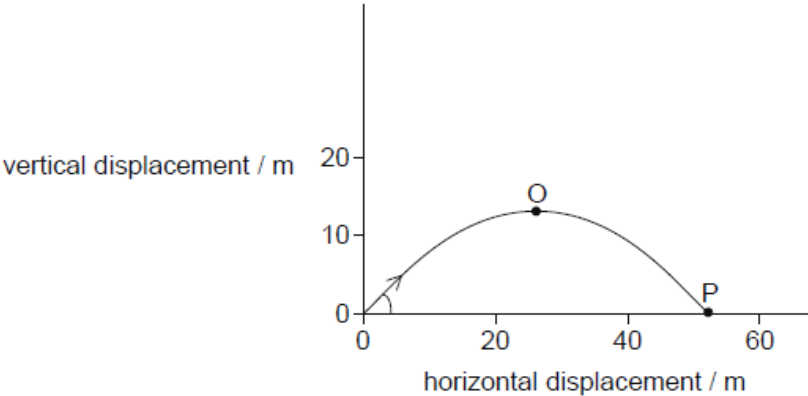


Mechanics motion SL *[165 marks]*

1. A truck has an initial speed of 20 m s^{-1} . It decelerates at 4.0 m s^{-2} . What is the distance taken by the truck to stop? *[1 mark]*

- A. 2.5 m
- B. 5.0 m
- C. 50 m
- D. 100 m

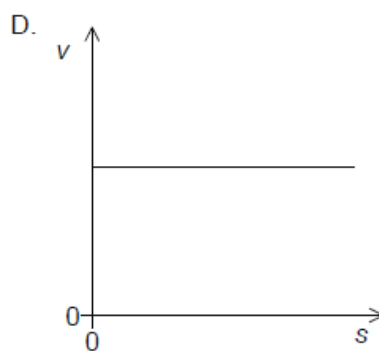
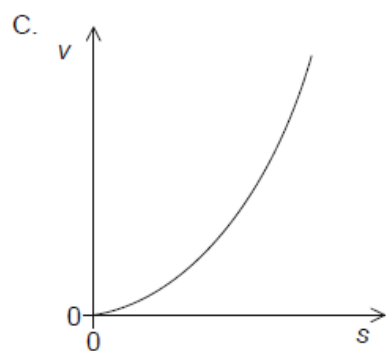
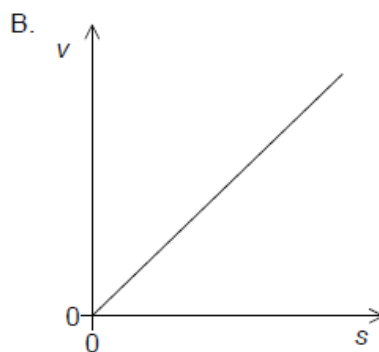
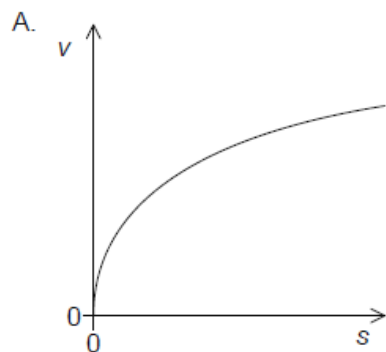
2. A projectile is fired at an angle to the horizontal. Air resistance is negligible. The path of the projectile is shown. *[1 mark]*



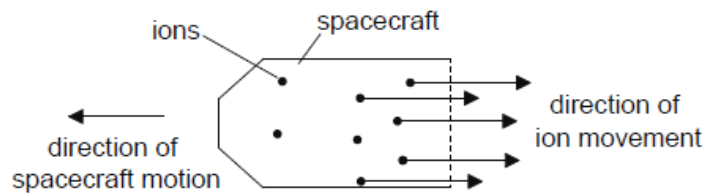
Which gives the magnitude of the horizontal component and the magnitude of the vertical component of the velocity of the projectile between O and P?

	Magnitude of horizontal component of velocity	Magnitude of vertical component of velocity
A.	constant	increases
B.	constant	constant
C.	increases	increases
D.	increases	constant

3. A runner starts from rest and accelerates at a constant rate throughout a race. Which graph shows the variation of speed v of the runner with distance travelled s ? [1 mark]



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



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

4a. Determine the initial acceleration of the spacecraft.

[2 marks]

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

4b. Estimate the maximum speed of the spacecraft.

[2 marks]

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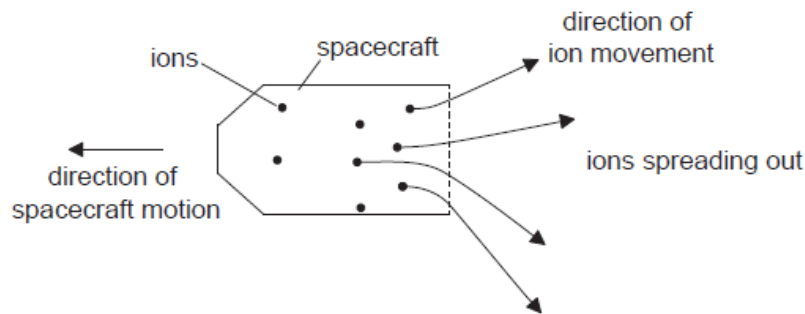
4c. Outline why scientists sometimes use estimates in making calculations. [1 mark]

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In practice, the ions leave the spacecraft at a range of angles as shown.



4d. Outline why the ions are likely to spread out. [2 marks]

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4e. Explain what effect, if any, this spreading of the ions has on the acceleration of the spacecraft.

[2 marks]

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

4f. Outline what is meant by the gravitational field strength at a point.

[2 marks]

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4g. Newton's law of gravitation applies to point masses. Suggest why the law can be applied to a satellite orbiting a spherical planet of uniform density. [1 mark]

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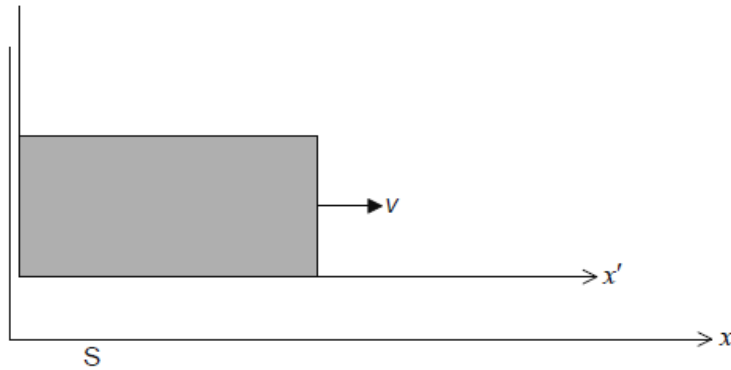
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The diagram shows the axes for two inertial reference frames. Frame S represents the ground and frame S' is a box that moves to the right relative to S with speed v .



5a. State what is meant by a reference frame.

[1
mark]

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When the origins of the two frames coincide all clocks show zero. At that instant a beam of light of speed c is emitted from the left wall of the box towards the right wall. The box has proper length L . Consider the event E = light arrives at the right wall of the box.

Using **Galilean** relativity,

5b. explain why the time coordinate of E in frame S is $t = \frac{L}{c}$.

