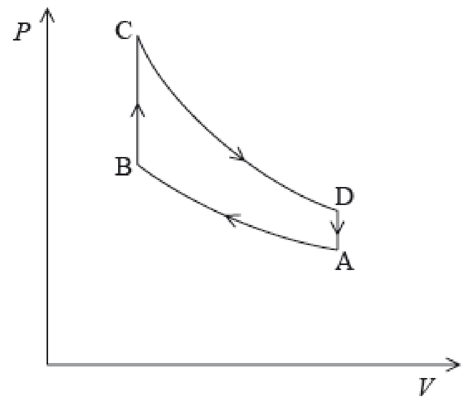
HL Paper 2

This question is about the thermodynamics of a car engine and the dynamics of the car.

A car engine consists of four cylinders. In each of the cylinders, a fuel-air mixture explodes to supply power at the appropriate moment in the cycle.

The diagram models the variation of pressure *P* with volume *V* for one cycle of the gas, ABCDA, in one of the cylinders of the engine. The gas in the cylinder has a fixed mass and can be assumed to be ideal.



The car is travelling at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. At this speed, the energy provided by the fuel injected into one cylinder in each cycle is 9200 J. One litre of fuel provides 56 MJ of energy.

A car is travelling along a straight horizontal road at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. The power output required at the wheels is 0.13 MW.

A driver moves a car in a horizontal circular path of radius 200 m. Each of the four tyres will not grip the road if the frictional force between a tyre and the road becomes less than 1500 N.

a. At point A in the cycle, the fuel-air mixture is at 18 °C. During process AB, the gas is compressed to 0.046 of its original volume and the pressure increases by a factor of 40. Calculate the temperature of the gas at point B. [1]

b. State the nature of the change in the gas that takes place during process BC in the cycle. [1]

c. Process CD is an adiabatic change. Discuss, with reference to the first law of thermodynamics, the change in temperature of the gas in the cylinder during process CD. [3]

d. Explain how the diagram can be used to calculate the net work done during one cycle. [2]

e. (i) Calculate the volume of fuel injected into one cylinder during one cycle. [3]

(ii) Each of the four cylinders completes a cycle 18 times every second. Calculate the distance the car can travel on one litre of fuel at a speed of $56\ \mathrm{m\,s^{-1}}$.

f. A car accelerates uniformly along a straight horizontal road from an initial speed of $12\ \mathrm{m\,s^{-1}}$ to a final speed of $28\ \mathrm{m\,s^{-1}}$ in a distance of 250 m. The mass of the car is 1200 kg. Determine the rate at which the engine is supplying kinetic energy to the car as it accelerates. [4]

g. (i) Calculate the total resistive force acting on the car when it is travelling at a constant speed of $56\ \mathrm{m\,s^{-1}}$. [5]

(ii) The mass of the car is 1200 kg. The resistive force *F* is related to the speed *v* by $F \propto v^2$. Using your answer to (g)(i), determine the maximum theoretical acceleration of the car at a speed of $28\ \mathrm{m\,s^{-1}}$.

h. (i) Calculate the maximum speed of the car at which it can continue to move in the circular path. Assume that the radius of the path is the same for each tyre. [6]

(ii) While the car is travelling around the circle, the people in the car have the sensation that they are being thrown outwards. Outline how Newton's first law of motion accounts for this sensation.

This question is about the energy of an orbiting satellite.

A space shuttle of mass *m* is launched in the direction of the Earth's South Pole.

The shuttle enters a circular orbit of radius R around the Earth.

a. The kinetic energy E_{K} given to the shuttle at its launch is given by the expression [2]

$$E_{\mathrm{K}} = \frac{7GMm}{8R_{\mathrm{E}}}$$

where G is the gravitational constant, M is mass of the Earth and R_{E} is the radius of the Earth. Deduce that the shuttle cannot escape the gravitational field of the Earth.

b.i. Show that the total energy of the shuttle in its orbit is given by $-\frac{GMm}{2R}$. Air resistance is negligible. [3]

b.ii. Using the expression for E_{K} in (a) and your answer to (b)(i), determine R in terms of R_{E}. [3]

c. In practice, the total energy of the shuttle decreases as it collides with air molecules in the upper atmosphere. Outline what happens to the speed of the shuttle when this occurs. [2]

This question is about escape speed and gravitational effects.

a. Explain what is meant by escape speed. [2]

b. Titania is a moon that orbits the planet Uranus. The mass of Titania is 3.5×10^{21} kg. The radius of Titania is 800 km. [5]

(i) Use the data to calculate the gravitational potential at the surface of Titania.

