 \times 10^6 \text{ W}$;

total power = $(2.7 + 1.7) \times 10^6 \text{ W} (= 4.4 \times 10^6 \text{ W})$;

fraction provided by kite = $\frac{1.7}{2.7+1.7}$;

38% **or** 0.38; (*must see answer to 2+ sig figs as answer is given*)

Allow answers in the range of 37 to 39% due to early rounding.

or

Award [3 max] for a reverse argument such as:

if 2.7 MW is 60%;

then kite power is $\frac{2}{3} \times 2.7 \text{ MW} = 1.8 \text{ MW}$;

shows that kite power is actually 1.7 MW; (*QED*)

- 5d. The kite is taken down and no longer produces a force on the ship. The resistive force F that opposes the motion of the ship is related to the speed v of the ship by [3 marks]

$$F = kv^2$$

where k is a constant.

Show that, if the power output of the engines remains at 2.7 MW, the speed of the ship will decrease to about 7 m s^{-1} . Assume that k is independent of whether the kite is in use or not.

Markscheme

$$P = (kv^2) \times v = kv^3;$$

$$\frac{v_1}{v_2} = \left(\sqrt[3]{\left(\frac{P_1}{P_2}\right)} = \right) \sqrt[3]{\left(\frac{7.7}{4.4}\right)} ;$$

final speed of ship = 7.2 m s^{-1} ; (*at least 2 sig figs required*).

Approximate answer given, marks are for working only.

The ship's engines are switched off and the ship comes to rest from a speed of 7 m s^{-1} in a time of 650 s.

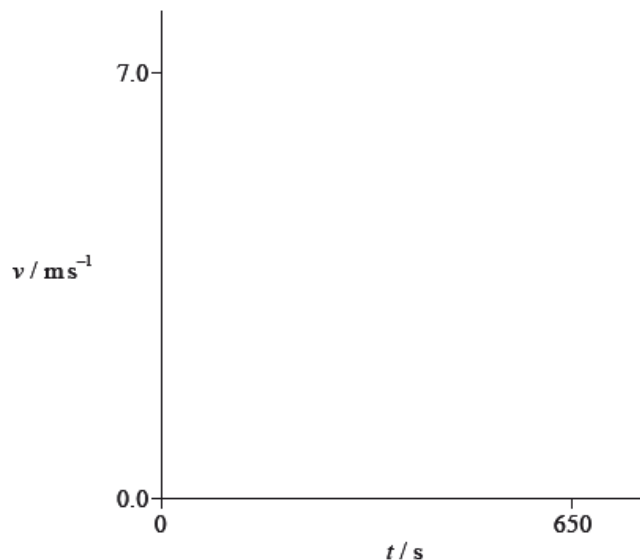
- 5e. Estimate the distance that the ship takes to stop. Assume that the acceleration is uniform.

[2 marks]

Markscheme

correct substitution of 7 or 7.2 into appropriate kinematic equation;
an answer in the range of 2200 to 2400 m;

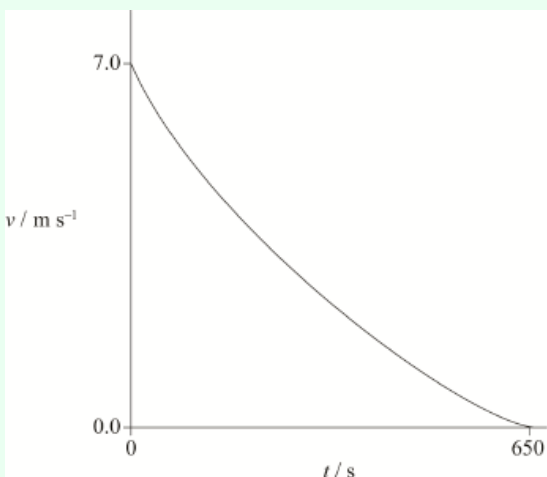
- 5f. It is unlikely that the acceleration of the ship will be uniform given that the [2 marks]
resistive force acting on the ship depends on the speed of the ship. Using
the axes, sketch a graph to show how the speed v varies with time t after the ship's
engines are switched off.



Markscheme

starts at $7.0/7.2 \text{ m s}^{-1}$; (allow ECF from (d)(i))

correct shape;



Part 2 Melting ice

- 5g. Describe, with reference to molecular behaviour, the process of melting ice. [2 marks]

Markscheme

in ice, molecules vibrate about a fixed point;

as their total energy increases, the molecules (partly) overcome the attractive force between them;

in liquid water the molecules are able to migrate/change position;

A container of negligible mass, isolated from its surroundings, contains 0.150 kg of ice at a temperature of -18.7°C . An electric heater supplies energy at a rate of 125 W .

- 5h. After a time interval of 45.0 s all of the ice has reached a temperature of 0°C without any melting. Calculate the specific heat capacity of ice. [2 marks]

Markscheme

$$(Q =) 45.0 \times 125 (= 5625 \text{ J});$$

$$c = \left(\frac{Q}{m\Delta\theta} = \right) 2.01 \times 10^3 \text{ J kg}^{-1}\text{K}^{-1};$$

5i. The following data are available.

[3 marks]

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

$$\text{Specific latent heat of fusion of ice} = 3.30 \times 10^5 \text{ J kg}^{-1}$$

Determine the final temperature of the water when the heater supplies energy for a further 600 s.

Markscheme

$$\text{energy available} = 125 \times 600 (= 75000 \text{ J});$$

$$\text{energy available to warm the water} = 75000 - [0.15 \times 3.3 \times 10^5] (= 25500 \text{ J});$$

$$\text{temperature} = \left(\frac{25500}{0.15 \times 4200} = \right) 40.5^\circ\text{C};$$

5j. The whole of the experiment in (f)(i) and (f)(ii) is repeated with a container [3 marks] of negligible mass that is not isolated from the surroundings. The temperature of the surroundings is 18 °C. Comment on the final temperature of the water in (f)(ii).

Markscheme

ice/water spends more time below 18 °C;

so net energy transfer is in to the system;

so final water temperature is higher;

or

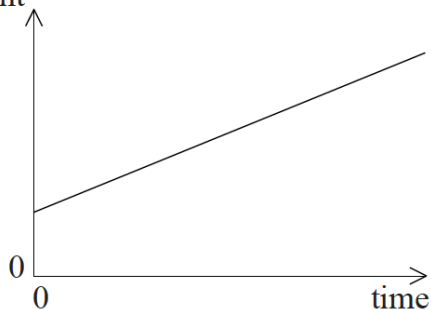
ice/water spends less time below 18 °C;

so net energy transfer is out of the system;

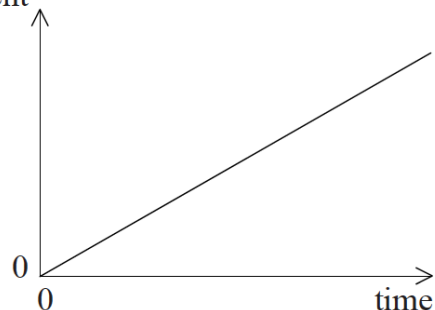
so final water temperature is lower;

6. A body moves on a straight line. The graphs show the variation of displacement with time. Which graph shows motion with negative acceleration? [1 mark]

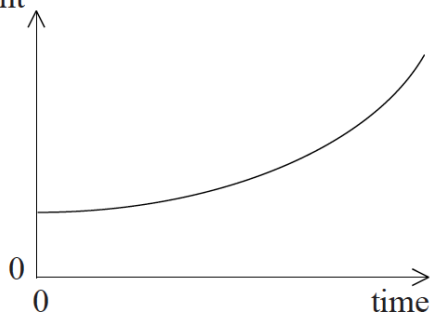
A. displacement



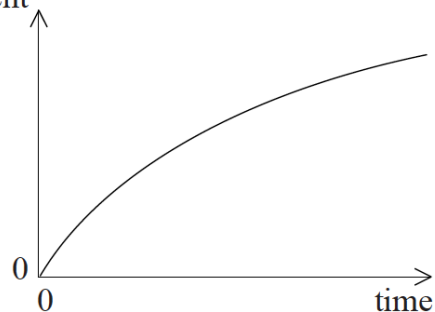
B. displacement



C. displacement



D. displacement



Markscheme

D

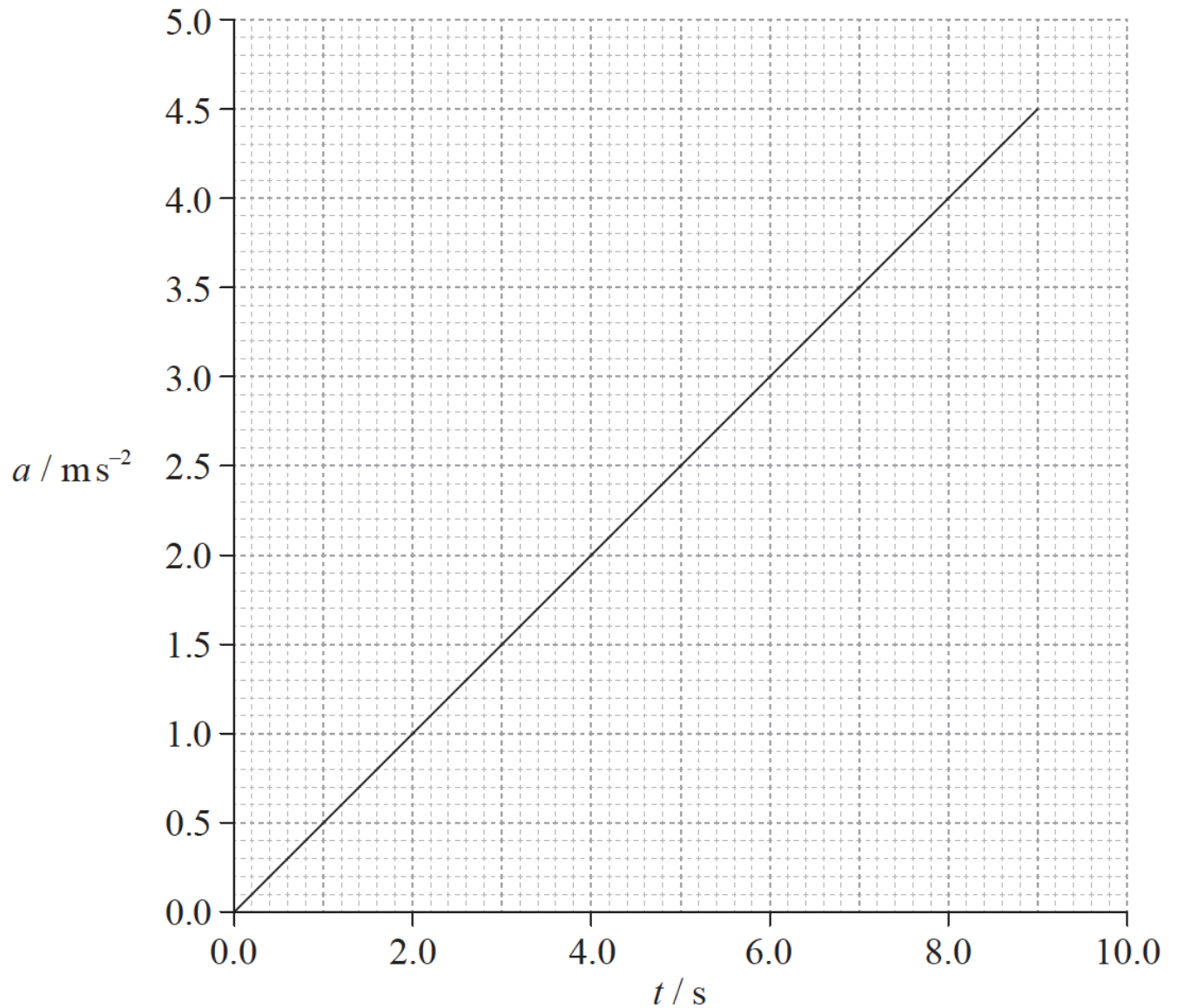
7. Each side of a metal cube is measured to be $2.0 \text{ cm} \pm 0.20 \text{ cm}$. What is the absolute uncertainty in the calculated volume of the cube? [1 mark]

- A. $\pm 0.08 \text{ cm}^3$
- B. $\pm 0.60 \text{ cm}^3$
- C. $\pm 0.80 \text{ cm}^3$
- D. $\pm 2.4 \text{ cm}^3$

Markscheme

D

8. A particle accelerates from rest. The graph shows how the acceleration a of the particle varies with time t . [1 mark]



What is the speed of the particle at $t=6.0\text{s}$?