[2 marks]

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5c. hence show that the space coordinate of E in frame S is $x = L + \frac{vL}{c}$. [1 mark]

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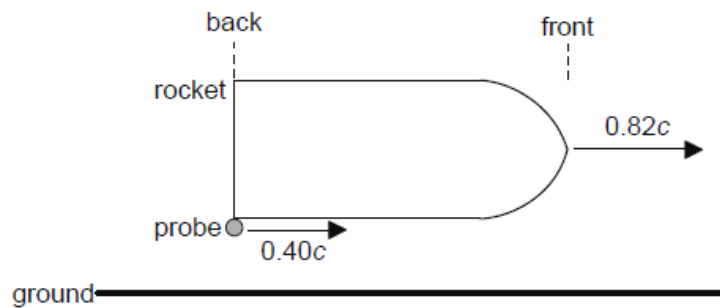
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A rocket of proper length 120 m moves to the right with speed $0.82c$ relative to the ground.



A probe is released from the back of the rocket at speed $0.40c$ relative to the rocket.

6a. Calculate the speed of the probe relative to the ground. [2 marks]

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- 6b. Determine the time it takes the probe to reach the front of the rocket according to an observer at rest in the rocket. [2 marks]

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- 6c. Determine the time it takes the probe to reach the front of the rocket according to an observer at rest on the ground. [3 marks]

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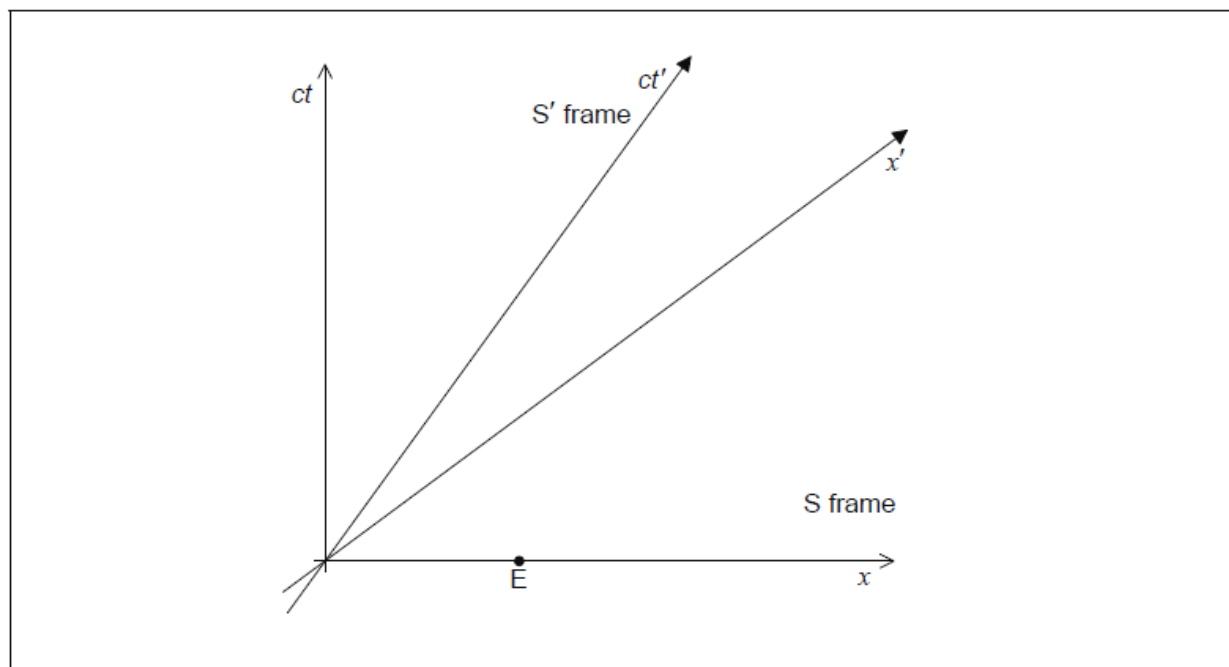
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The spacetime diagram shows the axes of an inertial reference frame S and the axes of a second inertial reference frame S' that moves relative to S with speed $0.745c$. When clocks in both frames show zero the origins of the two frames coincide.



Event E has coordinates $x = 1$ m and $ct = 0$ in frame S. Show that in frame S' the space coordinate and time coordinate of event E are

7a. $x' = 1.5$ m.

[2 marks]

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7b. $ct' = -1.1$ m.

[1
mark]

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7c. Label, on the diagram, the space coordinate of event E in the S' frame. Label this event with the letter P.

[1
mark]

- 7d. Label, on the diagram, the event that has coordinates $x' = 1.0$ m and $ct' = 0$. Label this event with the letter Q. [1 mark]

A rod at rest in frame S has proper length 1.0 m. At $t = 0$ the left-hand end of the rod is at $x = 0$ and the right-hand end is at $x = 1.0$ m.

- 7e. Using the spacetime diagram, outline without calculation, why observers in frame S' measure the length of the rod to be less than 1.0 m. [3 marks]

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- 7f. Using the spacetime diagram, estimate, in m, the length of this rod in the S' frame. [1 mark]

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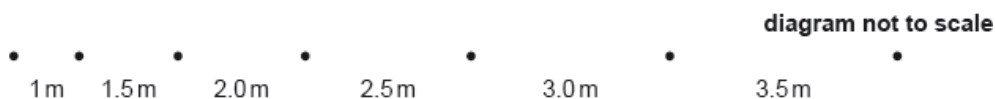
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8. An object is projected vertically upwards at time $t = 0$. Air resistance is negligible. The object passes the same point above its starting position at times 2 s and 8 s. [1 mark]

If $g = 10 \text{ m s}^{-2}$, what is the initial speed of the object?

- A. 50
- B. 30
- C. 25
- D. 4

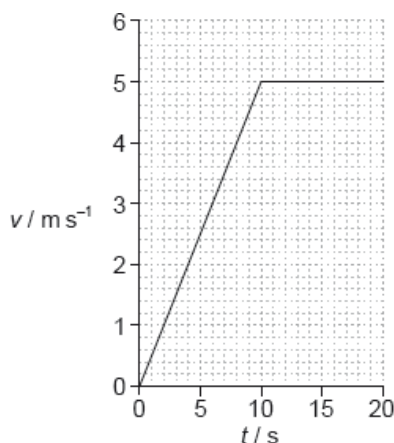
9. The distances between successive positions of a moving car, measured at equal time intervals, are shown. [1 mark]



The car moves with

- A. acceleration that increases linearly with time.
- B. acceleration that increases non-linearly with time.
- C. constant speed.
- D. constant acceleration.

10. A boy runs along a straight horizontal track. The graph shows how his speed v varies with time t . [1 mark]



After 15 s the boy has run 50 m. What is his instantaneous speed and his average speed when $t = 15 \text{ s}$?

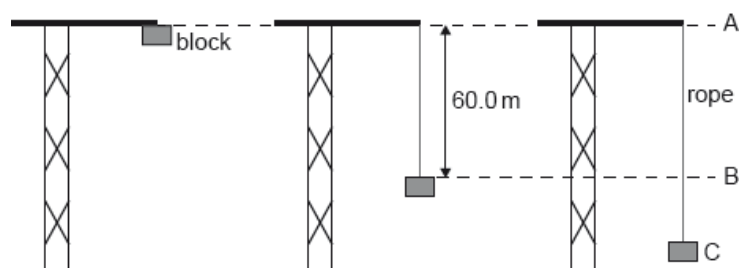
	Instantaneous speed / m s^{-1}	Average speed / m s^{-1}
A.	3.3	3.3
B.	3.3	5.0
C.	5.0	3.3
D.	5.0	5.0

11. Two balls X and Y with the same diameter are fired horizontally with the same initial momentum from the same height above the ground. The mass of X is greater than the mass of Y. Air resistance is negligible. [1 mark]

What is correct about the horizontal distances travelled by X and Y and the times taken by X and Y to reach the ground?