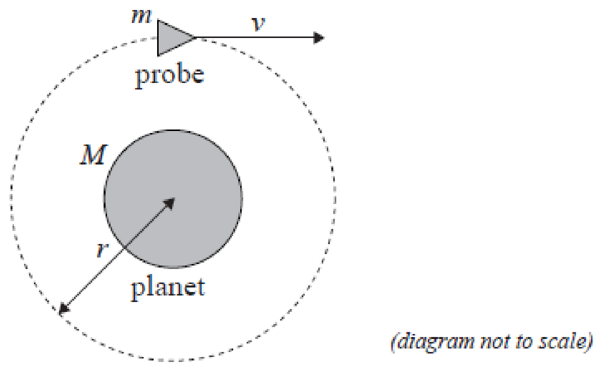
(ii) Use your answer to (b)(i) to determine the escape speed for Titania.

c. An astronaut visiting Titania throws an object away from him with an initial horizontal velocity of 1.8 m $\mathrm{s^{-1}}$. The object is 1.5 m above the moon's surface when it is thrown. The gravitational field strength at the surface of Titania is 0.37 N $\mathrm{kg^{-1}}$. [3]

Calculate the distance from the astronaut at which the object first strikes the surface.

This question is about a probe in orbit.

A probe of mass *m* is in a circular orbit of radius *r* around a spherical planet of mass *M*.



a. State why the work done by the gravitational force during one full revolution of the probe is zero. [1]

b. Deduce for the probe in orbit that its [4]

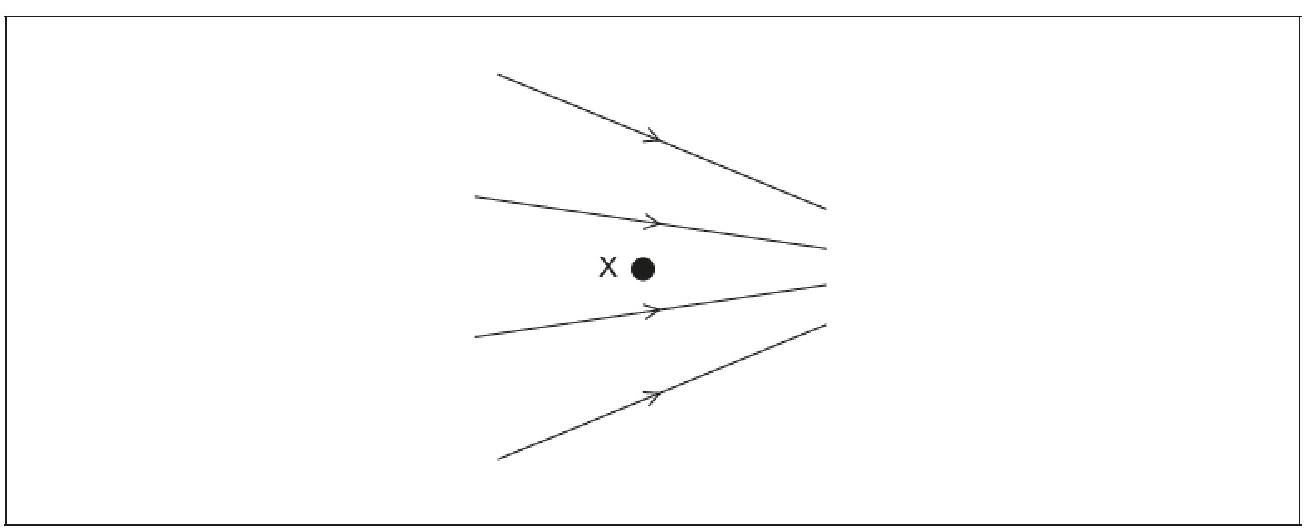
(i) speed is $v = \sqrt{\frac{GM}{r}}$.

(ii) total energy is $E = -\frac{GMm}{2r}$.

c. It is now required to place the probe in another circular orbit further away from the planet. To do this, the probe's engines will be fired for a very short time. [2]

State and explain whether the work done on the probe by the engines is positive, negative **or** zero.

A non-uniform electric field, with field lines as shown, exists in a region where there is no gravitational field. X is a point in the electric field. The field lines and X lie in the plane of the paper.



a. Outline what is meant by electric field strength. [2]

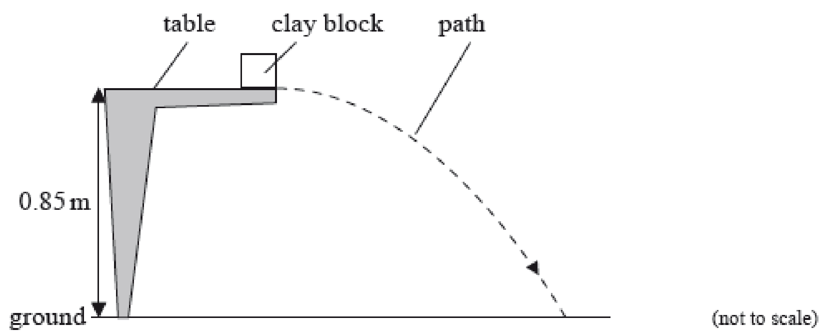
b. An electron is placed at X and released from rest. Draw, on the diagram, the direction of the force acting on the electron due to the field. [1]

c. The electron is replaced by a proton which is also released from rest at X. Compare, without calculation, the motion of the electron with the motion of the proton after release. You may assume that no frictional forces act on the electron or the proton. [4]

This question is in **two** parts. **Part 1** is about collisions. **Part 2** is about the gravitational field of Mars.