- A. 0.5 ms^{-1}
- B. 2.0 ms^{-1}
- C. 9.0 ms^{-1}
- D. 18 ms^{-1}

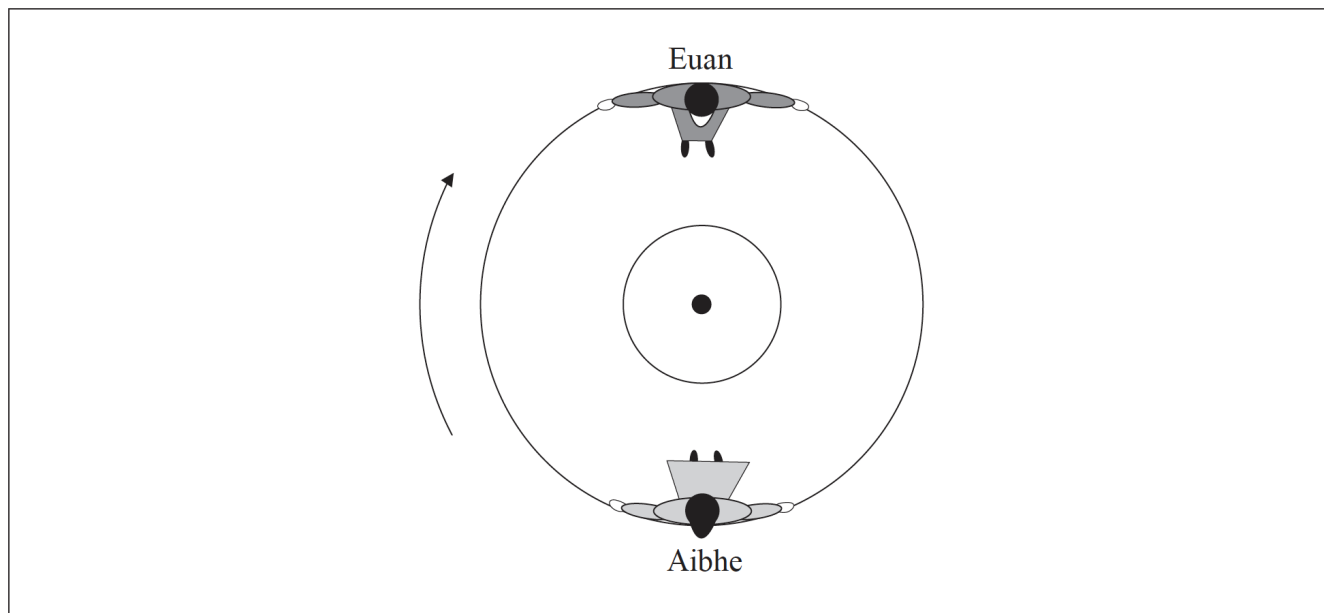
Markscheme

C

This question is in **two** parts. **Part 1** is about two children on a merry-go-round. **Part 2** is about electric circuits.

Part 1 Two children on a merry-go-round

Aibhe and Euan are sitting on opposite sides of a merry-go-round, which is rotating at constant speed around a fixed centre. The diagram below shows the view from above.



Aibhe is moving at speed 1.0ms^{-1} relative to the ground.

9a. Determine the magnitude of the velocity of Aibhe relative to

[2 marks]

(i) Euan.

(ii) the centre of the merry-go-round.

Markscheme

- (i) 2.0 **or** $0(\text{ms}^{-1})$;
- (ii) 1.0 **or** $0(\text{ms}^{-1})$;

- 9b. (i) Outline why Aibhe is accelerating even though she is moving at constant speed. [6 marks]
- (ii) Draw an arrow on the diagram on page 22 to show the direction in which Aibhe is accelerating.
- (iii) Identify the force that is causing Aibhe to move in a circle.
- (iv) The diagram below shows a side view of Aibhe and Euan on the merry-go-round.



Explain why Aibhe feels as if her upper body is being “thrown outwards”, away from the centre of the merry-go-round.

Markscheme

(i) her direction is changing;
hence her velocity is changing;

or

since her direction/velocity is changing;
a resultant/unbalanced/net force must be acting on her (hence she is accelerating);

(ii) arrow from Aibhe towards centre of merry-go-round;
Ignore length of arrow.

(iii) the force of the merry-go-round on Aibhe/her;

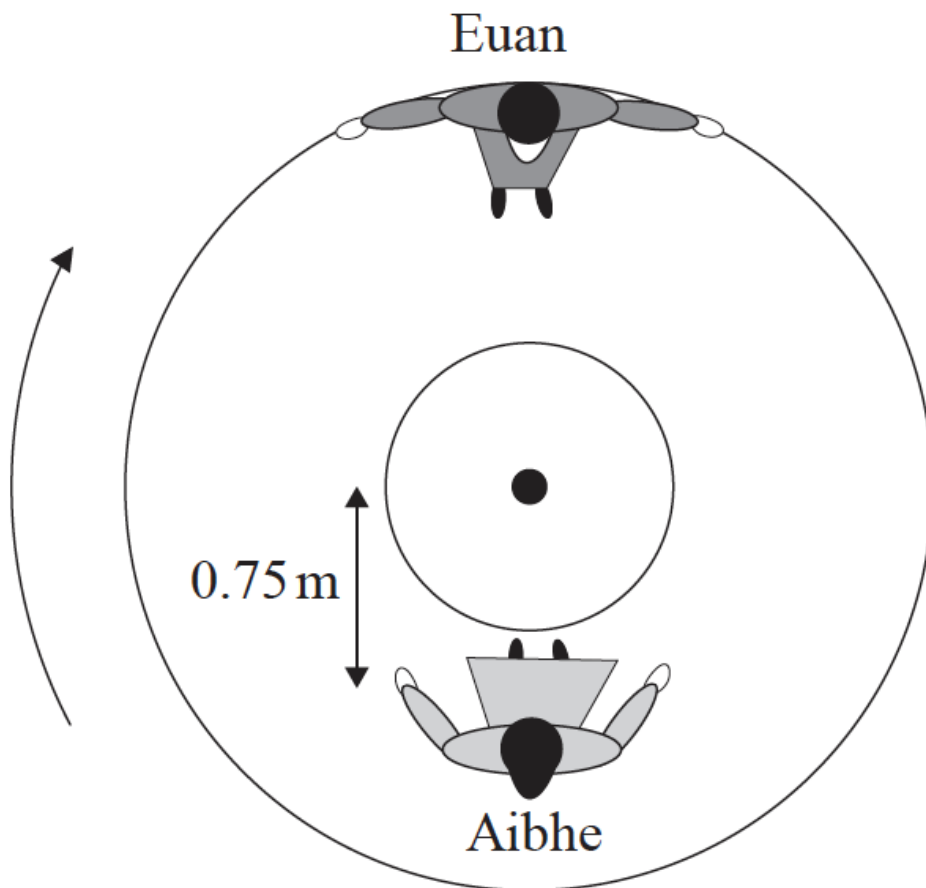
(iv) no force is acting on the upper body towards the centre of the circle / no centripetal force acting on the upper body (to maintain circular motion);
upper body (initially) continues to move in a straight line at constant speed/
velocity is tangential to circle;

- 9c. Euan is rotating on a merry-go-round and drags his foot along the ground [2 marks]
to act as a brake. The merry-go-round comes to a stop after 4.0 rotations.
The radius of the merry-go-round is 1.5 m. The average frictional force between his foot and the ground is 45 N. Calculate the work done.

Markscheme

distance travelled by Euan = $4.0 \times 2\pi \times 1.5 (= 37.70\text{m})$;
 $W (= F_{av}d = 45 \times 37.70) = 1700 \text{ (J)}$;

- 9d. Aibhe moves so that she is sitting at a distance of 0.75 m from the centre [5 marks] of the merry-go-round, as shown below.



Euan pushes the merry-go-round so that he is again moving at 1.0 ms^{-1} relative to the ground.

- (i) Determine Aibhe's speed relative to the ground.
- (ii) Calculate the magnitude of Aibhe's acceleration.

Markscheme

(i) Aibhe's period of revolution is the same as before;

from $v = \frac{2\pi r}{T}$, since r is halved, v is halved;

$$v = 0.5(\text{ms}^{-1});$$

Award **[3]** for a bald correct answer.

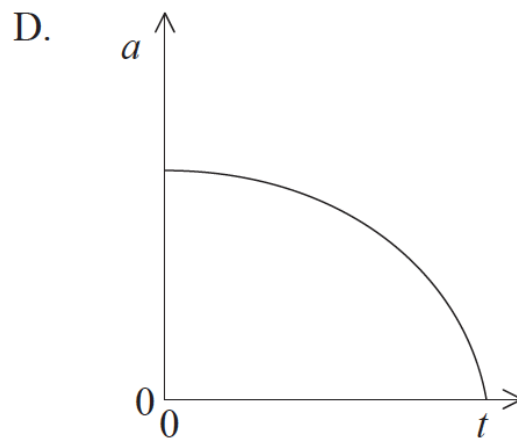
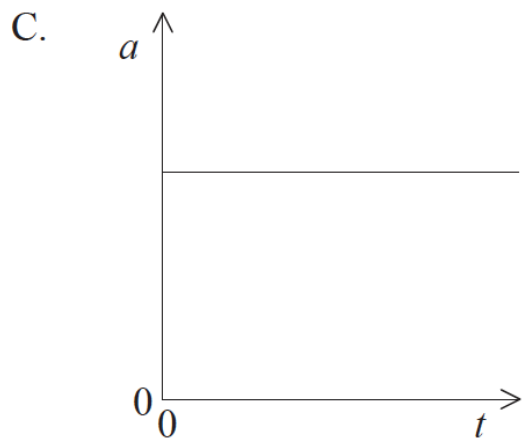
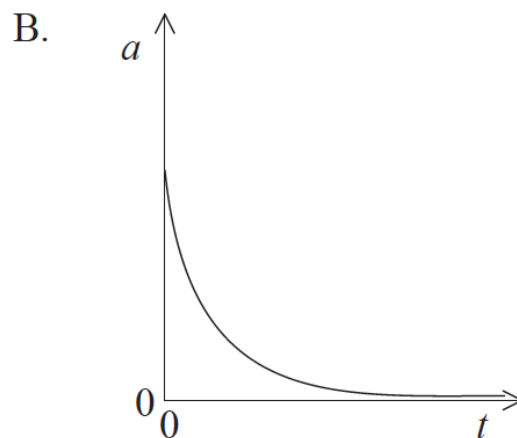
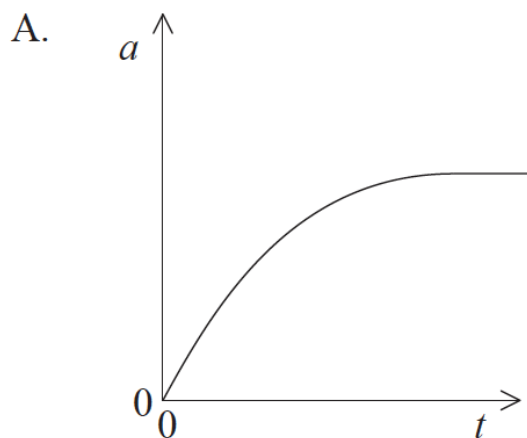
$$(ii) a \left(= \frac{v^2}{r} \right) = \frac{0.5^2}{0.75};$$

$$a = 0.33(\text{ms}^{-2});$$

Allow ECF from (d)(i).

Award **[2]** for a bald correct answer.

10. A tennis ball is dropped from the top of a high building. Air resistance **cannot** be neglected. Which graph represents the variation with time t of the magnitude of the acceleration a of the ball before it hits the ground? [1 mark]



Markscheme

B

This question is in **two** parts. **Part 1** is about Newton's laws and momentum. **Part 2** is about the greenhouse effect.

Part 1 Newton's laws and momentum

- 11a. State the condition for the momentum of a system to be conserved. [1 mark]

Markscheme

the net (external) force acting on the system is zero / no force acting on system / system is isolated;

- 11b. A person standing on a frozen pond throws a ball. Air resistance and friction can be considered to be negligible. [5 marks]
- (i) Outline how Newton's third law and the conservation of momentum apply as the ball is thrown.
- (ii) Explain, with reference to Newton's second law, why the horizontal momentum of the ball remains constant whilst the ball is in flight.

Markscheme

(i) no external force/system is isolated so change in momentum is zero; { *(do not accept momentum is conserved/constant)*
force on ball must be equal and opposite to force on the person;
so ball and person/Earth/pond move in opposite directions;

(ii) Newton's second law states that the rate of change of momentum is equal/proportional/directly proportional to the force acting;
the horizontal force acting on the ball is zero therefore the momentum must be constant/the rate of change of momentum is zero;

or

Newton's second law can be expressed as the force acting is equal to the product of mass and acceleration;
the horizontal force acting on the ball is zero therefore the acceleration is zero so velocity is constant (and therefore momentum is constant);

- 11c. The maximum useful power output of a locomotive engine is 0.75 M W. [2 marks]
The maximum speed of the locomotive as it travels along a straight horizontal track is 44 m s⁻¹. Calculate the frictional force acting on the locomotive at this speed.

Markscheme

$$F = \frac{P}{v} \text{ or } \frac{0.75 \times 10^6}{44};$$

17kN;

- 11d. The locomotive engine in (c) gives a truck X a sharp push such that X [4 marks]
moves along a horizontal track and collides with a stationary truck Y. As a result of the collision the two trucks stick together and move off with speed v . The following data are available.

Mass of truck X = 3.7×10^3 kg

Mass of truck Y = 6.3×10^3 kg

Speed of X just before collision = 4.0 m s^{-1}

(i) Calculate v .

(ii) Determine the kinetic energy lost as a result of the collision.

Markscheme

(i) $3.7 \times 4.0 = 10 \times v$;
 $v = 1.5 \text{ m s}^{-1}$;

(ii) KE lost = $\frac{1}{2} [3.7 \times 10^3 \times 4.0^2] - \frac{1}{2} [10 \times 10^3 \times 1.5^2]$;
= 18kJ;

- 11e. The trucks X and Y come to rest after travelling a distance of 40 m along [3 marks]
the horizontal track. Determine the average frictional force acting on X and Y.

Markscheme

$$\text{initial KE} = \left(\frac{1}{2} [10 \times 10^3 \times 1.5^2] \right) = 11250 \text{ J};$$

$$\text{friction} = \frac{11250}{40};$$

$$= 280 \text{ N};$$

or

use of kinematic equation to give $a = 0.274 \text{ ms}^{-1}$;

use of $F(=ma) = 10 \times 10^3 a$;

$$270/280 \text{ N};$$

Part 2 The greenhouse effect

11f. Nuclear fuels, unlike fossil fuels, produce no greenhouse gases.