	Horizontal distances	Time to reach ground
A.	X and Y the same	X and Y times the same
B.	X and Y the same	X takes a shorter time than Y
C.	X less than Y	X and Y times the same
D.	X less than Y	X takes a shorter time than Y

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



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

- 12a. At position B the rope starts to extend. Calculate the speed of the block at position B. [2 marks]

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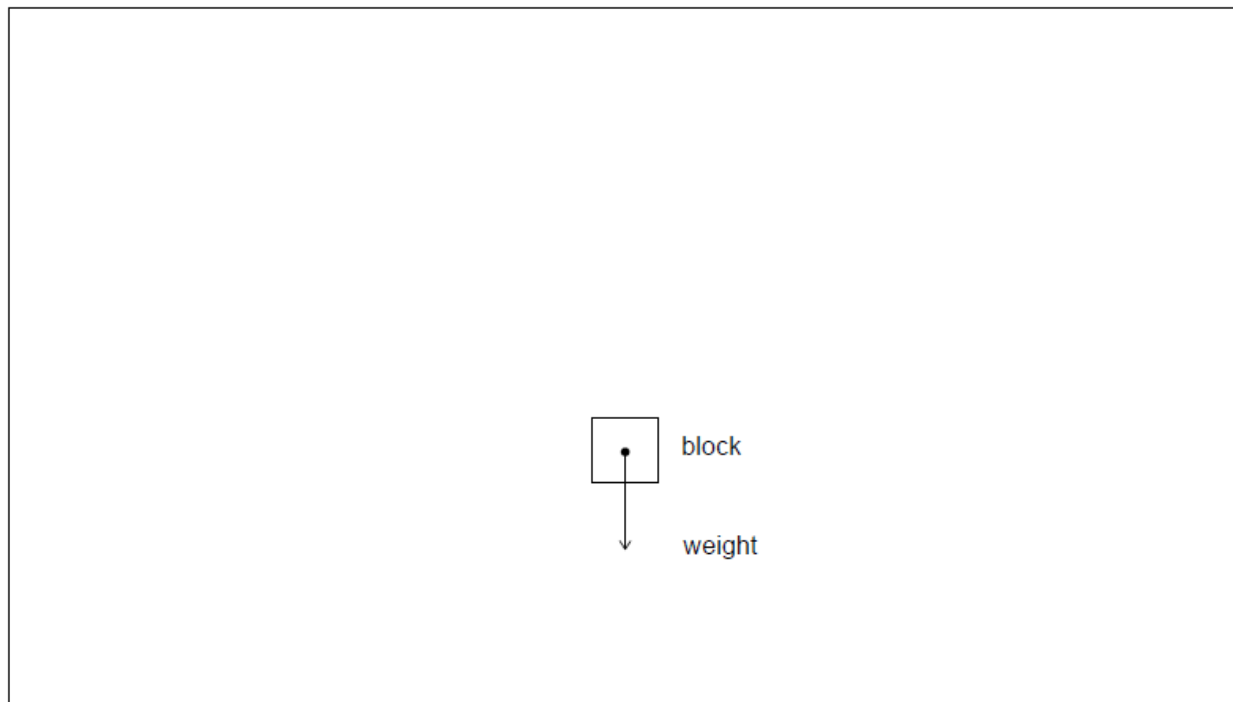
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At position C the speed of the block reaches zero. The time taken for the block to fall between B and C is 0.759 s. The mass of the block is 80.0 kg.

12b. Determine the magnitude of the average resultant force acting on the block between B and C. [2 marks]

[illegible]

12c. Sketch on the diagram the average resultant force acting on the block [2 marks]
between B and C. The arrow on the diagram represents the weight of the
block.



12d. Calculate the magnitude of the average force exerted by the rope on the [2 marks]
block between B and C.

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

12e. between A and B. [1 mark]

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12f. between B and C. [1 mark]

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- 12g. The length reached by the rope at C is 77.4 m. Suggest how energy considerations could be used to determine the elastic constant of the rope. [2 marks]

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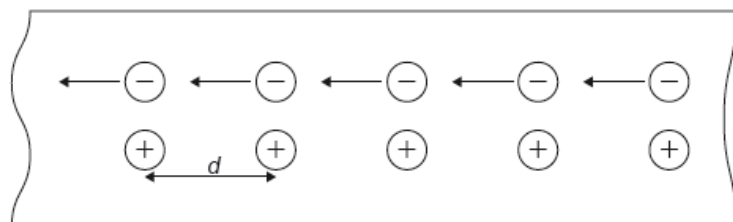
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The diagram shows the motion of the electrons in a metal wire carrying an electric current as seen by an observer X at rest with respect to the wire. The distance between adjacent positive charges is d .



- 13a. State whether the field around the wire according to observer X is electric, [1 mark]
magnetic or a combination of both.

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Observer Y is at rest with respect to the electrons.

13b. Discuss the change in d according to observer Y.

[2 marks]

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13c. Deduce whether the overall field around the wire is electric, magnetic or a combination of both according to observer Y. [2 marks]

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Muons are created in the upper atmosphere of the Earth at an altitude of 10 km above the surface. The muons travel vertically down at a speed of $0.995c$ with respect to the Earth. When measured at rest the average lifetime of the muons is $2.1\ \mu\text{s}$.

- 14a. Calculate, according to Galilean relativity, the time taken for a muon to travel to the ground. *[1 mark]*

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- 14b. Deduce why only a small fraction of the total number of muons created is expected to be detected at ground level according to Galilean relativity. *[1 mark]*

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- 14c. Calculate, according to the theory of special relativity, the time taken for a muon to reach the ground in the reference frame of the muon. *[2 marks]*

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- 14d. Discuss how your result in (b)(i) and the outcome of the muon decay experiment support the theory of special relativity. [2 marks]