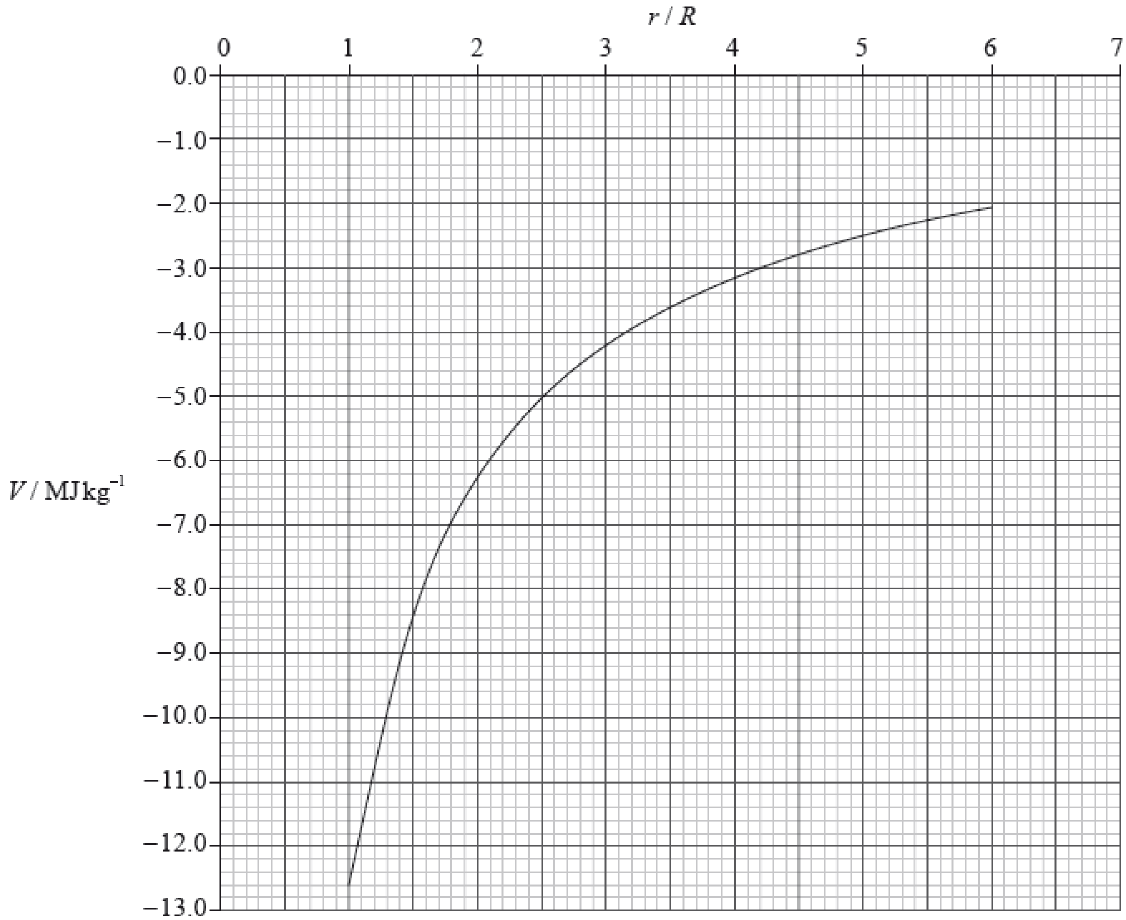
Part 1 Collisions

The experiment is repeated with the clay block placed at the edge of the table so that it is fired away from the table. The initial speed of the clay block is $4.3\ \mathrm{m\,s^{-1}}$ horizontally. The table surface is 0.85 m above the ground.



Part 2 Gravitational field of Mars

The graph shows the variation with distance r from the centre of Mars of the gravitational potential V. R is the radius of Mars which is 3.3 Mm. (Values of V for $r < R$ are not shown.)



A rocket of mass 1.2×10^4 kg lifts off from the surface of Mars. Use the graph to

Part 1.c. (i) Ignoring air resistance, calculate the horizontal distance travelled by the clay block before it strikes the ground. [7]

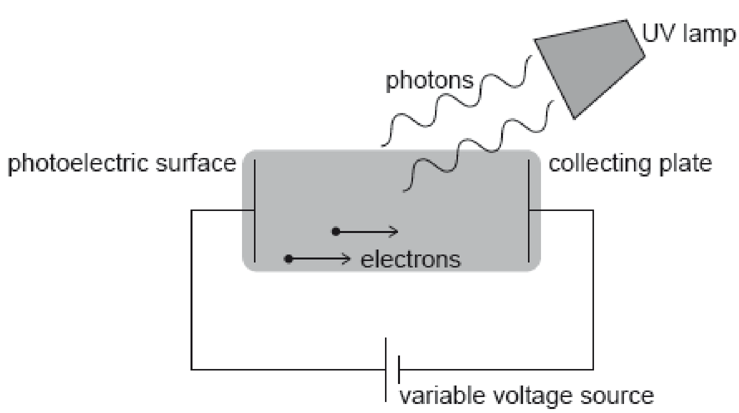
(ii) The diagram in (c) shows the path of the clay block neglecting air resistance. On the diagram, draw the approximate shape of the path that the clay block will take assuming that air resistance acts on the clay block.