[5 marks]

(i) Identify **two** greenhouse gases.

(ii) Discuss, with reference to the mechanism of infrared absorption, why the temperature of the Earth's surface would be lower if there were no greenhouse gases present in the atmosphere.

Markscheme

(i) methane/ CH_4 , water vapour/ H_2O , carbon dioxide/ CO_2 , nitrous oxide/ N_2O ;

Award [1] for any two of the above.

(ii) *mechanism:*

mention of resonance;

natural frequency of (resonating) greenhouse gas molecules is same as that of infrared radiation from Earth;

or

mention of energy level differences;

differences between energy levels of greenhouse gas molecules matches energy of infrared radiation from Earth;

explanation:

less infrared trapped if absorption is reduced;

so more infrared is transmitted through atmosphere;

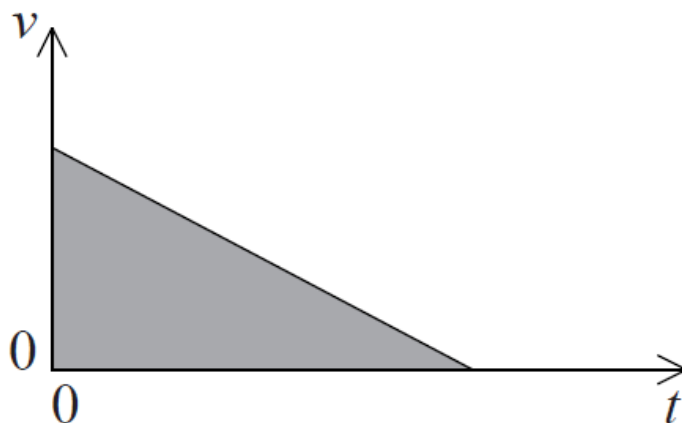
or

more infrared is trapped if absorption is increased;

so more infrared is re-radiated back to Earth;

Allow only one variant for each alternative.

12. The graph below shows how velocity v varies with time t for a ball thrown vertically upwards from the Earth's surface. [1 mark]



The shaded area is equal to the

- A. displacement.
- B. final velocity.
- C. change in velocity.
- D. acceleration

Markscheme

A

13. Two identical balls are dropped from a tall building, one a few seconds after the other. Air resistance is **not** negligible. As the balls fall, the distance between the balls will [1 mark]
- A. decrease.
 - B. increase.
 - C. increase then remain constant.
 - D. remain constant.

Markscheme

C

14. Which of the following is always true for an object moving in a straight line at constant speed? [1 mark]
- A. No forces act on the object.
 - B. No resultant force acts on the object.
 - C. The momentum of the object is zero.
 - D. No work is being done on the object.

Markscheme

B

15. An object, initially at rest, travels a distance d in a time t at a constant acceleration. What is the time taken for the object to travel $16d$ from rest at the same acceleration? [1 mark]
- A. $16t$
 - B. $8t$
 - C. $4t$
 - D. $2t$

Markscheme

C

16. An object is released above the surface of Earth. Which of the following correctly describes the speed and acceleration before it reaches terminal speed? [1 mark]

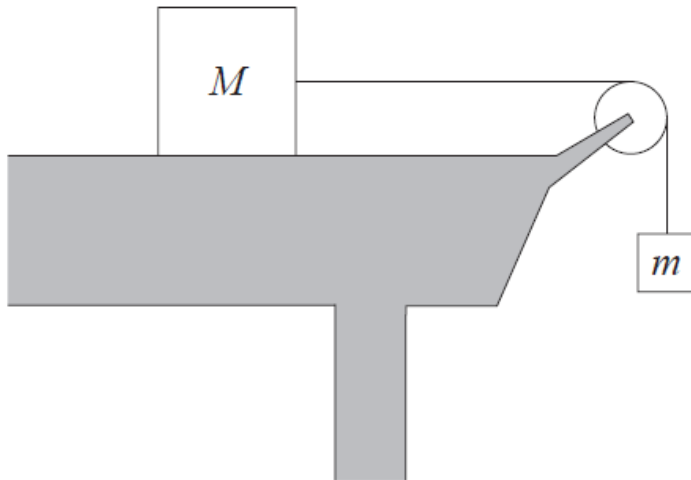
	Speed	Acceleration
A.	increases	remains constant
B.	increases	decreases
C.	remains constant	remains constant
D.	remains constant	decreases

Markscheme

B

17. An object of mass m is connected via a frictionless pulley to an object of mass M , where $M > m$. M rests on a horizontal frictionless surface

[1
mark]



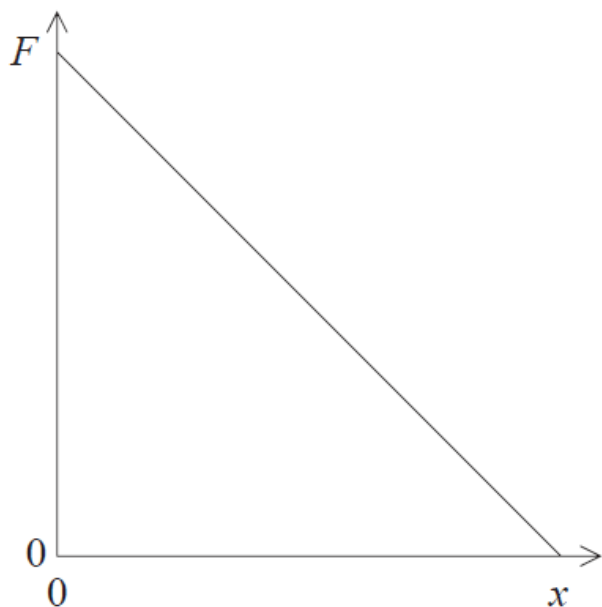
What is the acceleration of the system?

- A. $\frac{mg}{(M + m)}$
- B. $\frac{(M + m)g}{m}$
- C. $\frac{gm}{M}$
- D. Zero

Markscheme

A

18. The graph shows the variation with distance x of the magnitude of the net force F acting on a body initially at rest. [1 mark]



Which of the following describes how the kinetic energy and the acceleration of the body change with distance?

	Kinetic energy	Acceleration
A.	decrease	decrease
B.	decrease	increase
C.	increase	decrease
D.	increase	increase

Markscheme

C

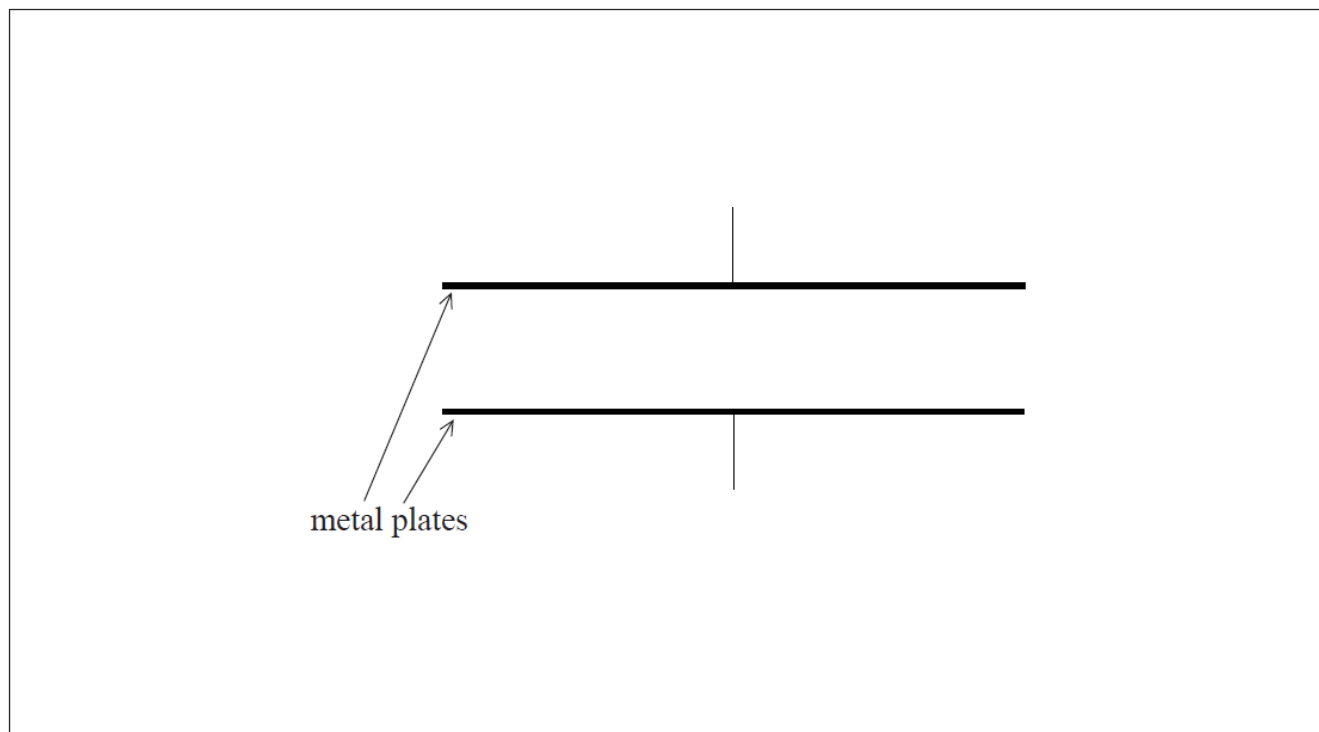
-
- 19a. Define *electric field strength*. [2 marks]

Markscheme

force per unit charge;

on a positive test charge / on a positive small charge;

- 19b. The diagram shows a pair of horizontal metal plates. Electrons can be deflected vertically using an electric field between the plates. [5 marks]

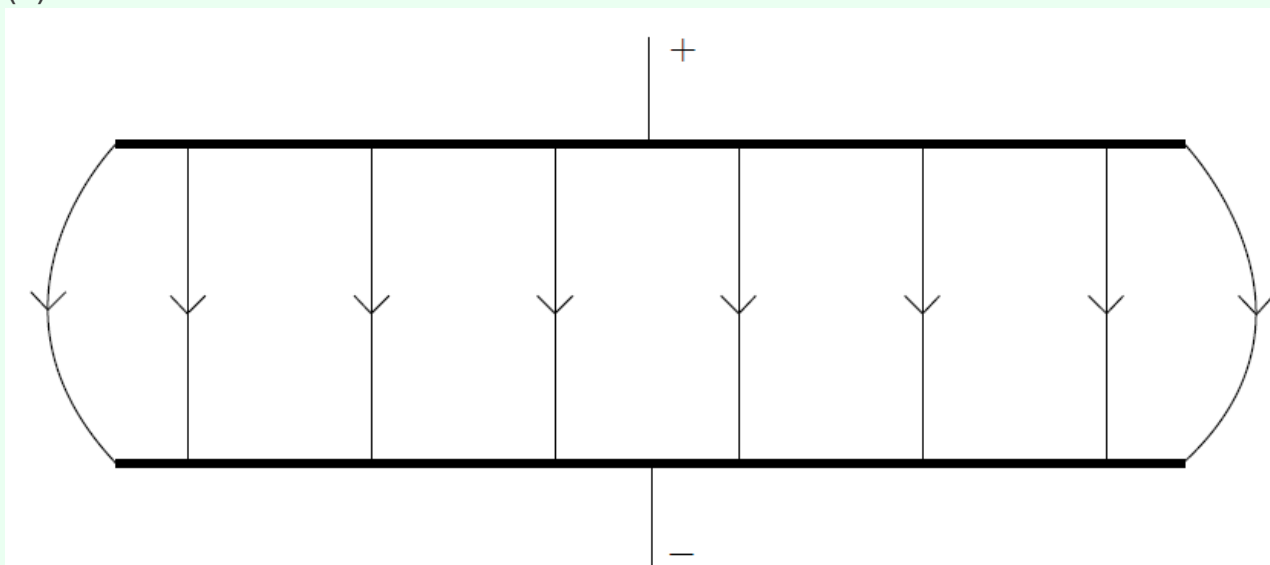


- (i) Label, on the diagram, the polarity of the metal plates which would cause an electron positioned between the plates to accelerate upwards.
- (ii) Draw the shape and direction of the electric field between the plates on the diagram.
- (iii) Calculate the force on an electron between the plates when the electric field strength has a value of $2.5 \times 10^3 \text{ NC}^{-1}$.