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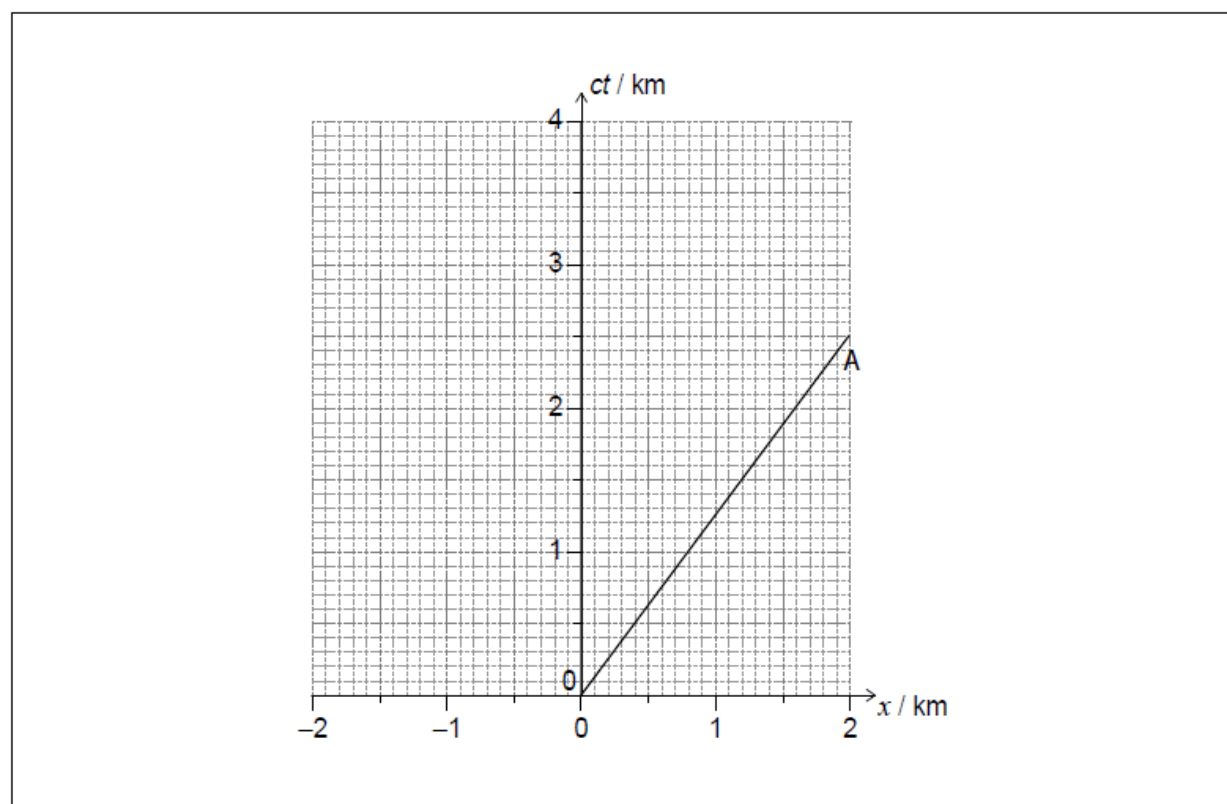
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An observer on Earth watches rocket A travel away from Earth at a speed of $0.80c$. The spacetime diagram shows the worldline of rocket A in the frame of reference of the Earth observer who is at rest at $x = 0$.



Another rocket, B, departs from the same location as A but later than A at $ct = 1.2$ km according to the Earth observer. Rocket B travels at a constant speed of $0.60c$ in the opposite direction to A according to the Earth observer.

- 15a. Draw on the spacetime diagram the worldline of B according to the Earth observer and label it B. [2 marks]

Rocket A and rocket B both emit a flash of light that are received simultaneously by the Earth observer. Rocket A emits the flash of light at a time coordinate $ct = 1.8$ km according to the Earth observer.

- 15b. Deduce, showing your working on the spacetime diagram, the value of ct [3 marks] according to the Earth observer at which the rocket B emitted its flash of light.

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- 15c. Explain whether or not the arrival times of the two flashes in the Earth [2 marks] frame are simultaneous events in the frame of rocket A.

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- 15d. Calculate the velocity of rocket B relative to rocket A. [2 marks]

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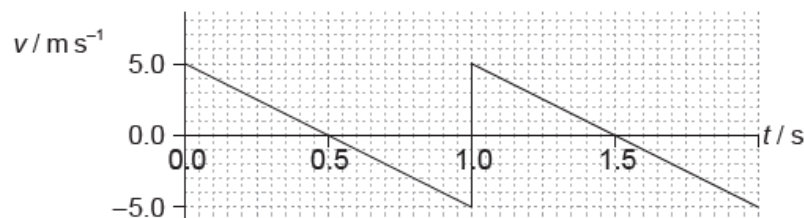
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16. The variation of the displacement of an object with time is shown on a graph. What does the area under the graph represent? [1 mark]
- A. No physical quantity
 - B. Velocity
 - C. Acceleration
 - D. Impulse

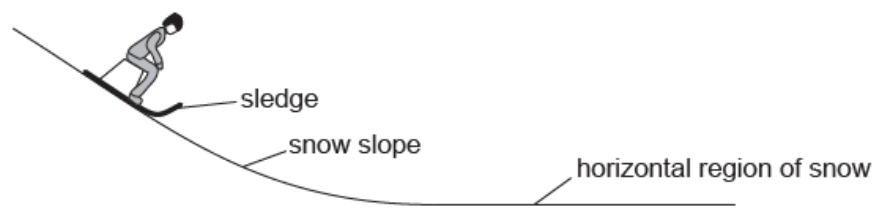
17. An object is thrown upwards. The graph shows the variation with time t of the velocity v of the object. [1 mark]



What is the total displacement at a time of 1.5 s, measured from the point of release?

- A. 0 m
 - B. 1.25 m
 - C. 2.50 m
 - D. 3.75 m
18. An object is released from a stationary hot air balloon at height h above the ground. [1 mark]
- An identical object is released at height h above the ground from another balloon that is rising at constant speed. Air resistance is negligible. What does **not** increase for the object released from the rising balloon?
- A. The distance through which it falls
 - B. The time taken for it to reach the ground
 - C. The speed with which it reaches the ground
 - D. Its acceleration

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



19a. Draw the free-body diagram for the sledge at the position shown on the snow slope. [2 marks]

Blank area for drawing the free-body diagram for the sledge on the snow slope.

19b. After leaving the snow slope, the girl on the sledge moves over a horizontal region of snow. Explain, with reference to the physical origin of the forces, why the vertical forces on the girl must be in equilibrium as she moves over the horizontal region. [3 marks]

Blank area for explaining why the vertical forces on the girl must be in equilibrium as she moves over the horizontal region.

- 19c. When the sledge is moving on the horizontal region of the snow, the girl [2 marks] jumps off the sledge. The girl has no horizontal velocity after the jump. The velocity of the sledge immediately after the girl jumps off is 4.2 m s^{-1} . The mass of the girl is 55 kg and the mass of the sledge is 5.5 kg. Calculate the speed of the sledge immediately before the girl jumps from it.

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- 19d. The girl chooses to jump so that she lands on loosely-packed snow rather [3 marks] than frozen ice. Outline why she chooses to land on the snow.

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

19e. Show that the acceleration of the sledge is about -2 m s^{-2} .

[3 marks]

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19f. Calculate the distance along the slope at which the sledge stops moving. [2 marks]
Assume that the coefficient of dynamic friction is constant.

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19g. The coefficient of static friction between the sledge and the snow is 0.14. [2 marks]
Outline, with a calculation, the subsequent motion of the sledge.

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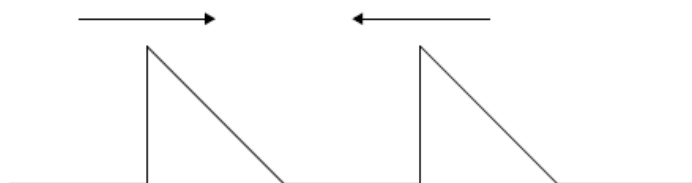
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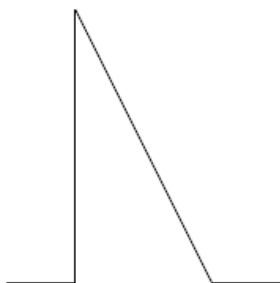
20. Two pulses are travelling towards each other.