Part 2.a. Define *gravitational potential energy* of a mass at a point. [1]

Part 2.b. (i) calculate the change in gravitational potential energy of the rocket at a distance 4*R* from the centre of Mars. [5]

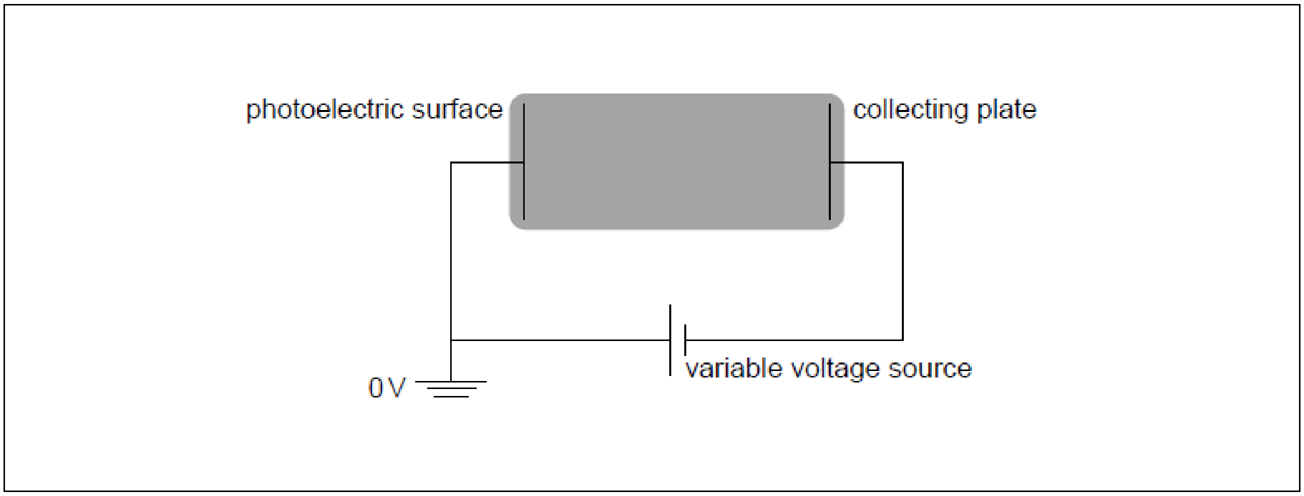
(ii) show that the magnitude of the gravitational field strength at a distance 4*R* from the centre of Mars is $0.23\ \mathrm{N\,kg^{-1}}$.

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.



a. Show that the energy of photons from the UV lamp is about 10 eV. [2]

b.i. Calculate, in J, the maximum kinetic energy of the emitted electrons. [2]

b.ii. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. [2]

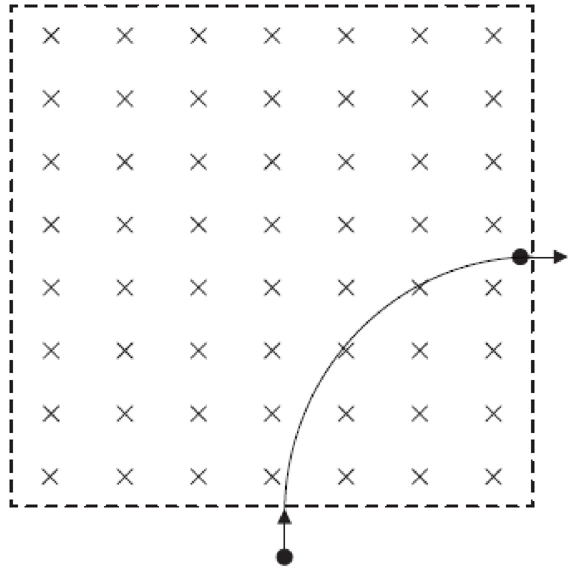
b.iii. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. [1]

c.i. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. [2]

c.ii. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. [2]

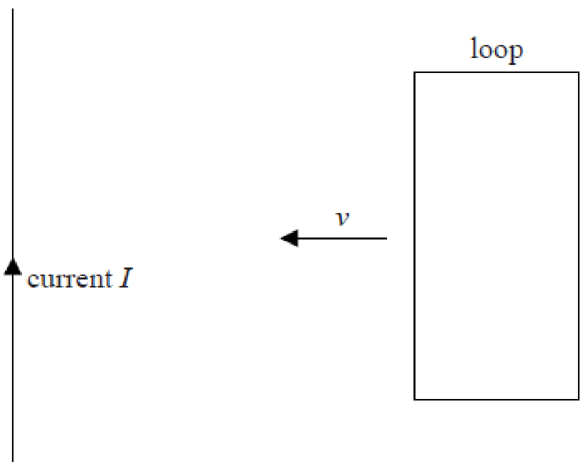
This question is about motion in a magnetic field.