Markscheme

(i) top plate positive and bottom negative (or +/- and ground);

(ii)



uniform (by eye) line spacing and edge effect, field lines touching both plates;

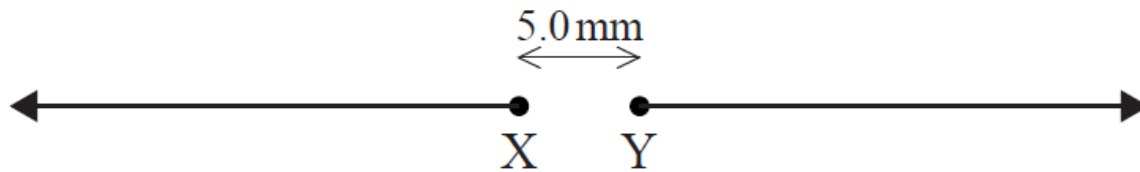
downward arrows (minimum of one and none upward);

(iii) $F = 2.5 \times 10^3 \times 1.6 \times 10^{-19}$

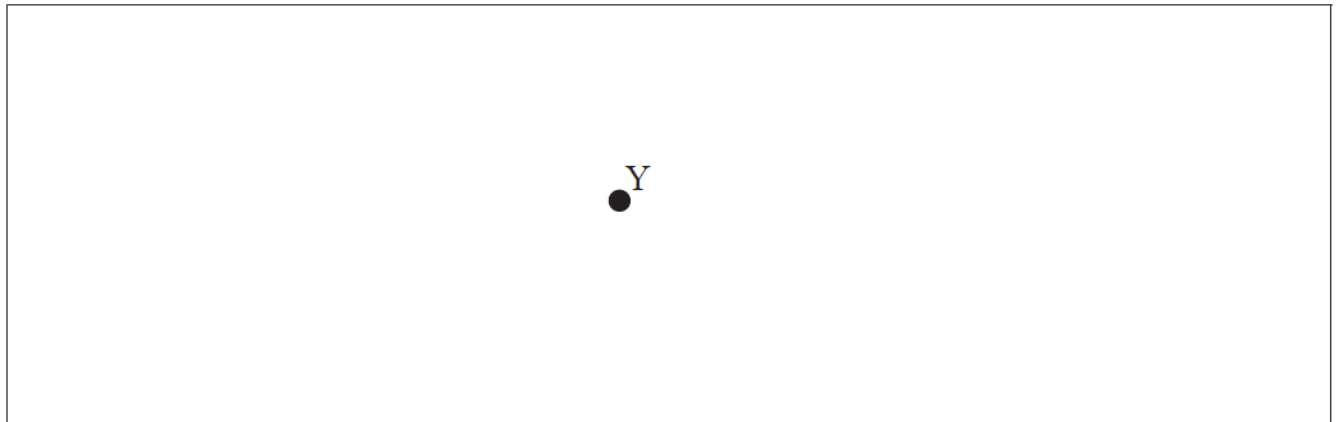
4.0×10^{-16} (N);

*Award **[2]** for a bald correct answer.*

- 19c. The diagram shows two isolated electrons, X and Y, initially at rest in a vacuum. The initial separation of the electrons is 5.0 mm. The electrons subsequently move apart in the directions shown. [8 marks]



- Show that the initial electric force acting on each electron due to the other electron is approximately $9 \times 10^{-24} \text{ N}$.
- Calculate the initial acceleration of one electron due to the force in (c)(i).
- Discuss the motion of one electron after it begins to move.
- The diagram shows Y as seen from X, at one instant. Y is moving into the plane of the paper. For this instant, draw on the diagram the shape and direction of the magnetic field produced by Y.



Markscheme

(i) use of $F = \frac{(1.60 \times 10^{-19})^2}{4\pi\epsilon_0(5.0 \times 10^{-3})^2}$ **or** $F = \frac{(1.60 \times 10^{-19})^2}{(5.0 \times 10^{-3})^2} \times 8.99 \times 10^9$;

$9.2 \times 10^{-24} \text{ (N)}$;

(ii) $1.0 \times 10^7 \text{ (ms}^{-2}\text{)}$ ($9.9 \times 10^6 \text{ (ms}^{-2}\text{)}$ if $9 \times 10^{-24} \text{ (N)}$ used);

- (iii) electron will continue to accelerate;
 speed increases with acceleration;
 acceleration reduces with separation;
 when outside the field no further acceleration/constant speed;
 any reference to accelerated charge radiating and losing (kinetic) energy;

- (iv) minimum of two concentric circles centred on Y;
 anti-clockwise;

This question is about kinematics.

20a. Fiona drops a stone from rest vertically down a water well. She hears the *[3 marks]* splash of the stone striking the water 1.6 s after the stone leaves her hand. Estimate the

(i) distance between Fiona's hand and the water surface.

(ii) speed with which the stone hits the water.

Markscheme

(i) $s = 12.5/12.6$ (m);

Allow $g = 10 \text{ ms}^{-2}$, answer is 12.8.

(ii) $v = \sqrt{2gs}$ **or** gt ; (allow any use of suvat equations)

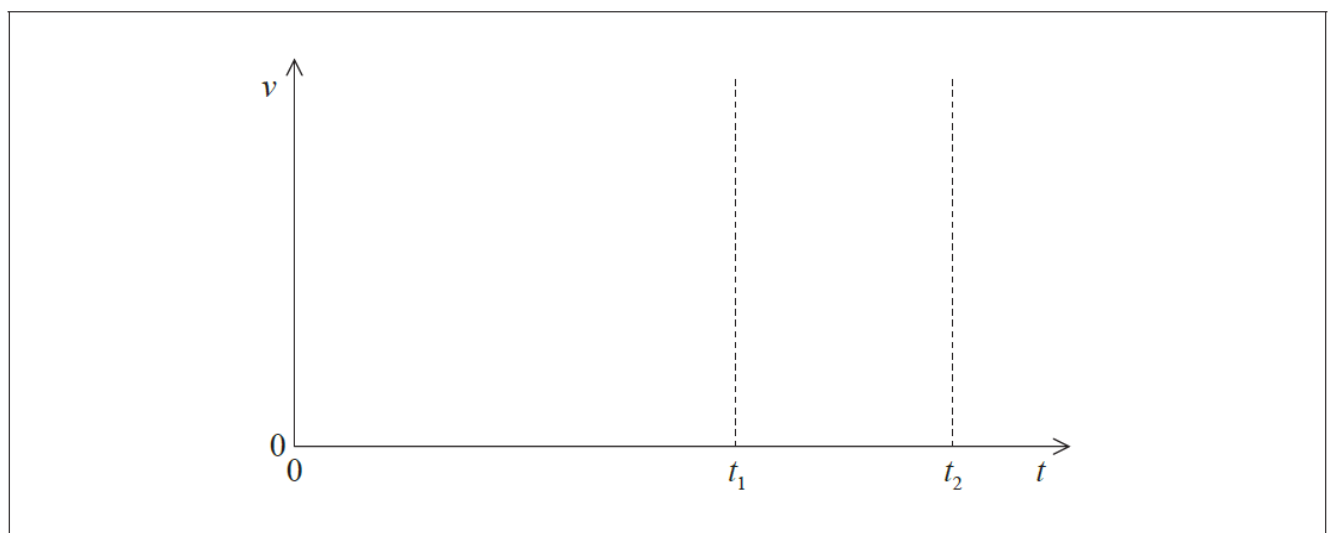
$= \left(\sqrt{2 \times 9.8 \times 12.5} = \right) 15.7 \text{ (ms}^{-1}\text{)};$

Award **[2]** for a bald correct answer.

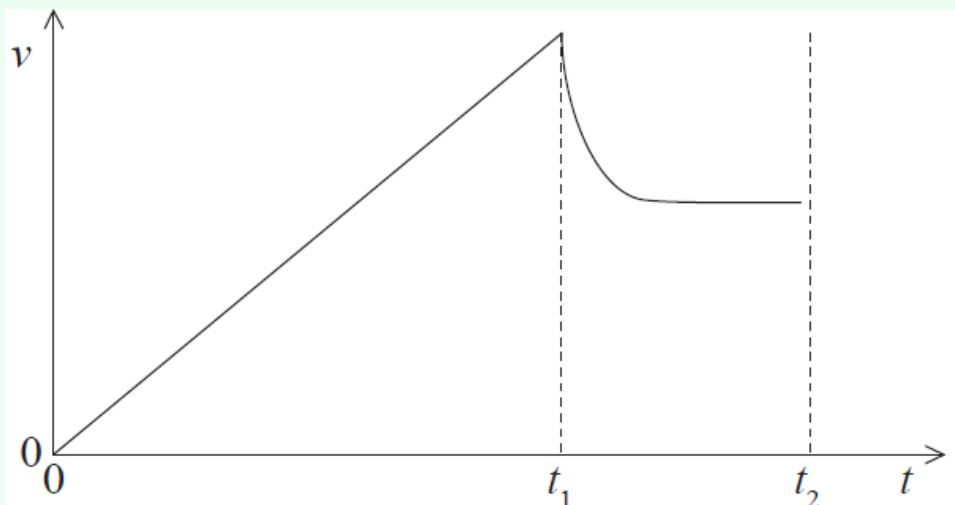
Allow $g = 10 \text{ ms}^{-2}$ answer is 16.0 ms^{-1} .

Allow ECF from (a)(i)

20b. After the stone in (a) hits the water surface it rapidly reaches a terminal *[3 marks]* speed as it falls through the water. The stone leaves Fiona's hand at time $t = 0$. It hits the water surface at t_1 and it comes to rest at the bottom of the water at t_2 . Using the axes below, sketch a graph to show how the speed v of the stone varies from time $t = 0$ to just before $t = t_2$. (There is no need to add any values to the axes.)



Markscheme

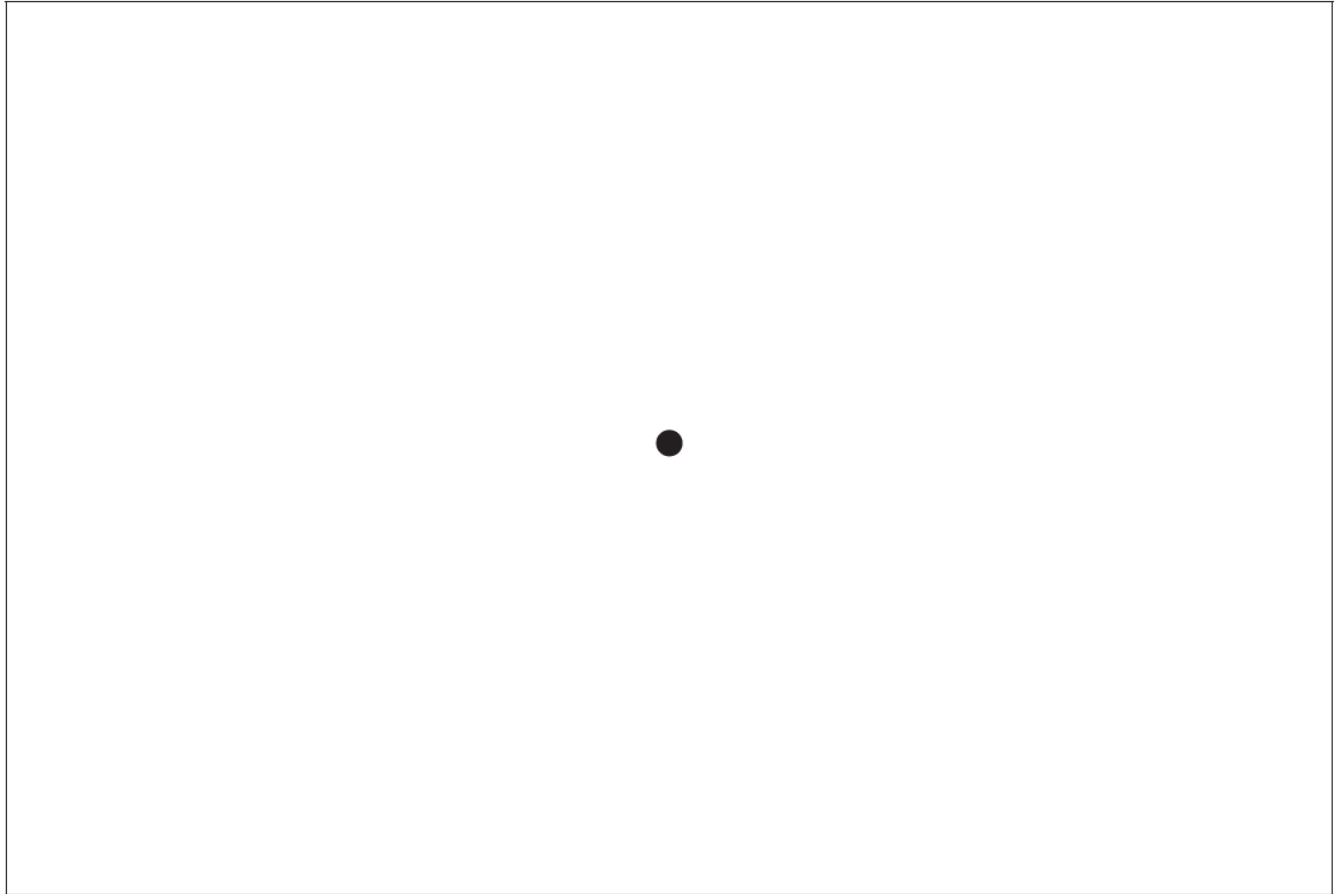


straight line to water surface; (*allow a slight curve within 10 % of t_1*) clear decrease after hitting surface; (*allow straight line or concave curve as shown, do not allow convex curve*)

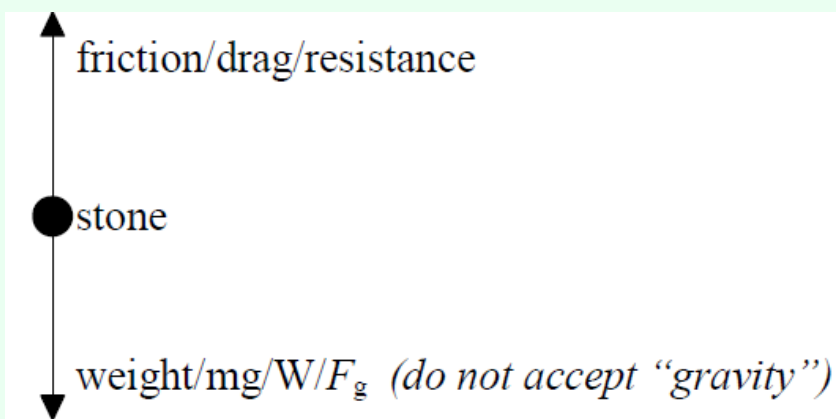
constant non-zero speed reached smaller than maximum; (*speed must be less than maximum velocity*)

Do not penalize answers where a curve is drawn to the dotted lines as there should not be a discontinuity at the two lines. Do not penalize if the line continues to t_2 or zero velocity shown at t_2 .