[1
mark]

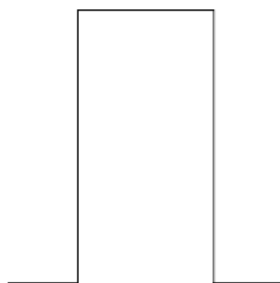


What is a possible pulse shape when the pulses overlap?

A.



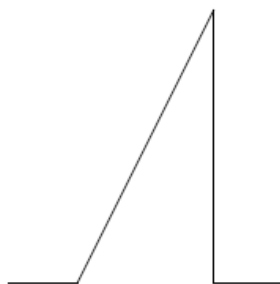
B.



C.

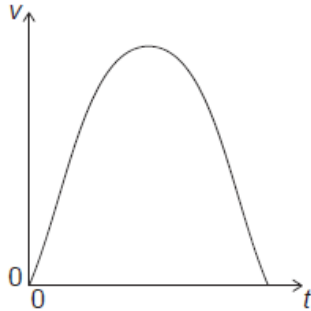


D.

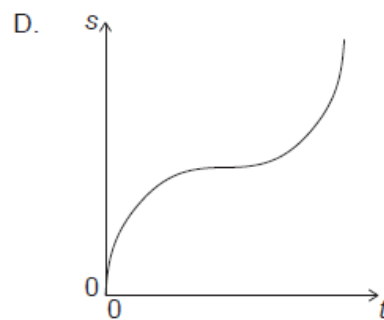
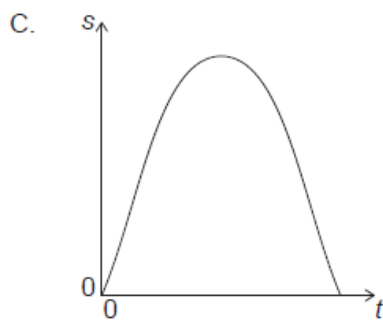
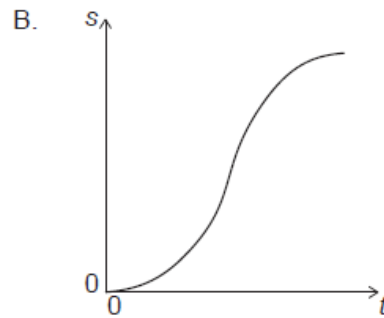
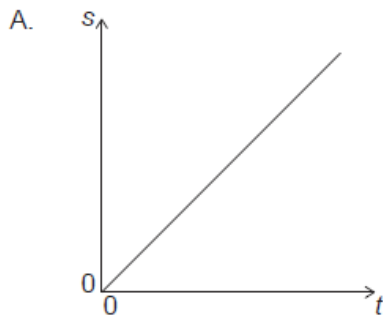


21. An object is released from rest in the gravitational field of the Earth. Air resistance is negligible. How far does the object move during the fourth second of its motion? [1 mark]
- A. 15 m
B. 25 m
C. 35 m
D. 45 m

22. The graph shows the variation of speed v of an object with time t . [1 mark]



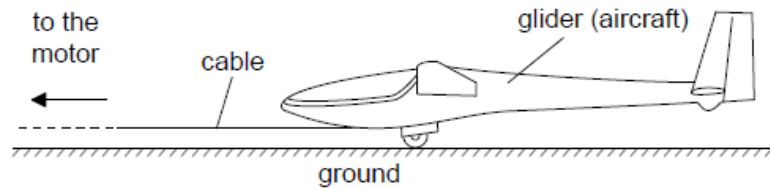
Which graph shows how the distance s travelled by the object varies with t ?



23. A ball is tossed vertically upwards with a speed of 5.0 m s^{-1} . After how many seconds will the ball return to its initial position? [1 mark]
- A. 0.50 s
B. 1.0 s
C. 1.5 s
D. 2.0 s

24. A projectile is fired horizontally from the top of a cliff. The projectile hits the ground 4 s later at a distance of 2 km from the base of the cliff. What is the height of the cliff? [1 mark]
- A. 40 m
 - B. 80 m
 - C. 120 m
 - D. 160 m
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25. A tennis ball is released from rest at a height h above the ground. At each bounce 50 % of its kinetic energy is lost to its surroundings. What is the height reached by the ball after its second bounce? [1 mark]
- A. $\frac{h}{8}$
 - B. $\frac{h}{4}$
 - C. $\frac{h}{2}$
 - D. zero

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



- 26a. The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s . Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. *[2 marks]*

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- 26b. The glider and pilot have a total mass of 492 kg . During the acceleration the glider is subject to an average resistive force of 160 N . Determine the average tension in the cable as the glider accelerates. *[3 marks]*

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26c. The cable is pulled by an electric motor. The motor has an overall efficiency of 23 %. Determine the average power input to the motor. [3 marks]

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26d. The cable is wound onto a cylinder of diameter 1.2 m. Calculate the angular velocity of the cylinder at the instant when the glider has a speed of 27 m s^{-1} . Include an appropriate unit for your answer. [2 marks]

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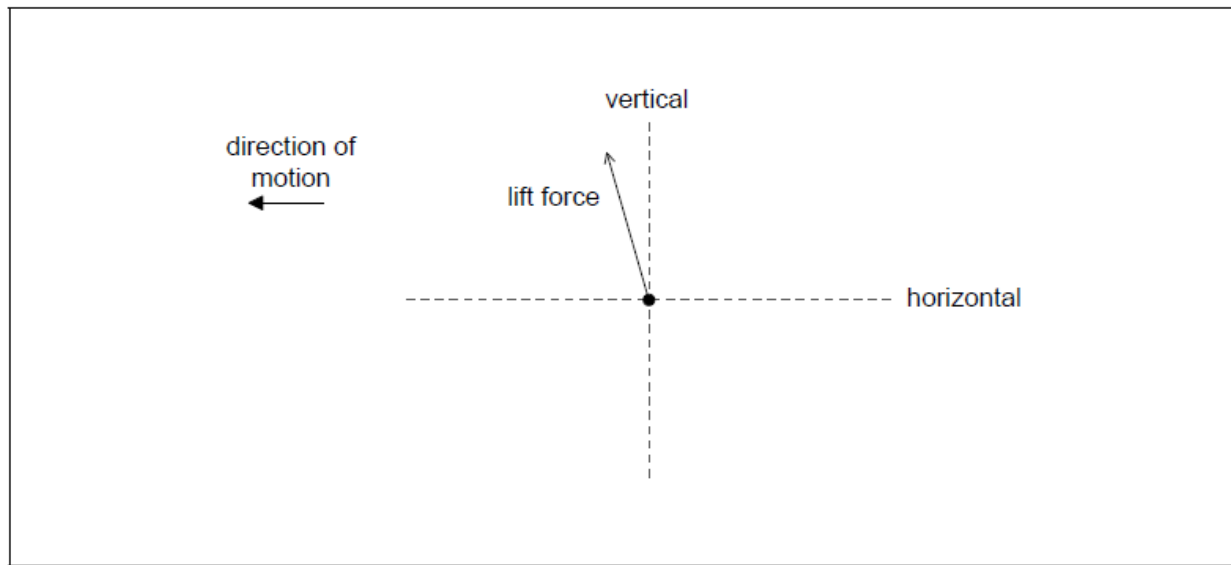
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- 26e. After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider. [2 marks]



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

- 26f. Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. [2 marks]