An electron, that has been accelerated from rest by a potential difference of 250 V, enters a region of magnetic field of strength 0.12 T that is directed into the plane of the page.



a. The electron's path while in the region of magnetic field is a quarter circle. Show that the time the electron spends in the region of magnetic field is 7.5×10^{-11}s. [1]

c. A square loop of conducting wire is placed near a straight wire carrying a constant current *I*. The wire is in the same plane as the loop. [4]

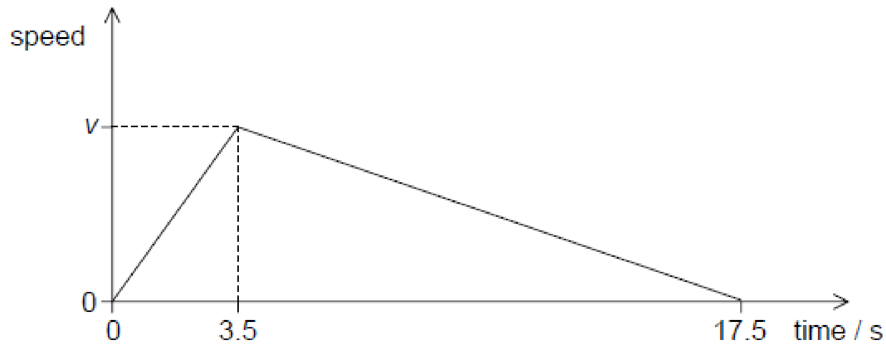


The loop is made to move with constant speed *v* towards the wire.

(i) Explain, by reference to Faraday's and Lenz's laws of electromagnetic induction, why work must be done on the loop.

(ii) Suggest what becomes of the work done on the loop.

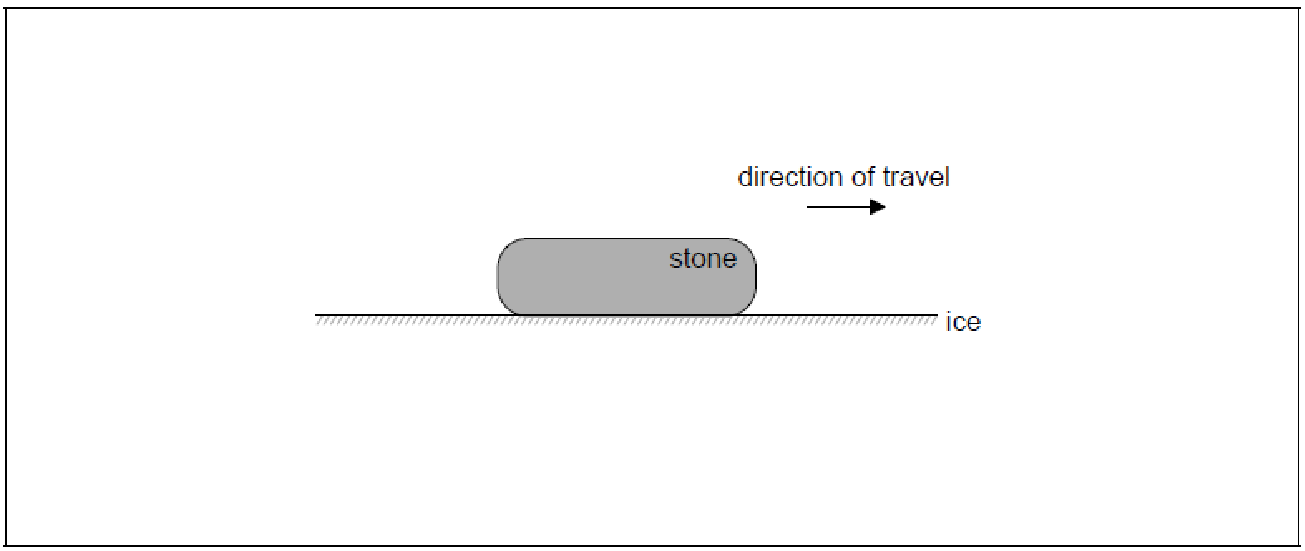
Curling is a game played on a horizontal ice surface. A player pushes a large smooth stone across the ice for several seconds and then releases it. The stone moves until friction brings it to rest. The graph shows the variation of speed of the stone with time.



The total distance travelled by the stone in 17.5 s is 29.8 m.

