SL Paper 2

This question is about gravitation and uniform circular motion.

Phobos, a moon of Mars, has an orbital period of 7.7 hours and an orbital radius of $9.4 \times 10^3\ \mathrm{km}$.

a. Outline why Phobos moves with uniform circular motion. [3]

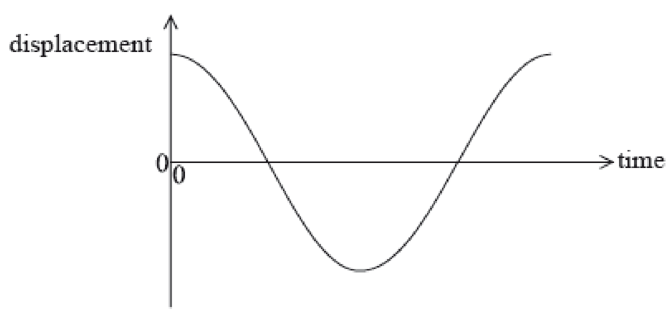
b. Show that the orbital speed of Phobos is about $2\ \mathrm{km\,s^{-1}}$. [2]

c. Deduce the mass of Mars. [3]

This question is in **two** parts. **Part 1** is about a simple pendulum. **Part 2** is about the Rutherford model of the atom.

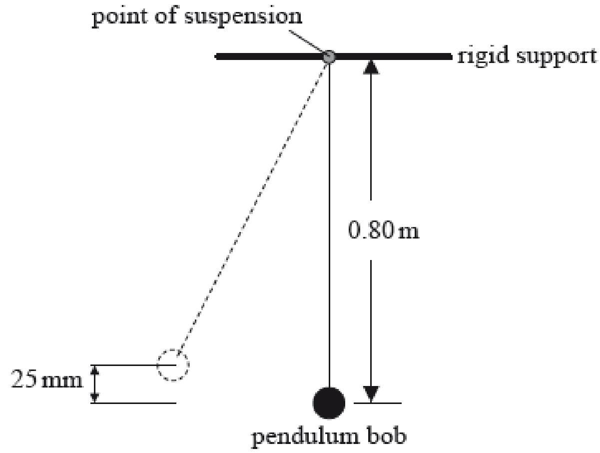
Part 1 Simple pendulum

A pendulum consists of a bob suspended by a light inextensible string from a rigid support. The pendulum bob is moved to one side and then released. The sketch graph shows how the displacement of the pendulum bob undergoing simple harmonic motion varies with time over one time period.

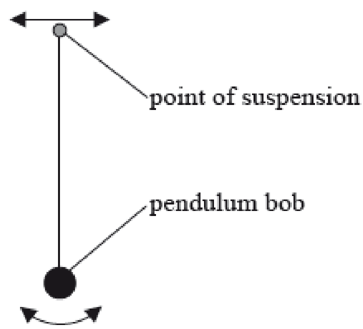


On the sketch graph above,

A pendulum bob is moved to one side until its centre is 25 mm above its rest position and then released.



The point of suspension of a pendulum bob is moved from side to side with a small amplitude and at a variable driving frequency f.



For each value of the driving frequency a steady constant amplitude A is reached. The oscillations of the pendulum bob are lightly damped.

Part 2 Rutherford model of the atom

The isotope gold-197 $\left({}^{197}_{79}Au\right)$ is stable but the isotope gold-199 $\left({}^{199}_{79}Au\right)$ is not.

Part 1.a. (i) label with the letter A a point at which the acceleration of the pendulum bob is a maximum. [2]

(ii) label with the letter V a point at which the speed of the pendulum bob is a maximum.

Part 1.b. Explain why the magnitude of the tension in the string at the midpoint of the oscillation is greater than the weight of the pendulum bob. [3]

Part 1.c. (i) Show that the speed of the pendulum bob at the midpoint of the oscillation is $0.70\ \mathrm{m\,s^{-1}}$. [5]

(ii) The mass of the pendulum bob is 0.057 kg. The centre of the pendulum bob is 0.80 m below the support. Calculate the magnitude of the tension in the string when the pendulum bob is vertically below the point of suspension.

Part 1.d. (i) On the axes below, sketch a graph to show the variation of A with f. [4]

(ii) Explain, with reference to the graph in (d)(i), what is meant by resonance.

Part e. The pendulum bob is now immersed in water and the variable frequency driving force in (d) is again applied. Suggest the effect this immersion of the pendulum bob will have on the shape of your graph in (d)(i). [2]

Part 2 a. Most alpha particles used to bombard a thin gold foil pass through the foil without a significant change in direction. A few alpha particles are deviated from their original direction through angles greater than 90°. Use these observations to describe the Rutherford atomic model. [5]

Part 2.b. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. [4]

(ii) A nucleus of $^{199}_{79}\mathrm{Au}$ decays to a nucleus of $^{199}_{80}\mathrm{Hg}$ with the emission of an electron and another particle. State the name of this other particle.