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26g. At a particular instant in the flight the glider is losing 1.00 m of vertical height for every 6.00 m that it goes forward horizontally. At this instant, the horizontal speed of the glider is 12.5 m s^{-1} . Calculate the **velocity** of the glider. Give your answer to an appropriate number of significant figures. [3 marks]

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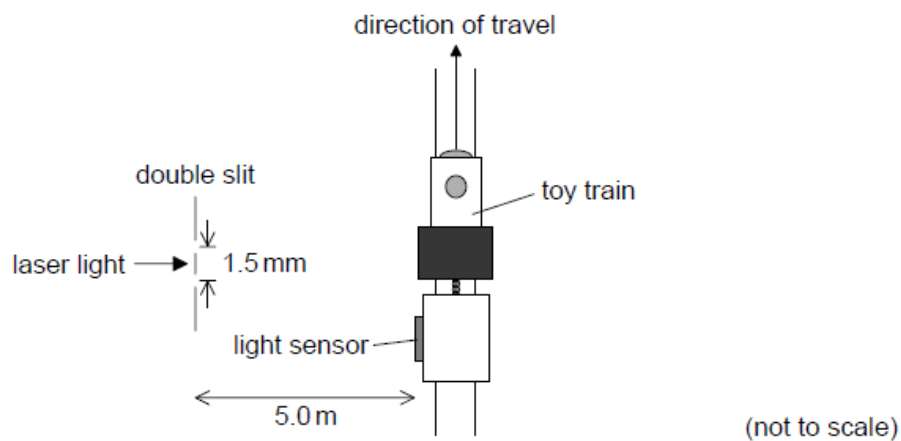
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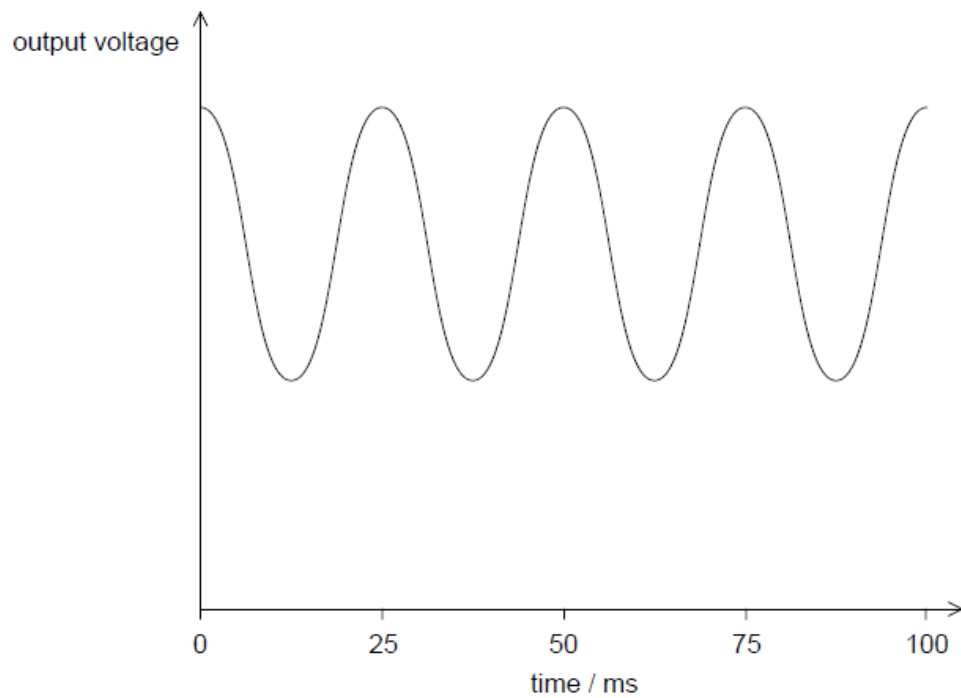
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A student investigates how light can be used to measure the speed of a toy train.



Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.



27a. Explain, with reference to the light passing through the slits, why a series [3 marks]
of voltage peaks occurs.

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27b. The slits are separated by 1.5 mm and the laser light has a wavelength of [1
 6.3×10^{-7} m. The slits are 5.0 m from the train track. Calculate the mark]
separation between two adjacent positions of the train when the output
voltage is at a maximum.

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27c. Estimate the speed of the train.

[2 marks]

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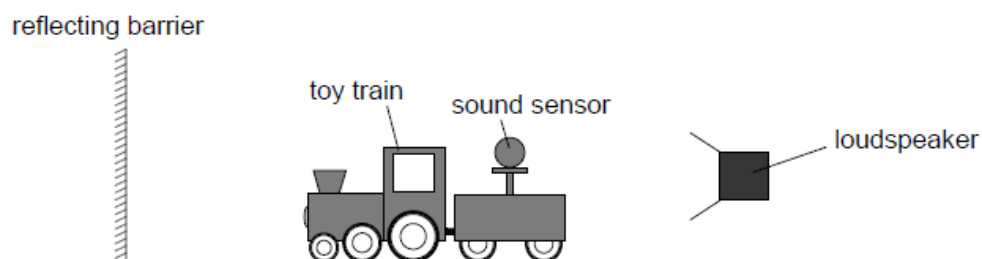
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27d. In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier. [2 marks]



The sound sensor gives a graph of the variation of output voltage with time along the track that is similar in shape to the graph shown in the resource. Explain how this effect arises.