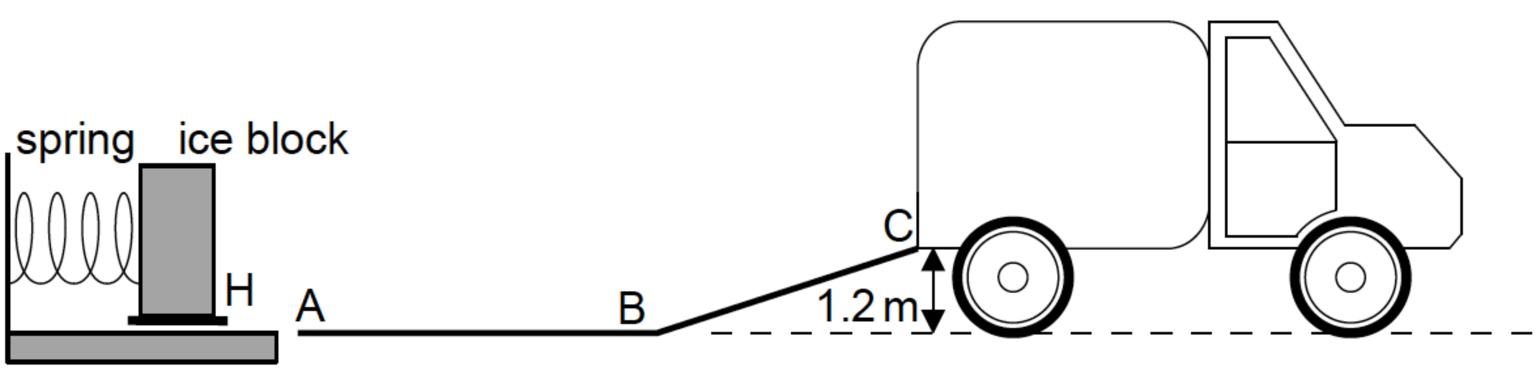
b. Determine the coefficient of dynamic friction between the stone and the ice during the last 14.0 s of the stone's motion. [3]

c. The diagram shows the stone during its motion **after** release. [3]



Label the diagram to show the forces acting on the stone. Your answer should include the name, the direction **and** point of application of each force.

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.



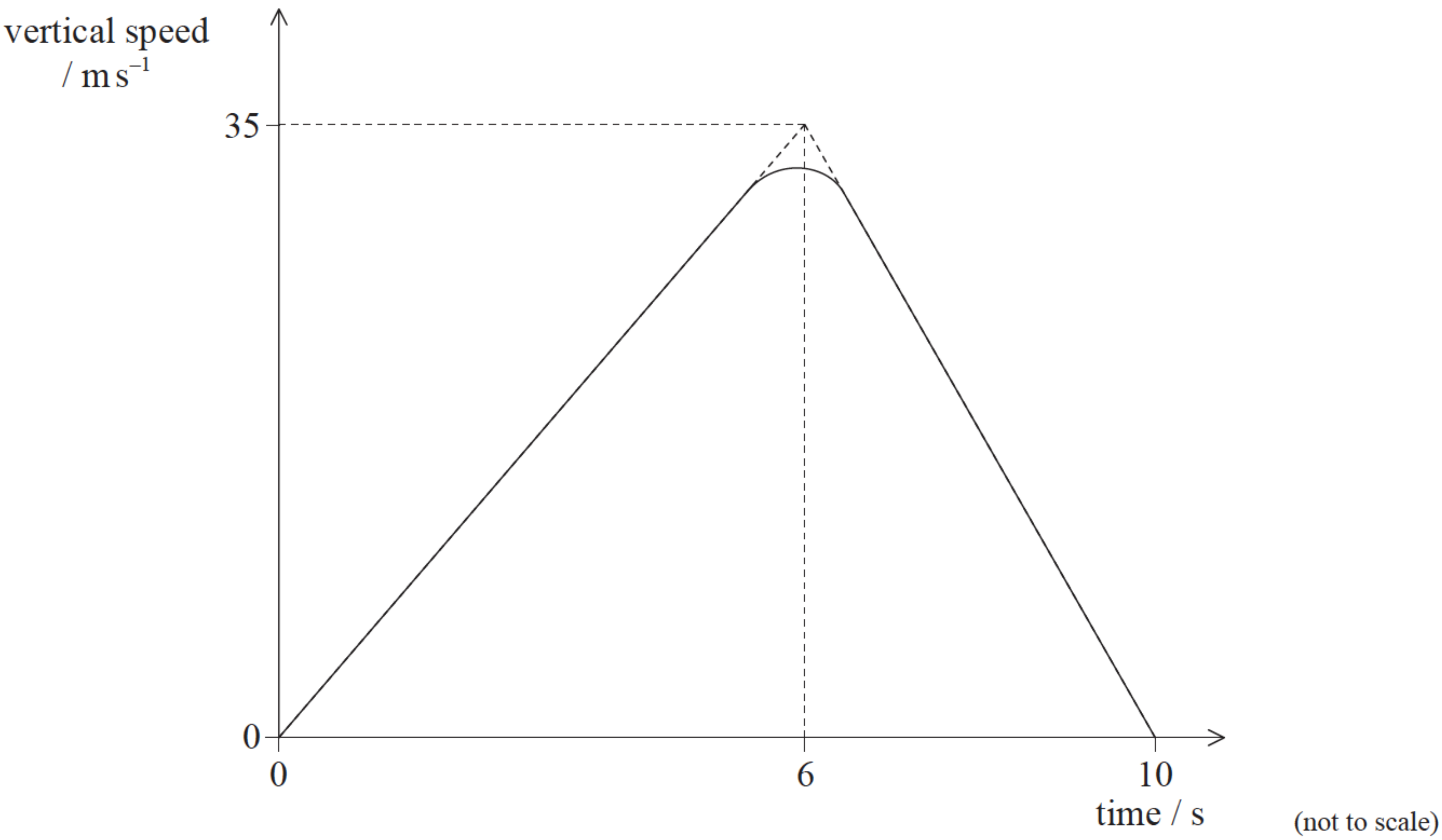
Assume that the surface of the ramp is frictionless and that the masses of the spring and the holder are negligible compared to the mass of the ice block.