20c. Draw and label a free-body diagram representing the forces acting on the [2 marks]
stone as it falls through the water at its terminal speed.



Markscheme



correctly labelled forces;

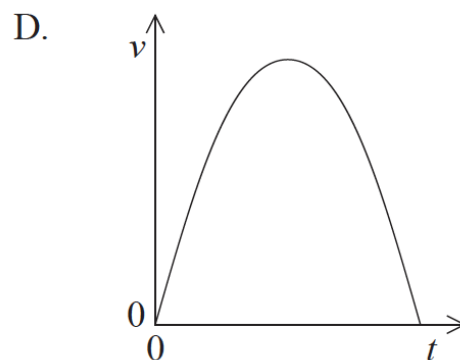
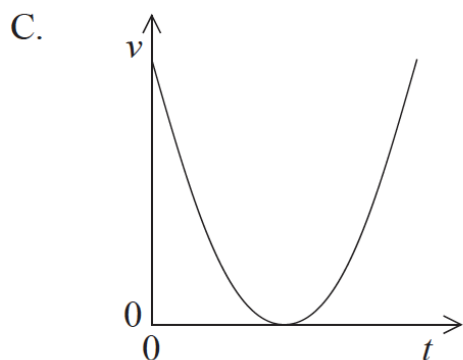
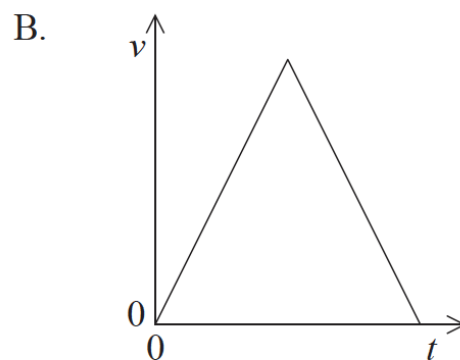
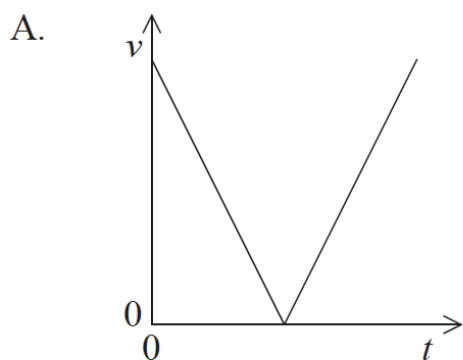
correct direction and equal lengths; (*judge by eye*)

Accept co-linear/vector arrows that do not begin at the stone.

Accept arrow heads finalizing at the stone.

Treat mention of upthrust as neutral.

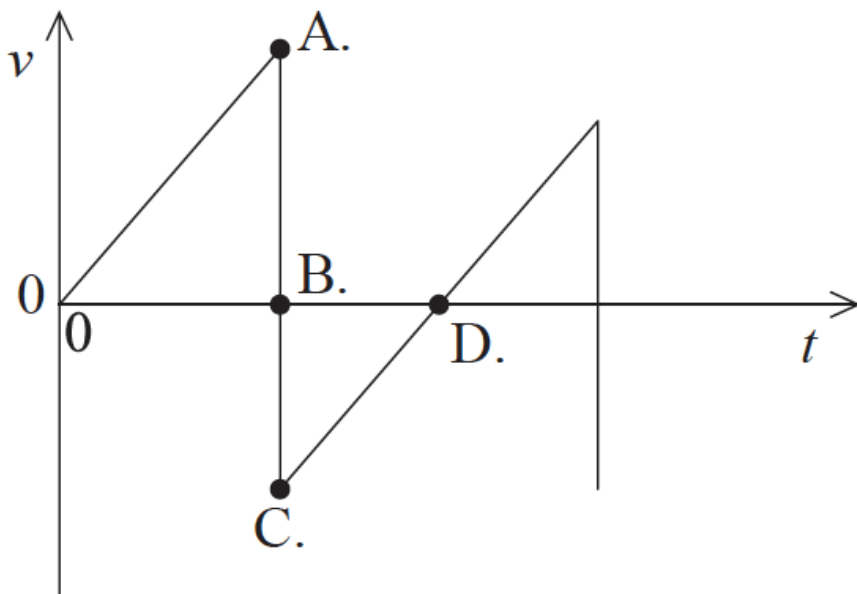
21. An object is thrown upwards leaving the thrower's hand at time $t=0$. Which [1 mark]
graph shows how speed v varies with t as the object rises and falls?



Markscheme

A

22. A ball is released at time $t=0$ above a horizontal surface. The graph shows the variation of velocity v with time. Which of the following shows the highest point of the ball after one bounce? [1 mark]

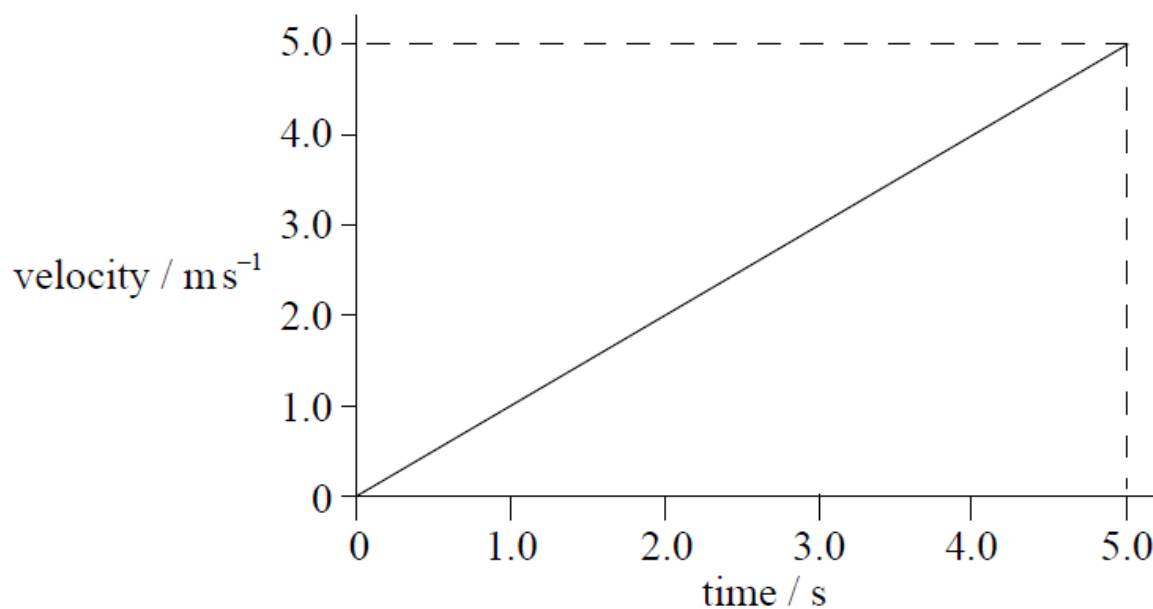


Markscheme

D

23. The velocity-time graph for an accelerating object that is traveling in a straight line is shown below.

[1
mark]



Which of the following is the change in displacement of the object in the first 5.0 seconds?

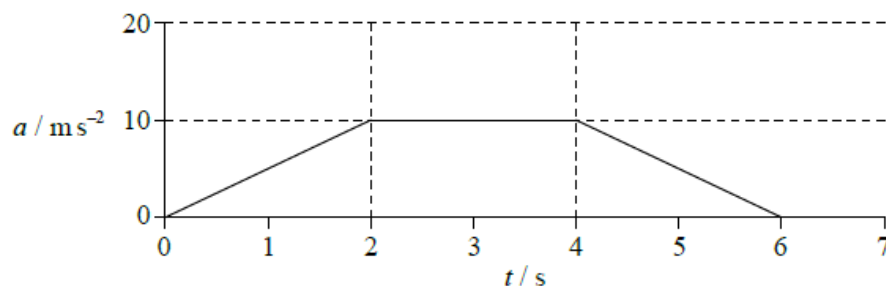
- A. 25.0 m
- B. 12.5 m
- C. 5.0 m
- D. 1.0 m

Markscheme

B

24. The graph shows the acceleration a of an object as time t varies.

[1
mark]



What is the magnitude of the change in the velocity of the object between 0 and 3 seconds?

- A. 5 ms^{-1}
- B. 10 ms^{-1}
- C. 20 ms^{-1}
- D. 30 ms^{-1}

Markscheme

C

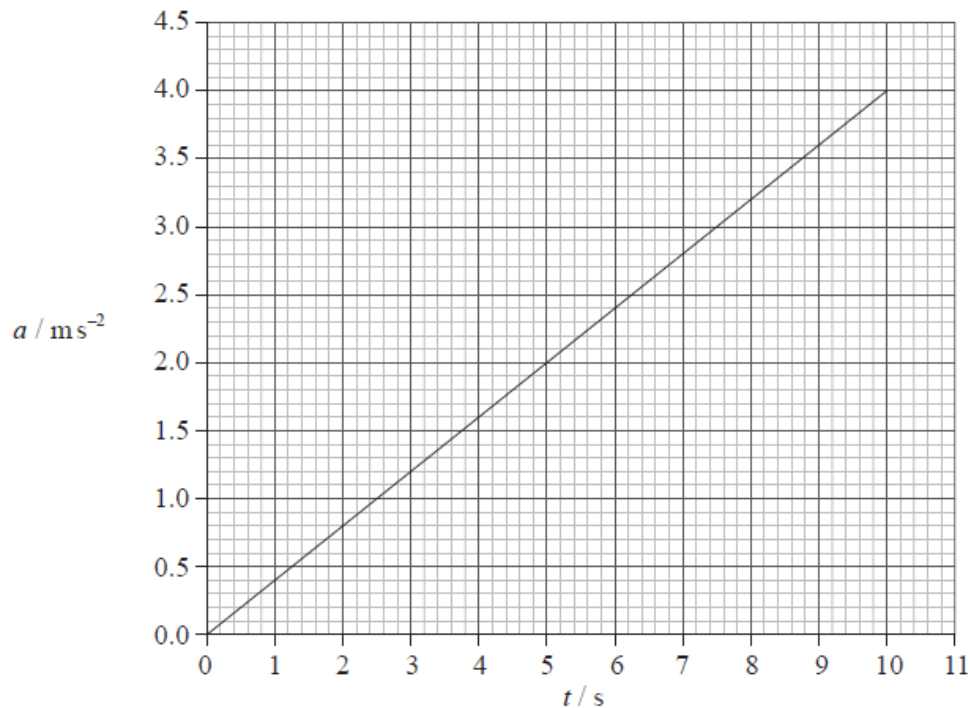
This question is about kinematics.

25a. State the difference between average speed and instantaneous speed. [2 marks]

Markscheme

average speed is the speed over a period of time/distance; instantaneous speed is the speed at a particular instant in time/point in space.

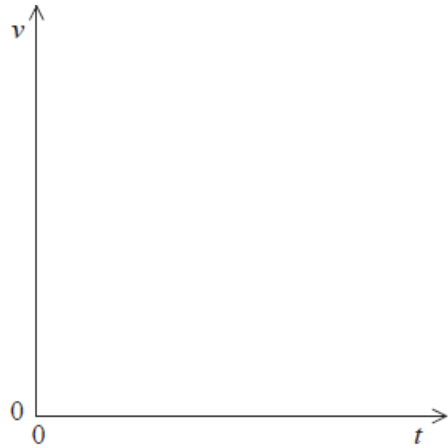
25b. The graph shows how the acceleration a of a particle varies with time t . [3 marks]



At time $t = 0$ the instantaneous speed of the particle is zero.

(i) Calculate the instantaneous speed of the particle at $t = 7.5 \text{ s}$.

(ii) Using the axes below, sketch a graph to show how the instantaneous speed v of the particle varies with t .



Markscheme

(i) speed = (area under graph) = $\frac{1}{2} \times 7.5 \times 3$;
= 10 **or** 11 **or** 11.3 (ms^{-1});

(ii) suitable curve approximating to $v = kt^2$;

26. A stone is thrown vertically upwards from the surface of Earth. Which of the following quantities will **not** become zero while the stone is in the air? [1 mark]
- A. Speed
 - B. Velocity
 - C. Momentum
 - D. Acceleration

Markscheme

D

27. An ice-hockey puck is slid along ice in a straight line. The puck travels at a steady speed of 20 ms^{-1} and experiences no frictional force. How far does the puck travel in 2.5 s? [1 mark]
- A. 5 m
 - B. 8 m
 - C. 25 m
 - D. 50 m

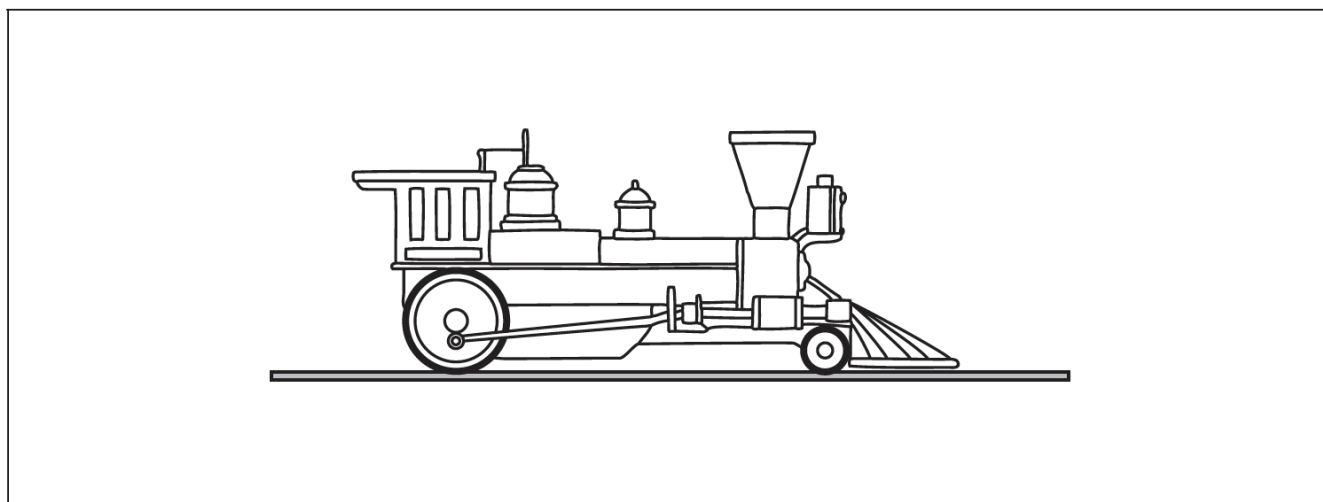
Markscheme

D

This question is in two parts. **Part 1** is about forces. **Part 2** is about internal energy.