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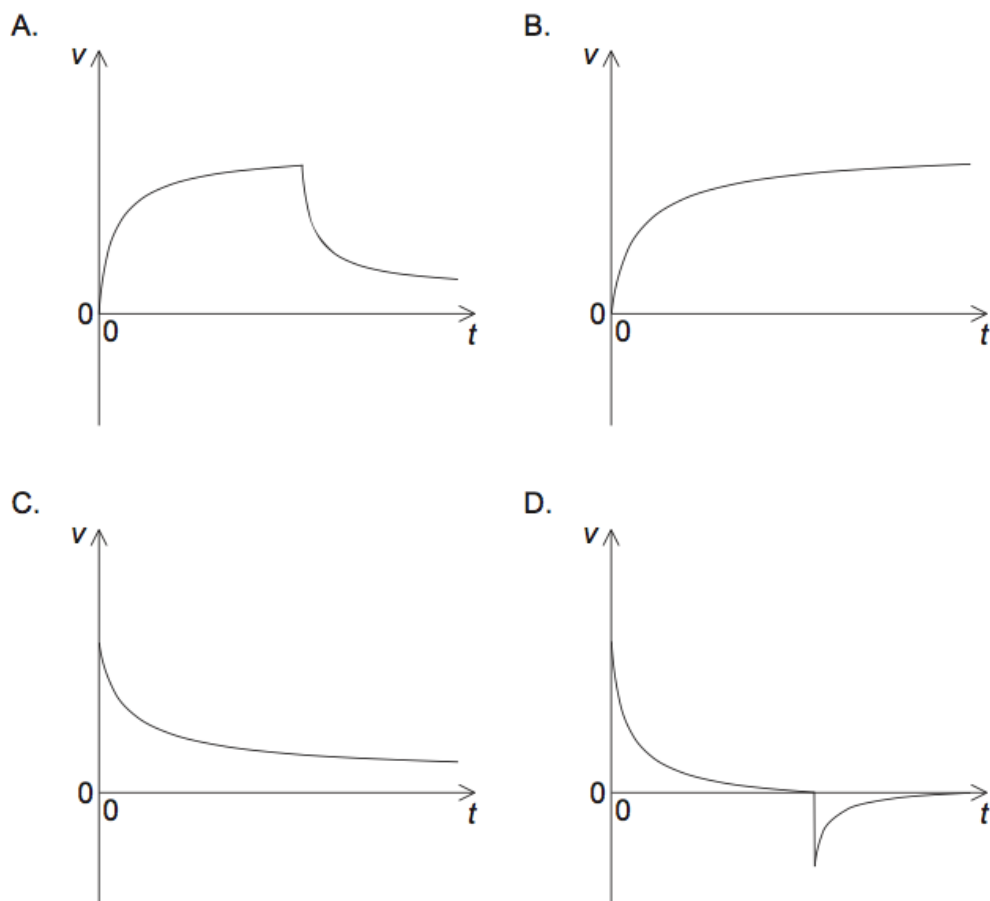
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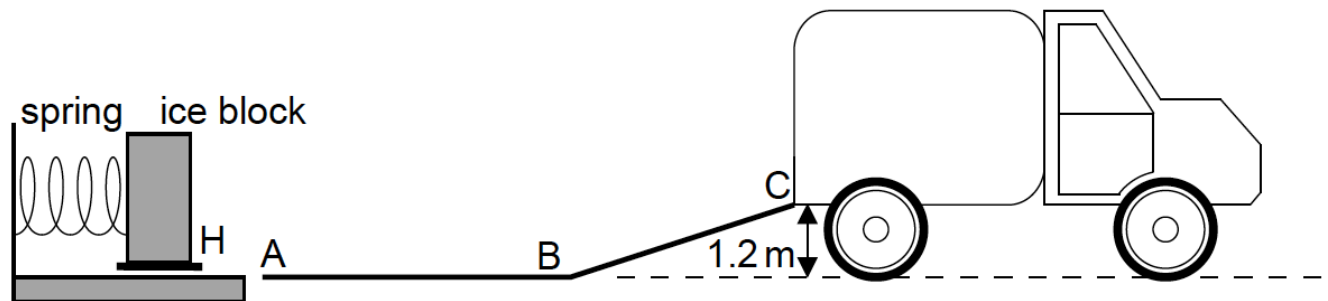
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28. An object of weight W is falling vertically at a constant speed in a fluid. What is the magnitude of the drag force acting on the object? [1 mark]
- A. 0
B. $\frac{W}{2}$
C. W
D. $2W$

29. An aircraft is moving horizontally. A parachutist leaves the aircraft and a few seconds later opens her parachute. Which graph shows the variation of the vertical speed v with time t for the parachutist from the time she leaves the aircraft until just before landing? [1 mark]



A company designs a spring system for loading ice blocks onto a truck. The ice block is placed in a holder H in front of the spring and an electric motor compresses the spring by pushing H to the left. When the spring is released the ice block is accelerated towards a ramp ABC. When the spring is fully decompressed, the ice block loses contact with the spring at A. The mass of the ice block is 55 kg.



Assume that the surface of the ramp is frictionless and that the masses of the spring and the holder are negligible compared to the mass of the ice block.

30a. (i) The block arrives at C with a speed of 0.90ms^{-1} . Show that the elastic [4 marks]
energy stored in the spring is 670J.

(ii) Calculate the speed of the block at A.

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30b. Describe the motion of the block

[3 marks]

(i) from A to B with reference to Newton's first law.

(ii) from B to C with reference to Newton's second law.

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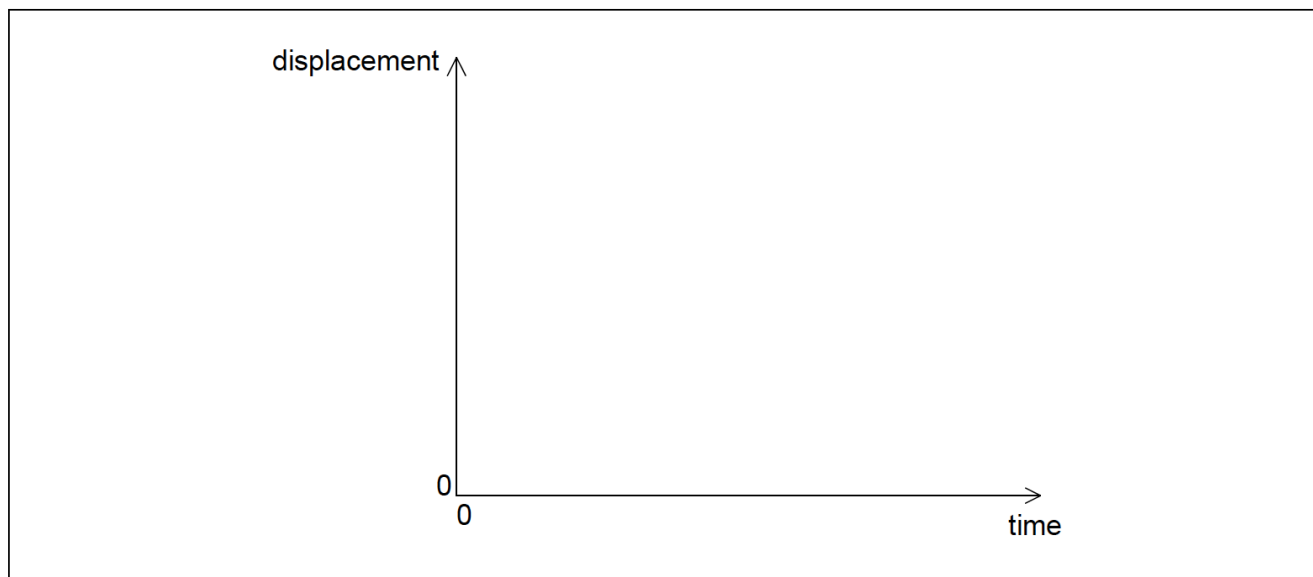
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30c. On the axes, sketch a graph to show how the displacement of the block varies with time from A to C. (You do not have to put numbers on the axes.) [2 marks]



30d. The spring decompression takes 0.42s. Determine the average force that the spring exerts on the block. [2 marks]

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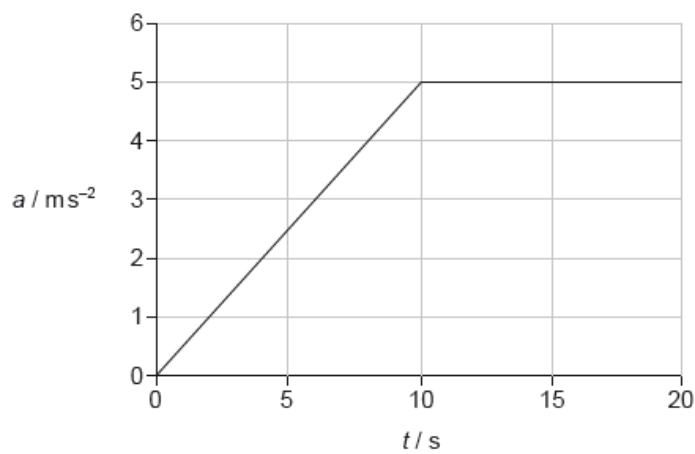
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- 30e. The electric motor is connected to a source of potential difference 120V [2 marks]
and draws a current of 6.8A. The motor takes 1.5s to compress the
spring.