On a particular day, the ice blocks experience a frictional force because the section of the ramp from A to B is not cleaned properly. The coefficient of dynamic friction between the ice blocks and the ramp AB is 0.030. The length of AB is 2.0 m.

Determine whether the ice blocks will be able to reach C.

Part 2 Rocket motion

A test model of a two-stage rocket is fired vertically upwards from the surface of Earth. The sketch graph shows how the vertical speed of the rocket varies with time from take-off until the first stage of the rocket reaches its maximum height.



a. (i) Show that the maximum height reached by the first stage of the rocket is about 170 m. [7]

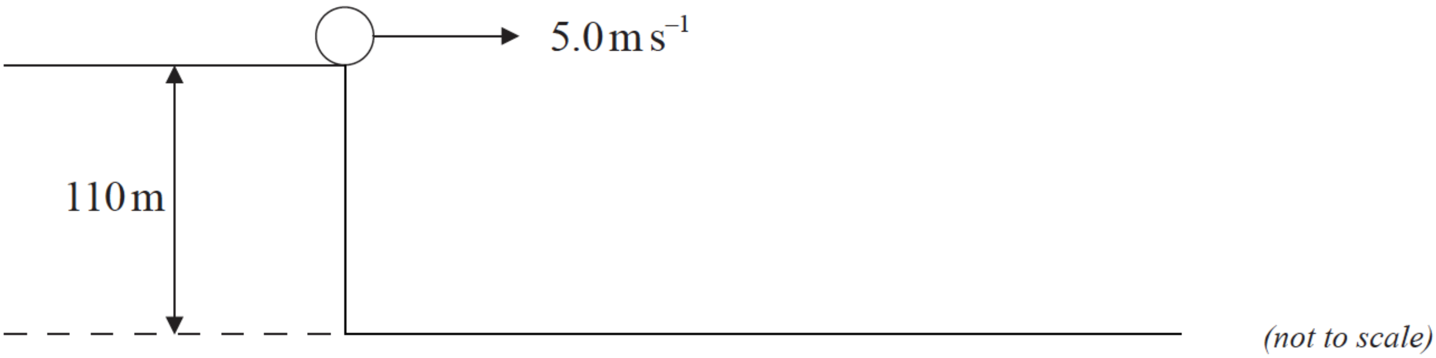
(ii) On reaching its maximum height, the first stage of the rocket falls away and the second stage fires so that the rocket acquires a constant horizontal velocity of 56 m s^{-1}. Calculate the velocity at the instant when the second stage of the rocket returns to the surface of the Earth. Ignore air resistance.

b. A full-scale version of the rocket reaches a height of 260km when the first stage falls away. Using the data below, calculate the speed at which the second stage of the rocket will orbit the Earth at a height of 260km. [3]