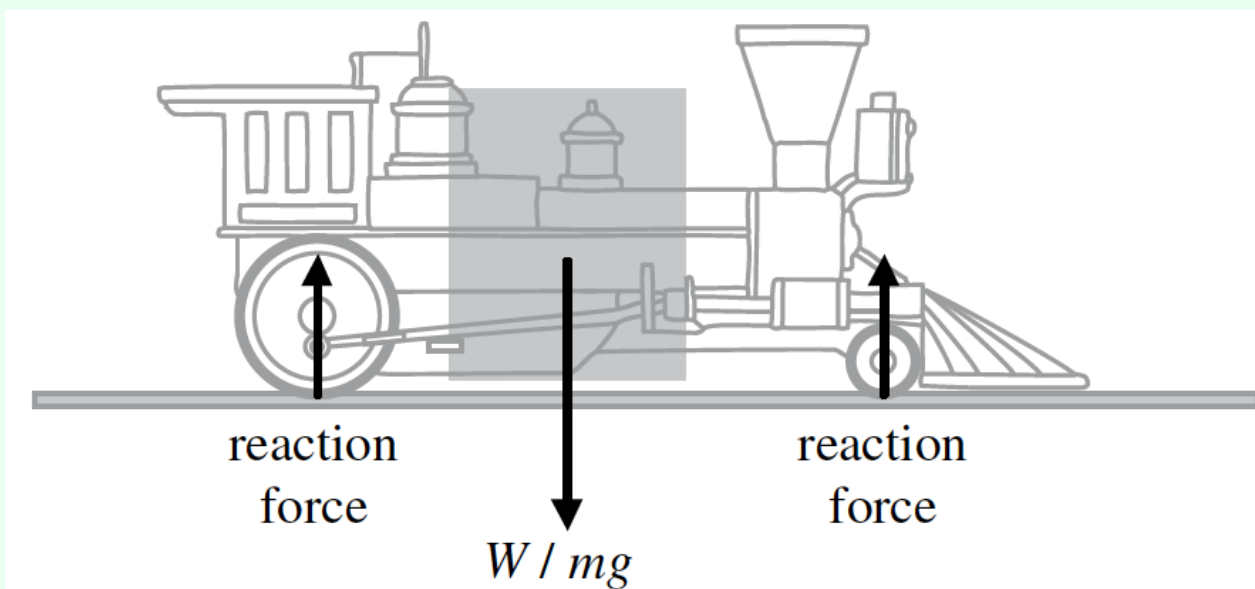
Part 1 Forces

A railway engine is travelling along a horizontal track at a constant velocity.



- 28a. On the diagram above, draw labelled arrows to represent the vertical forces that act on the railway engine. [3 marks]

Markscheme



The shaded box shows the acceptable range of position for W/mg .

*single downward arrow labelled W /weight **or** mg /gravity force; (do not allow gravity)*

two upward arrows labelled reaction/contact forces; (do not allow for only one arrow seen)

arrow positions as shown in diagram;

- 28b. Explain, with reference to Newton's laws of motion, why the velocity of the railway engine is constant. [2 marks]

Markscheme

horizontal forces have resultant of zero; (*must describe or imply horizontal force*)

valid statement linked to theory (*e.g.* Newton 1/Newton 2/conservation of momentum)

explaining why zero force results in constant velocity/zero acceleration;

- 28c. The constant horizontal velocity of the railway engine is 16 ms^{-1} . A total horizontal resistive force of 76 kN acts on the railway engine. [2 marks]

Calculate the useful power output of the railway engine.

Markscheme

power = 16×76000 ;
1.2 MW;

- 28d. The power driving the railway engine is switched off. The railway engine stops, from its speed of 16 ms^{-1} , without braking in a distance of 1.1 km. A student hypothesizes that the horizontal resistive force is constant. [2 marks]

Based on this hypothesis, calculate the mass of the railway engine.

Markscheme

acceleration = $\frac{16^2}{2 \times 1100}$ (= 0.116);

$m = \left(\frac{7.6 \times 10^4}{0.116} \right) 6.5 \times 10^5 \text{ kg}$;

Award [2] for a bald correct answer.

or

use of $Fs = \frac{1}{2}mv^2$;

$m = \left(\frac{2 \times 7.6 \times 10^4 \times 1100}{16^2} \right) 6.5 \times 10^5 \text{ kg}$;

Award [2] for a bald correct answer.

28e. Another hypothesis is that the horizontal force in (c) consists of two components. One component is a constant frictional force of 19 kN. The other component is a resistive force F that varies with speed v where F is proportional to v^3 . [5 marks]

(i) State the value of the magnitude of F when the railway engine is travelling at 16 ms^{-1} .

(ii) Determine the **total** horizontal resistive force when the railway engine is travelling at 8.0 ms^{-1} .

Markscheme

(i) 57 kN;

$$(ii) F_8 = \frac{F_{16}}{2^3};$$

$$F_8 = 7.1 \text{ (kN)};$$

$$\text{total force} = 19 + 7.1 \text{ (kN)};$$

$$= 26 \text{ kN};$$

Award [4] for a bald correct answer.

or

$$k = \left(\frac{57 \times 10^3}{16^3} \right) = 13.91;$$

$$F_8 = (13.91 \times 8^3) = 7.1 \text{ (kN)};$$

$$\text{total force} = 19 + 7.1 \text{ (kN)};$$

$$= 26 \text{ kN};$$

Award [4] for a bald correct answer.

28f. On its journey, the railway engine now travels around a curved track at constant speed. Explain whether or not the railway engine is accelerating. [3 marks]

Markscheme

direction of engine is constantly changing;

velocity is speed + direction / velocity is a vector;

engine is accelerating as velocity is changing;

Award [0] for a bald correct answer.

or

centripetal force required to maintain circular motion;

quotes Newton 1/Newton 2;

so engine is accelerating as a force acts;

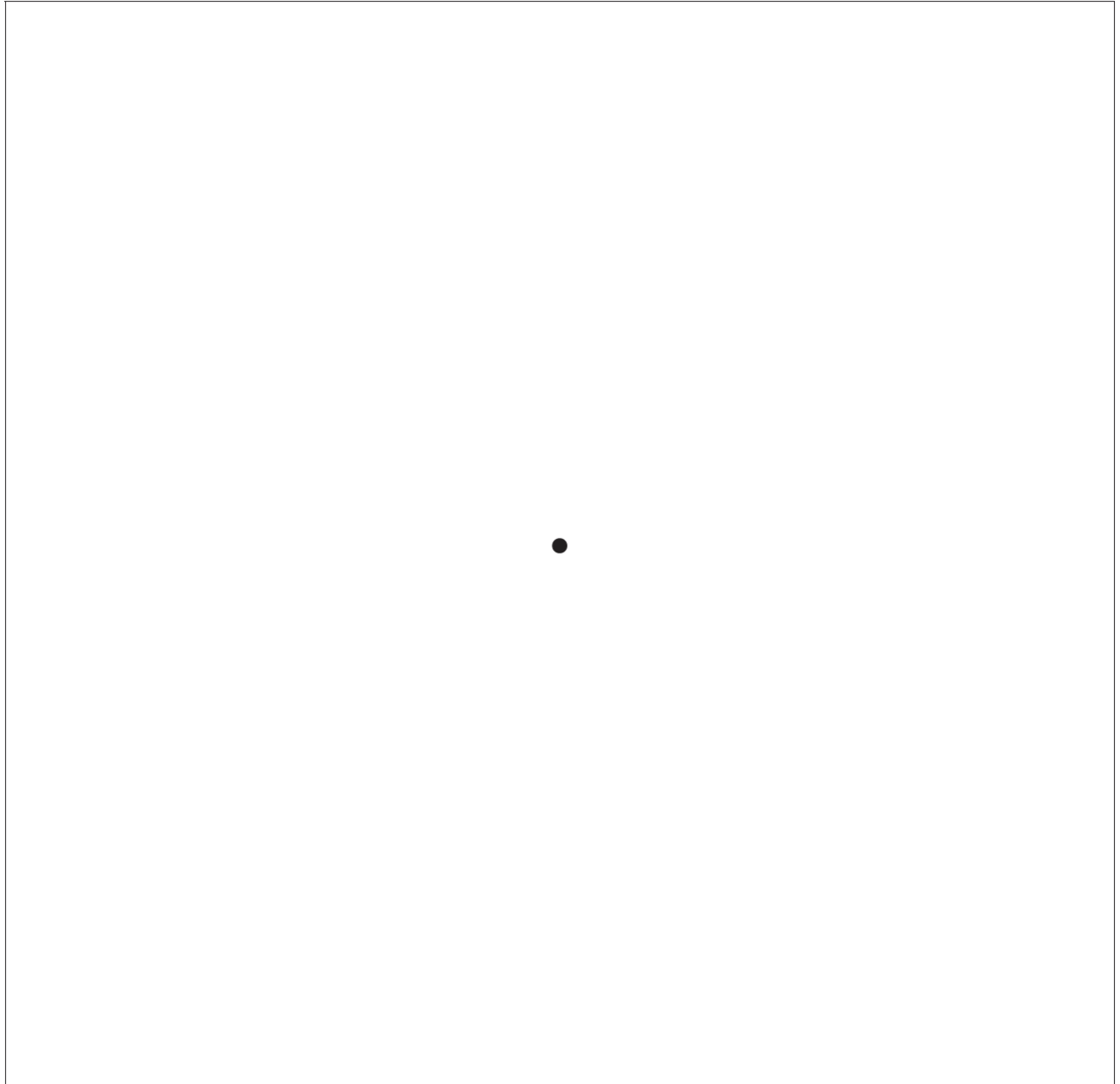
Award [0] for a bald correct answer.

Part 2 Electric motor

An electric motor is used to raise a load.

29a. Whilst being raised, the load accelerates uniformly upwards. The weight of the cable is negligible compared to the weight of the load. *[6 marks]*

(i) Draw a labelled free-body force diagram of the forces acting on the accelerating load. The dot below represents the load.



(ii) The load has a mass of 350 kg and it takes 6.5 s to raise it from rest through a height of 8.0 m.

Determine the tension in the cable as the load is being raised.

Markscheme

(i) upward arrow labelled T /tension/force in cable and downward arrow labelled W / mg /weight/gravity force; { *both needed* }
tension arrow length > weight length;

(ii) $a = \frac{2s}{t^2};$

$$a = \left(\frac{2 \times 8.0}{6.5^2} \right) = 0.38 \text{ (ms}^{-2}\text{)};$$

$$T = ma + mg \text{ **or** } T = 350(0.38 + 9.8);$$

3.6 kN;

Allow $g = 10 \text{ N kg}^{-1}$ (same answer to 2 sf).

29b. The electric motor can be adjusted such that, after an initial acceleration, [4 marks] the load moves at constant speed. The motor is connected to a 450 V supply and with the load moving at constant speed, it takes the motor 15 s to raise the load through 7.0 m.

(i) Calculate the power delivered to the load by the motor.

(ii) The current in the motor is 30 A. Estimate the efficiency of the motor.

Markscheme

(i) change in gpe = $350 \times 9.81 \times 7.0 (= 24 \text{ kJ})$;

$$\text{power} \left(= \frac{24 \times 10^3}{15} \right) = 1.6 \text{ kW};$$

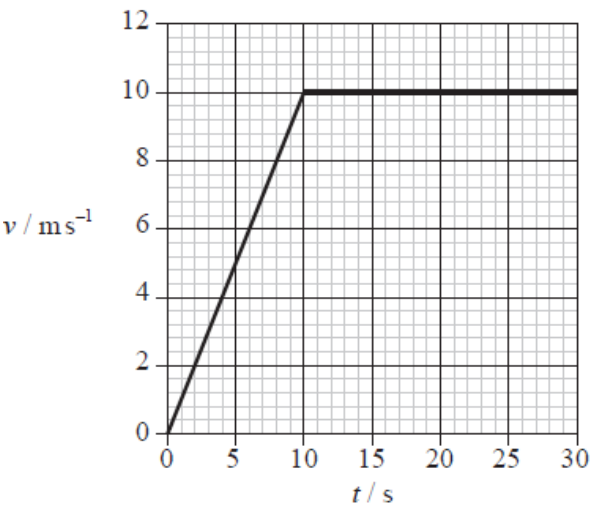
Allow $g = 10 \text{ N kg}^{-1}$.