Estimate the efficiency of the motor.

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31. An object is at rest at time $t = 0$. The variation with t of the acceleration a [1
of the object is shown from $t = 0$ to $t = 20$ s. mark]



What is the speed of the object when $t = 15$ s?

- A. 25 m s^{-1}
- B. 50 m s^{-1}
- C. 75 m s^{-1}
- D. 100 m s^{-1}

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins or other markings on the paper.

32b. Calculate the distance travelled by B in this time.

[2 marks]

32c. B slows down while I remains at a constant speed. The driver in each car [3 marks]
wears a seat belt. Using Newton's laws of motion, explain the difference
in the tension in the seat belts of the two cars.

A third car O with mass 930 kg joins the race. O collides with I from behind, moving along the same straight line as I. Before the collision the speed of I is 45 m s^{-1} and its mass is 850 kg. After the collision, I and O stick together and move in a straight line with an initial combined speed of 52 m s^{-1} .

32d. Calculate the speed of O immediately before the collision.

[2 marks]

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32e. The duration of the collision is 0.45 s. Determine the average force acting on O. [2 marks]

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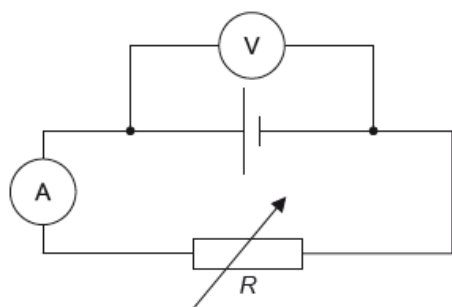
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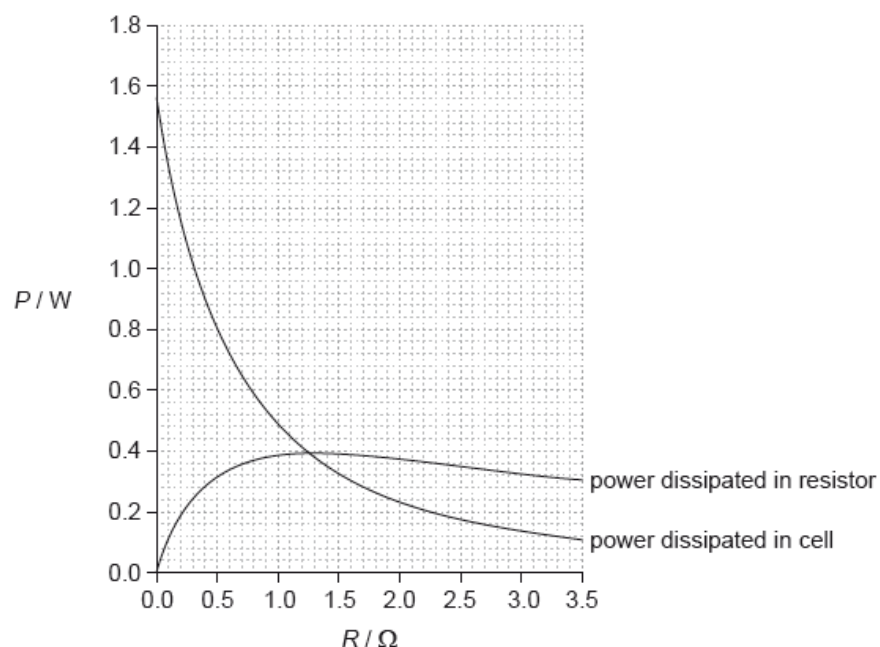
This question is in **two** parts. **Part 1** is about kinematics and Newton’s laws of motion.

Part 2 Electrical circuits

The circuit shown is used to investigate how the power developed by a cell varies when the load resistance R changes.



The variable resistor is adjusted and a series of current and voltage readings are taken. The graph shows the variation with R of the power dissipated in the cell and the power dissipated in the variable resistor.



- 32f. An ammeter and a voltmeter are used to investigate the characteristics of [2 marks]
a variable resistor of resistance R . State how the resistance of the
ammeter and of the voltmeter compare to R so that the readings of the instruments
are reliable.

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32g. Show that the current in the circuit is approximately 0.70 A when
 $R = 0.80 \, \Omega$.

[3 marks]

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The cell has an internal resistance.

32h. Outline what is meant by the internal resistance of a cell.

[2 marks]

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32i. Determine the internal resistance of the cell.

[3 marks]

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32j. Calculate the electromotive force (emf) of the cell.

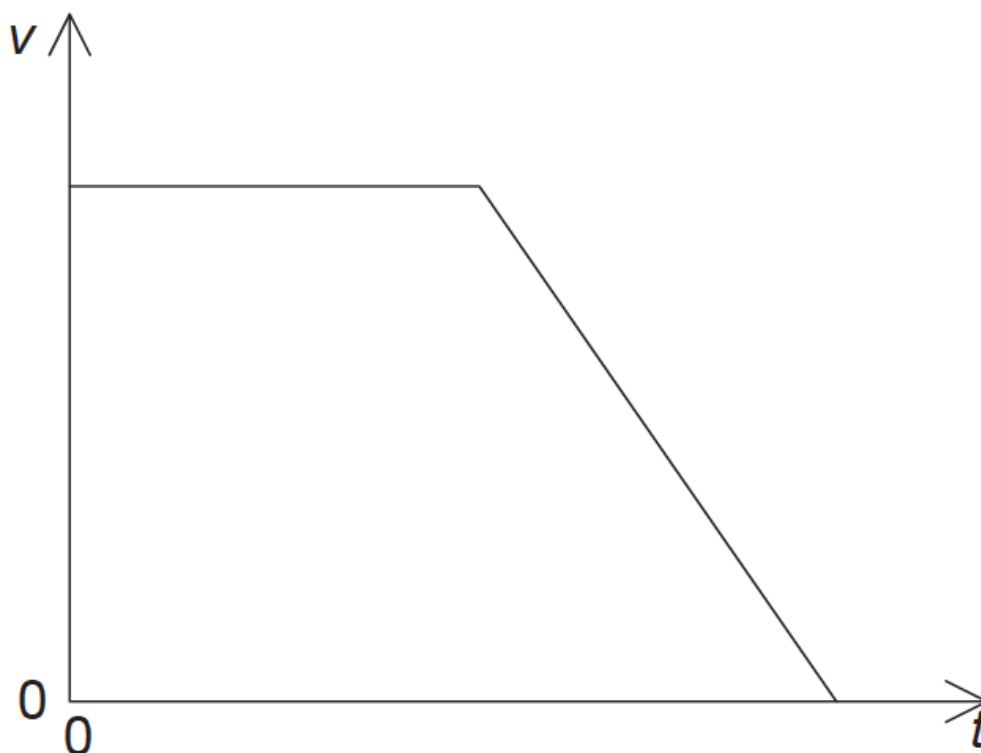
[2 marks]

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33. A tennis ball is released from rest and falls vertically through a small distance in air. What is the change in the speed of the ball and the change in the acceleration of the ball as it falls? [1 mark]

	Speed of the ball	Acceleration of the ball
A.	increases	decreases
B.	decreases	increases
C.	increases	increases
D.	decreases	decreases

34. The graph below shows the variation with time t of the velocity v of a car travelling in a straight line. [1 mark]



Which graph shows the variation with t of the displacement s of the car?