Mass of Earth = 6.0×10^{24} kg
Radius of Earth = 6.4×10^{6} m

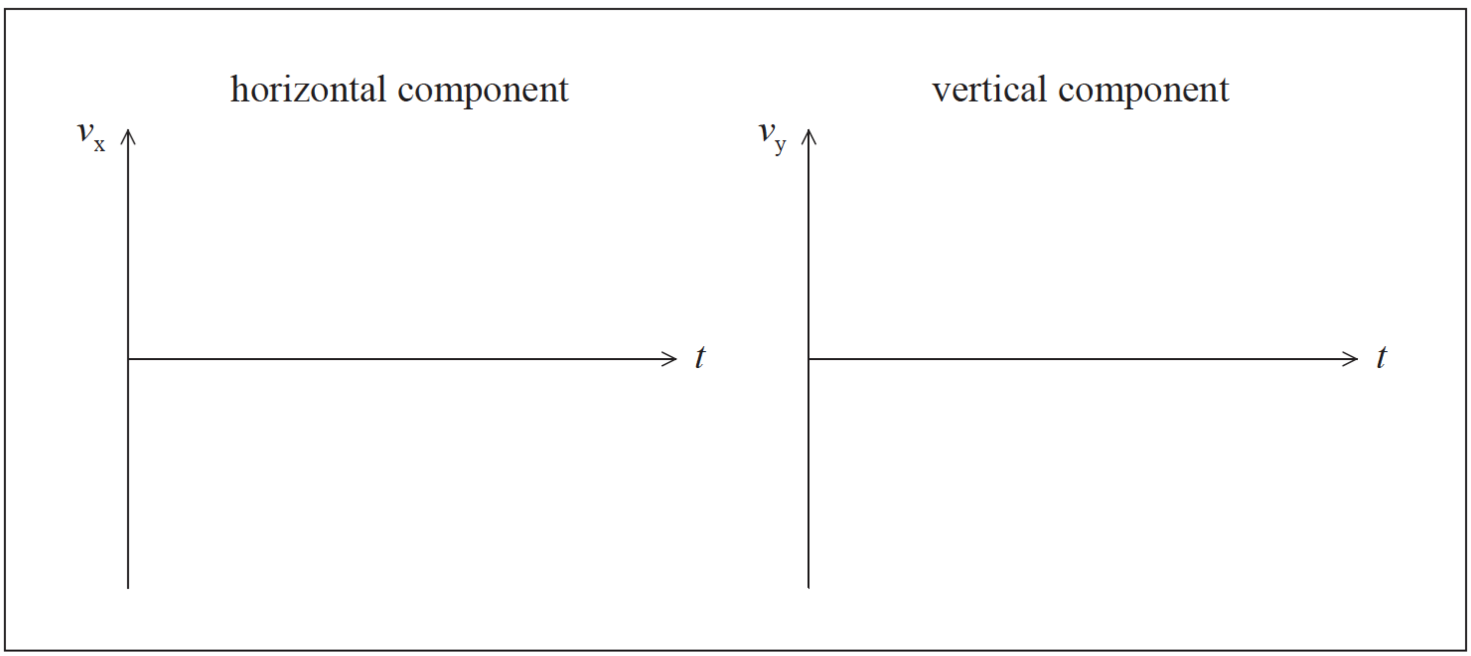
Part 2 Projectile motion

A ball is projected horizontally at 5.0ms^{-1} from a vertical cliff of height 110m. Assume that air resistance is negligible and use g=10ms^{-2}.



a. (i) State the magnitude of the horizontal component of acceleration of the ball after it leaves the cliff. [3]

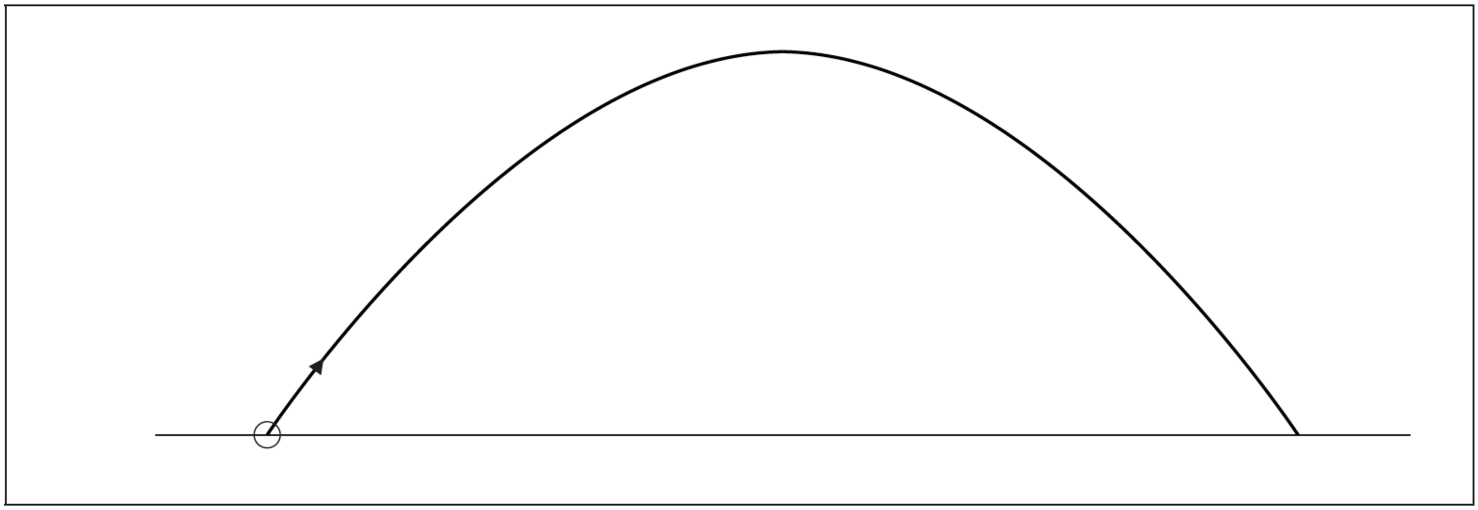
(ii) On the axes below, sketch graphs to show how the horizontal and vertical components of the velocity of the ball, v_x and v_y , change with time t until just before the ball hits the ground. It is not necessary to calculate any values.



b. (i) Calculate the time taken for the ball to reach the ground. [4]

(ii) Calculate the horizontal distance travelled by the ball until just before it reaches the ground.

c. Another projectile is launched at an angle to the ground. In the absence of air resistance it follows the parabolic path shown below. [3]



On the diagram above, sketch the path that the projectile would follow if air resistance were not negligible.