(ii) power input to motor = 13.5 (kW);

$$\text{efficiency} = \left(\frac{1.6}{13.5} \right) = 0.12 \text{ **or** } 12\%;$$

30. Joseph runs along a long straight track. The variation of his speed v with time t is shown below.

[1 mark]



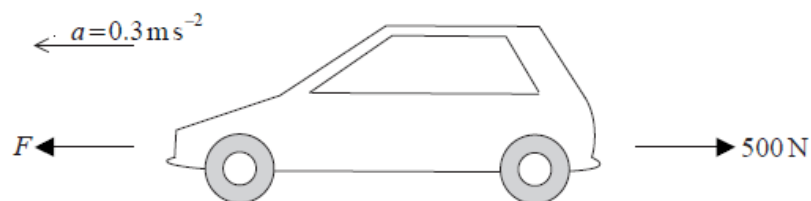
After 25 seconds Joseph has run 200 m. Which of the following is correct at 25 seconds?

	Instantaneous speed / m s^{-1}	Average speed / m s^{-1}
A.	8 m s^{-1}	8 m s^{-1}
B.	8 m s^{-1}	10 m s^{-1}
C.	10 m s^{-1}	8 m s^{-1}
D.	10 m s^{-1}	10 m s^{-1}

Markscheme

C

31. A car of mass 1000 kg accelerates on a straight, flat, horizontal road with an acceleration $a = 0.3 \text{ m s}^{-2}$. The driving force F on the car is opposed by a resistive force of 500 N. [1 mark]



The net (resultant) force on the car is

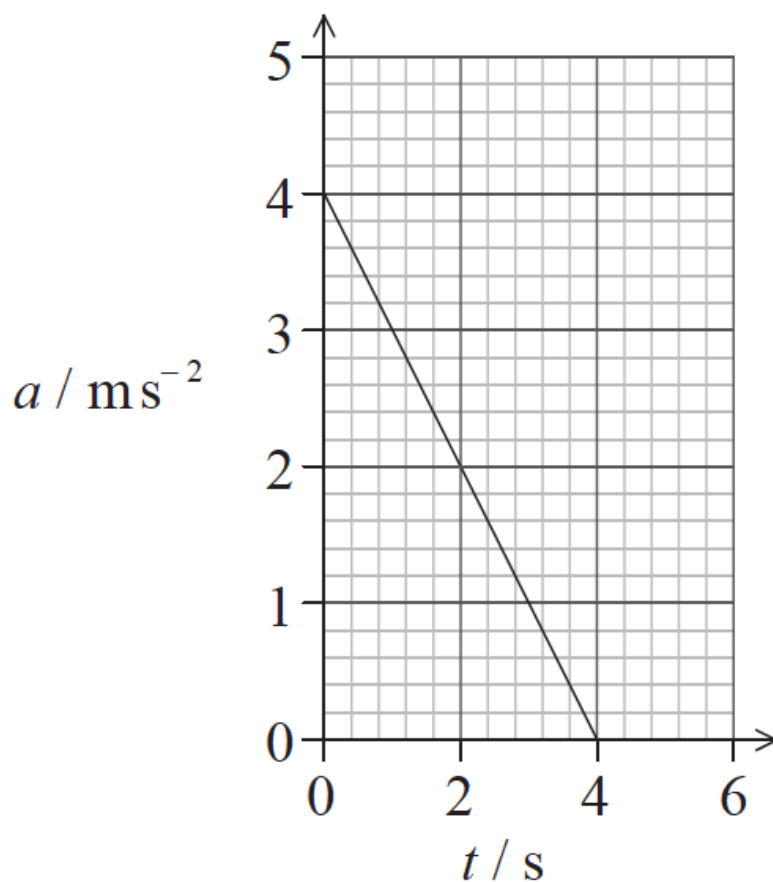
- A. 200 N.
- B. 300 N.
- C. 500 N.
- D. 800 N.

Markscheme

B

32.

[1

The graph shows the variation with time t of the acceleration a of an object. *mark]*

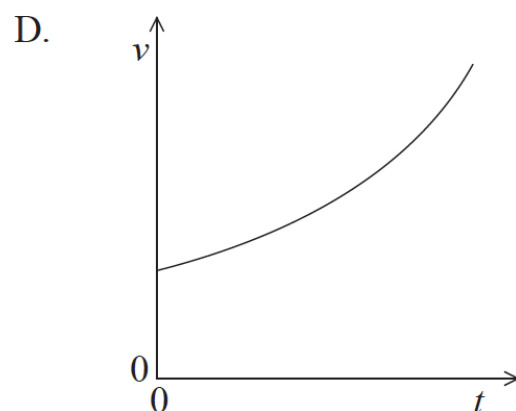
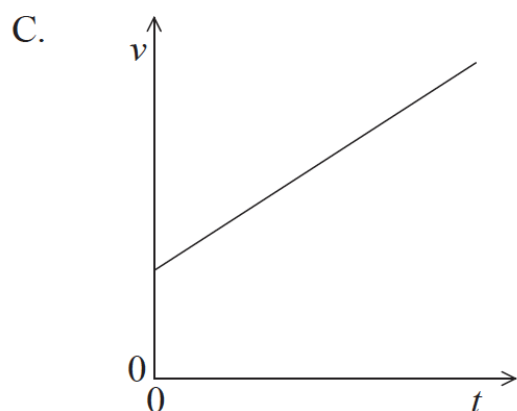
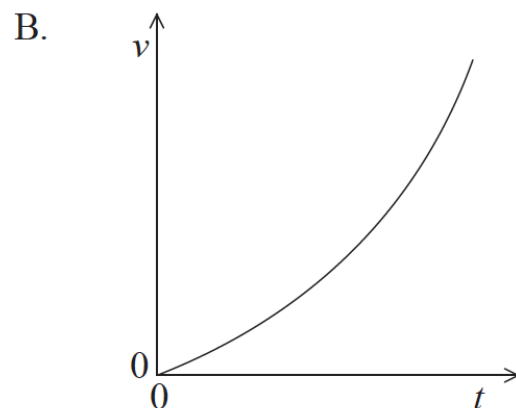
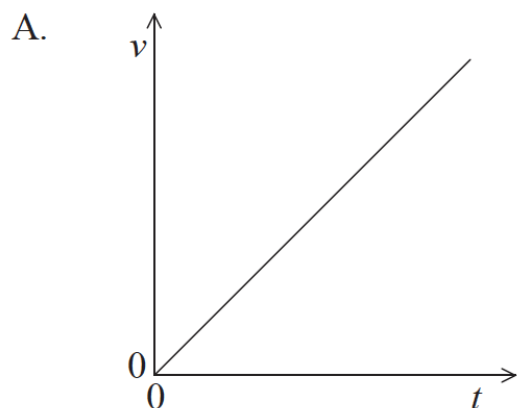
Which of the following is the change in velocity of the object in the time interval 0 to 4 s?

- A. -8 ms^{-1}
- B. -4 ms^{-1}
- C. $+4 \text{ ms}^{-1}$
- D. $+8 \text{ ms}^{-1}$

Markscheme

D

33. A car accelerates from rest. The acceleration increases with time. Which graph shows the variation with time t of the speed v of the car? [1 mark]



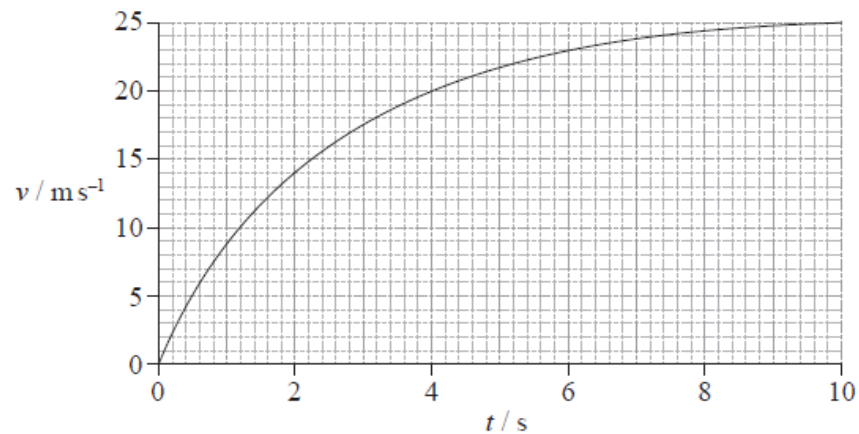
Markscheme

B

This question is in **two** parts. **Part 1** is about mechanics and thermal physics. **Part 2** is about nuclear physics.

Part 1 Mechanics and thermal physics

The graph shows the variation with time t of the speed v of a ball of mass 0.50 kg, that has been released from rest above the Earth's surface.



The force of air resistance is **not** negligible. Assume that the acceleration of free fall is $g = 9.81 \text{ m s}^{-2}$.

- 34a. State, without any calculations, how the graph could be used to determine [1 mark]
the distance fallen.

Markscheme

the area under the curve;

34b. (i) In the space below, draw and label arrows to represent the forces on the ball at 2.0 s. [7 marks]

ball at
 $t = 2.0 \text{ s}$ ●

Earth's surface —————

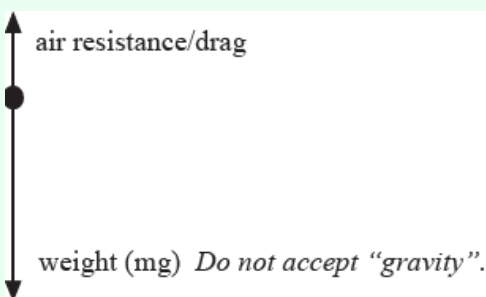
(ii) Use the graph opposite to show that the acceleration of the ball at 2.0 s is approximately 4 ms^{-2} .

(iii) Calculate the magnitude of the force of air resistance on the ball at 2.0 s.

(iv) State and explain whether the air resistance on the ball at $t = 5.0 \text{ s}$ is smaller than, equal to **or** greater than the air resistance at $t = 2.0 \text{ s}$.

Markscheme

(i) arrows as shown, with up arrow shorter;



(ii) drawing of tangent to curve at $t = 2.0 \text{ s}$;
calculation of slope of tangent in range $3.6 - 4.4 \text{ ms}^{-2}$;
Award [0] for calculations without a tangent but do not be particular about size of triangle.

(iii) calculation of $F = ma = 0.50 \times 4 = 2 \text{ N}$
 $R (= mg - ma = 0.50 \times 9.81 - 0.50 \times 4) \approx 3 \text{ N}$;

(iv) the acceleration is decreasing;
and so R is greater;

or

air resistance forces increase with speed;
since speed at 5.0 s is greater so is resistance force;

34c. After 10 s the ball has fallen 190 m.

[6 marks]

(i) Show that the sum of the potential and kinetic energies of the ball has decreased by 780 J.

(ii) The specific heat capacity of the ball is $480 \text{ J kg}^{-1} \text{ K}^{-1}$. Estimate the increase in the temperature of the ball.

(iii) State an assumption made in the estimate in (c)(ii).

Markscheme

(i) loss of potential energy is $mg\Delta h = 0.50 \times 9.81 \times 190 = 932\text{J}$;

gain in kinetic energy is $\frac{1}{2}mv^2 = \frac{1}{2}0.50 \times 25^2 = 156\text{J}$;

loss of mechanical energy is $932 - 156$;
 $\approx 780\text{J}$

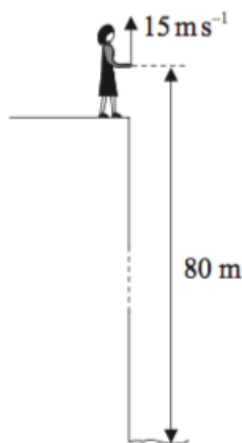
(ii) $mc\Delta\theta = 780\text{J}$;

$\Delta\theta = \left(\frac{780}{0.5 \times 480}\right) \approx 3\text{K}/3^\circ\text{C}$;

(iii) all the lost energy went into heating just the ball / no energy transferred to surroundings / the ball was heated uniformly;

This question is about kinematics.

Lucy stands on the edge of a vertical cliff and throws a stone vertically upwards.



The stone leaves her hand with a speed of 15ms^{-1} at the instant her hand is 80m above the surface of the sea. Air resistance is negligible and the acceleration of free fall is 10ms^{-2} .

35a. Calculate the maximum height reached by the stone as measured from the point where it is thrown. [2 marks]

Markscheme

$$h = \frac{v^2}{2g};$$

$$= \left(\frac{225}{20} \right) 11\text{m};$$

Award **[1 max]** for 91m or 91.25m (candidate adds cliff height incorrectly).

- 35b. Determine the time for the stone to reach the surface of the sea after leaving Lucy's hand. [3 marks]

Markscheme

time to reach maximum height=1.5s;

time to fall 91m=4.3s;

total time=5.8s;

Answer can be alternatively expressed as 3.0 (to return to hand) +2.8 (to fall 80m).

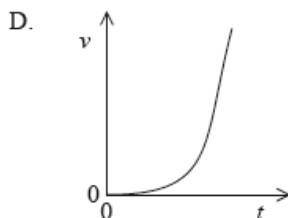
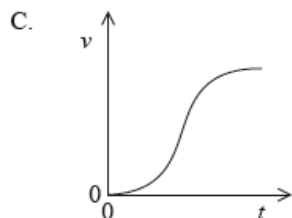
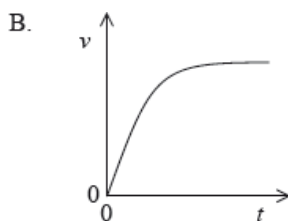
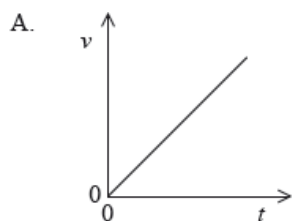
or

use of $s=ut+\frac{1}{2}at^2$;

$$80=-15t+5t^2 \text{ or } -80=15t-5t^2;$$

$$t=5.8\text{s};$$

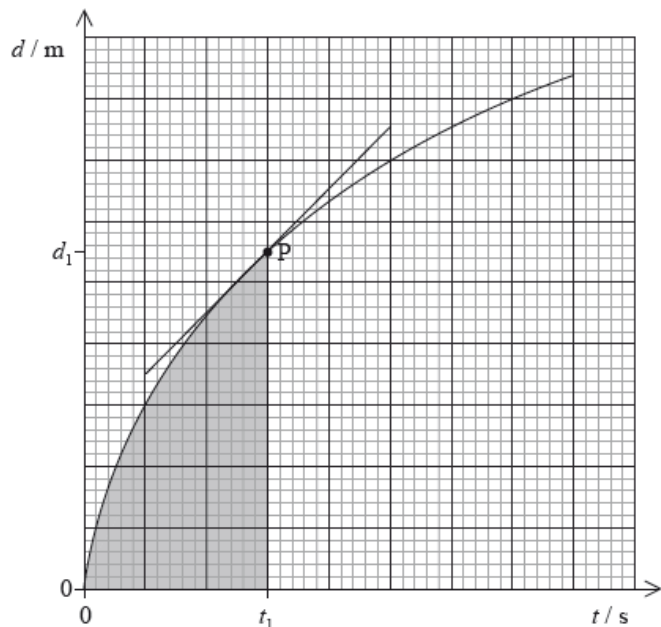
36. A raindrop falling from rest at time $t = 0$ reaches terminal velocity. Which graph best represents how the speed v varies with time t ? [1 mark]



Markscheme

B

37. The graph shows how the displacement d of an object varies with time t . [1 mark]
The tangent to the curve at time t_1 is also shown.



Which of the following gives the speed of the object at point P?

- A. the gradient at P
- B. the shaded area
- C. $\frac{1}{\text{gradient at P}}$
- D. $\frac{d_1}{t_1}$

Markscheme

A

In 1997 a high-speed car of mass 1.1×10^4 kg achieved the world land speed record. The car accelerated uniformly in two stages as shown in the table. The car started from rest.

	Time / s	Speed attained at end of stage / m s^{-1}
Stage 1	0.0 – 4.0	44
Stage 2	4.0 – 12	280

Use the data to calculate the

38a. average acceleration of the car in stage 1.

[1
mark]

Markscheme

11 ms^{-2} ;

38b. average net force required to accelerate the car in stage 2.

[3 marks]

Markscheme

$$\Delta v = 236;$$

$$a = \left(\frac{236}{8} =\right) 29.5 \text{ (ms}^{-2}\text{)};$$

$$(F = 1.1 \times 10^4 \times 29.5) = 3.2 \times 10^5 \text{ N};$$

Award **[2 max]** for omission of initial speed (answer is 390 kN).

Award **[3]** for correct bald answer.

38c. total distance travelled by the car in 12 s.

[2 marks]

Markscheme

phase 1 distance 88 m / phase 2 distance 1296 m;

total 1400 m;

Award [2] for correct bald answer.

Watch for significant figure penalty in this question (1384 m).

Award [1 max] for $\frac{1}{2}at^2$ substituted correctly for first phase, if no distances evaluated and answer incorrect.

Award [1 max] for correct addition of incorrect phase 1 and/or 2 distance(s).

This question is in **two** parts. **Part 1** is about the production of energy in nuclear fission. **Part 2** is about collisions.

Part 1 Production of energy in nuclear fission

A possible fission reaction is



39a. (i) State the value of x .

[6 marks]

(ii) Show that the energy released when one uranium nucleus undergoes fission in the reaction in (a) is about 2.8×10^{-11} J.

Mass of neutron	= 1.00867 u
Mass of U - 235 nucleus	= 234.99333 u
Mass of Kr - 92 nucleus	= 91.90645 u
Mass of Ba - 141 nucleus	= 140.88354 u

(iii) State how the energy of the neutrons produced in the reaction in (a) is likely to compare with the energy of the neutron that initiated the reaction.

Markscheme

(i) 3;

$$(ii) \Delta m = 234.99333 - 91.90645 - 140.88354 - [2 \times 1.00867];$$

$$= 0.186 \text{ (u)};$$

$$\text{energy released} = 0.186 \times 931 = 173 \text{ (MeV)};$$

$$173 \times 10^6 \times 1.6 \times 10^{-19};$$

$$(= 2.768) \approx 2.8 \times 10^{-11} \text{ (J)}$$

or

$$\Delta m = 234.99333 - 91.90645 - 140.88354 - [2 \times 1.00867];$$

$$= 0.186 \text{ (u)};$$

$$\text{mass converted} = 0.186 \times 1.66 \times 10^{-27} (= 3.09 \times 10^{-28});$$

$$(\text{use of } E = mc^2) \text{ energy} = 3.09 \times 10^{-28} \times 9 \times 10^{16};$$

$$(= 2.77) \approx 2.8 \times 10^{-11} \text{ (J)}$$

Award [2 max] if mass difference is incorrect.

If candidate carries forward an incorrect value from (a)(i) [2 is common], treat this as ecf in (a)(ii).

Award [3 max] if the candidate uses a value for x inconsistent with (a)(i).

(iii) greater/higher energy;

39b. Outline the role of the moderator.

[2 marks]

Markscheme

reduces neutron speed to (thermal) lower speeds;

so that chance of initiating fission is higher;

Accept "fast neutrons cannot cause fission" for 2nd marking point.

39c. A nuclear power plant that uses U-235 as fuel has a useful power output [4 marks]
of 16 MW and an efficiency of 40%. Assuming that each fission of U-235
gives rise to 2.8×10^{-11} J of energy, determine the mass of U-235 fuel used per
day.

Markscheme

40% efficient so 40 (MW) required;

$$\frac{40 \times 10^6}{2.8 \times 10^{-11}} = 1.43 \times 10^{18} \text{ per second};$$

number of fissions per day = 1.23×10^{23} ;

$$\left(= \frac{1.23 \times 10^{23} \times 235}{6 \times 10^{23}} \right) = 48 \text{ g per day};$$

Part 2 Collisions

39d. State the principle of conservation of momentum.

[2 marks]

Markscheme

the total momentum of a system is constant;

provided external force does not act;

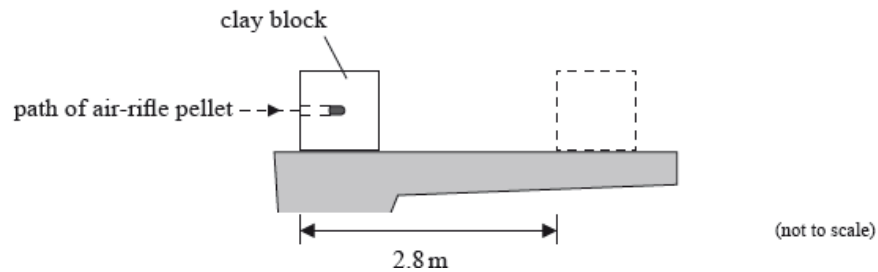
or

the momentum of an isolated/closed system;

is constant;

*Award **[1]** for momentum before collision equals collision afterwards.*

In an experiment, an air-rifle pellet is fired into a block of modelling clay that rests on a table.



The air-rifle pellet remains inside the clay block after the impact.

As a result of the collision, the clay block slides along the table in a straight line and comes to rest. Further data relating to the experiment are given below.

Mass of air - rifle pellet	= 2.0 g
Mass of clay block	= 56 g
Velocity of impact of air - rifle pellet	= 140 m s^{-1}
Stopping distance of clay block	= 2.8 m

39e. (i) Show that the initial speed of the clay block after the air-rifle pellet strikes it is 4.8 m s^{-1} . [6 marks]

(ii) Calculate the average frictional force that the surface of the table exerts on the clay block whilst the clay block is moving.

Markscheme

(i) initial momentum = $2.0 \times 10^{-3} \times 140$;

$$\text{final speed } \frac{2.0 \times 10^{-3} \times 140}{5.6 \times 10^{-2} + 2.0 \times 10^{-3}};$$

$$= 4.8 \text{ m s}^{-1}$$

Watch for incorrect mass values in equation.

(ii) initial kinetic energy of pellet + clay block = $\frac{1}{2}mv^2$;

$$0.5 \times 0.058 \times 4.8^2 (= 0.67 \text{ J});$$

$$\text{force} = \frac{\text{work done}}{\text{distance travelled}};$$

$$= 0.24 \text{ N};$$

or

use of appropriate kinematic equation with consistent sign usage *e.g.* $a = \frac{u^2 - v^2}{2s}$;

$$a = \frac{4.8^2}{2 \times 2.8};$$

$$F = \frac{0.058 \times 4.8^2}{2 \times 2.8};$$

$$= 0.24 \text{ N};$$

- 39f. Discuss the energy transformations that occur in the clay block and the air-rifle pellet from the moment the air-rifle pellet strikes the block until the clay block comes to rest. [3 marks]

Markscheme

kinetic energy of pellet is transferred to kinetic energy of clay block;

and internal energy of pellet and clay block;

clay block loses kinetic energy as thermal energy/heat;

- 39g. The clay block is dropped from rest from the edge of the table and falls vertically to the ground. The table is 0.85 m above the ground. Calculate the speed with which the clay block strikes the ground. [2 marks]

Markscheme

$$v = \sqrt{2gs};$$

$$= 4.1 \text{ m s}^{-1};$$

Allow $g = 10 \text{ m s}^{-2}$ answer 4.1 m s^{-2}

Award **[2]** for bald correct answer.

40. The time taken for a stone dropped from rest to fall vertically through 16 m [1
is 2.0 s. Based on these measurements, what is the best estimate for the mark]
acceleration of free fall?
- A. 4.0 m s^{-2}
 - B. 8.0 m s^{-2}
 - C. 9.8 m s^{-2}
 - D. 10 m s^{-2}

Markscheme

B

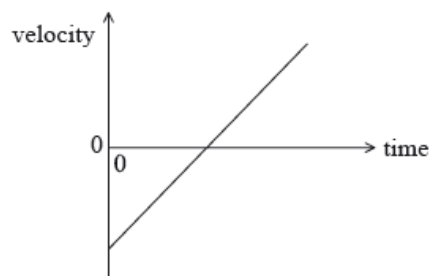
41. Two balls of different mass are dropped from the top of a tall building one [1
after the other. The distance between the balls mark]
- A. increases with time.
 - B. depends on the initial velocity only.
 - C. remains constant.
 - D. depends on the mass of the balls.

Markscheme

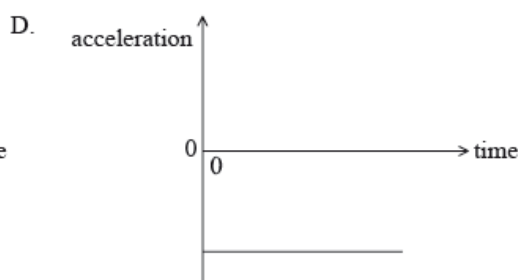
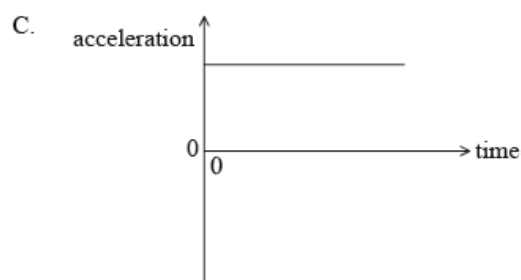
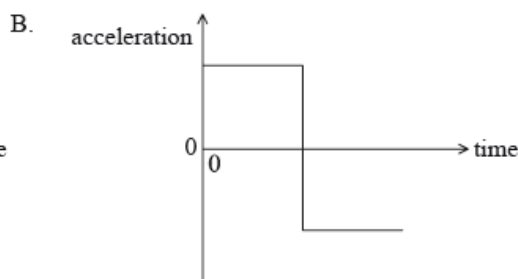
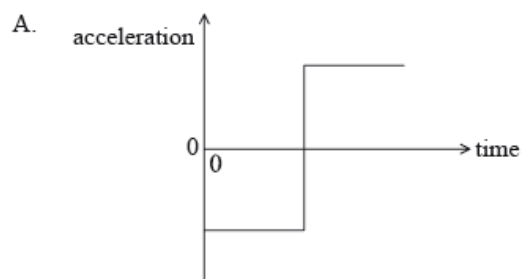
A

42. The graph shows how the velocity of a particle varies with time.

[1
mark]



Which of the following graphs correctly shows how the acceleration of the particle varies with time?



Markscheme

C

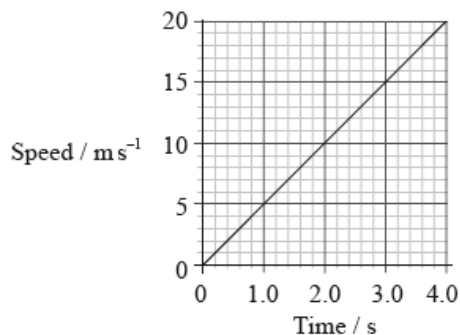
43. A skydiver jumped out of an airplane. On reaching a terminal speed of 60 m s^{-1} , she opened her parachute. Which of the following describes her motion after opening her parachute? [1 mark]

- A. She went upwards for a short time, before falling to Earth at a speed of 60 m s^{-1} .
- B. She continued downwards at 60 m s^{-1} , but hit the ground with less force.
- C. She continued to fall but reached a new terminal speed of less than 60 m s^{-1} .
- D. She went upwards for a short time, before falling to Earth at a speed of less than 60 m s^{-1} .

Markscheme

C

44. The graph is a speed versus time graph for an object that is moving in a straight line. [1 mark]



The distance travelled by the object during the first 4.0 seconds is

- A. 80 m.
- B. 40 m.
- C. 20 m.
- D. 5 m.

Markscheme

B