Part 2 Gravitational fields and electric fields

a. The magnitude of gravitational field strength *g* is defined from the equation shown below. [4]

$$g = \frac{F_g}{m}$$

The magnitude of electric field strength *E* is defined from the equation shown below.

$$E = \frac{F_E}{q}$$

For each of these defining equations, state the meaning of the symbols

(i) F_g.

(ii) F_E.

(iii) m.

(iv) q.

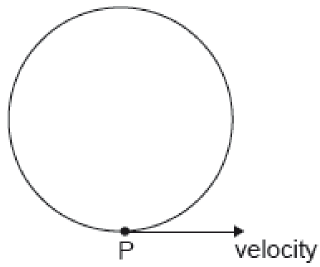
b. In a simple model of the hydrogen atom, the electron is regarded as being in a circular orbit about the proton. The magnitude of the electric field strength at the electron due to the proton is E_p. The magnitude of the gravitational field strength at the electron due to the proton is g_p. [5]

(i) Draw the electric field pattern of the proton alone.

(ii) Determine the order of magnitude of the ratio shown below.

$$\frac{E_p}{g_p}$$

An electron moves in circular motion in a uniform magnetic field.



The velocity of the electron at point P is 6.8×10^5 m s^{-1} in the direction shown.

The magnitude of the magnetic field is 8.5 T.

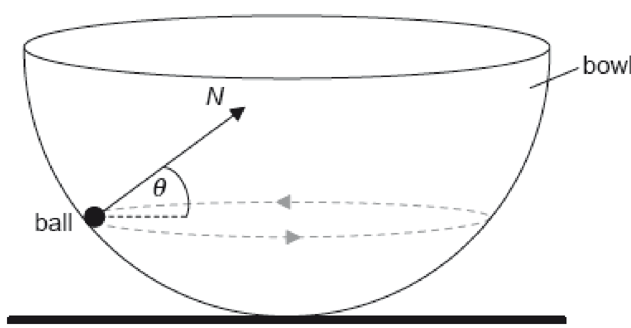
a. State the direction of the magnetic field. [1]

b. Calculate, in N, the magnitude of the magnetic force acting on the electron. [1]

c.i. Explain why the electron moves at constant speed. [1]

c.ii. Explain why the electron moves on a circular path. [2]

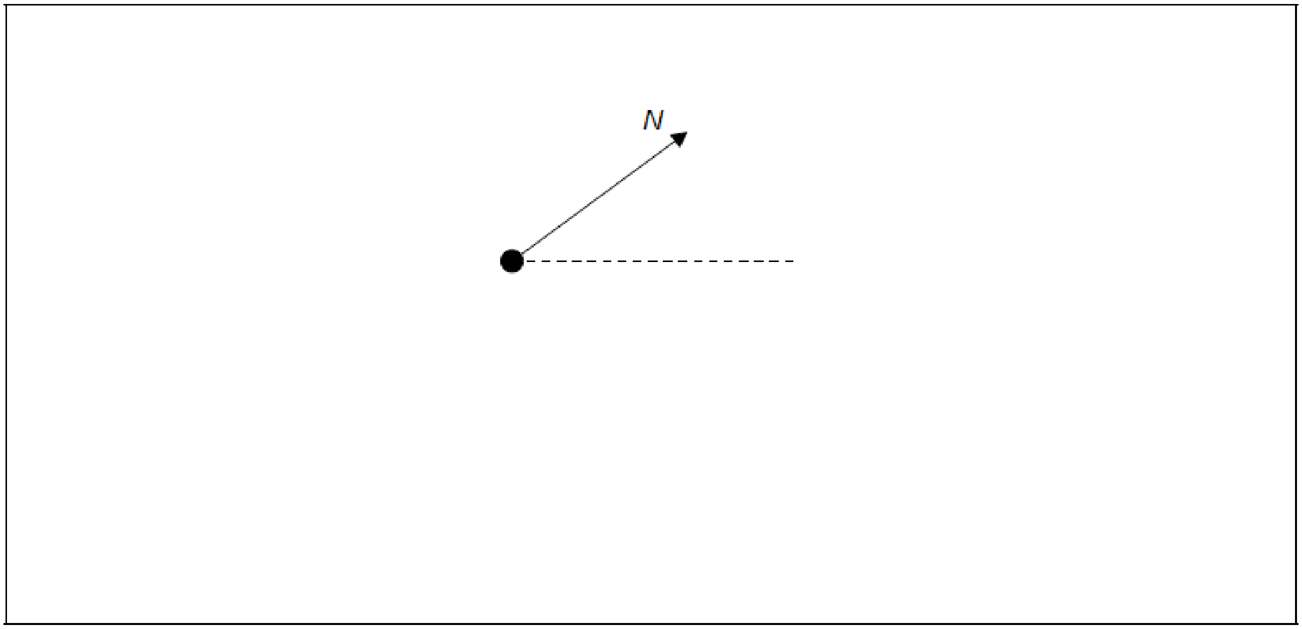
A small ball of mass *m* is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.



The normal reaction force *N* makes an angle θ to the horizontal.

a.i. State the direction of the resultant force on the ball. [1]

a.ii. On the diagram, construct an arrow of the correct length to represent the weight of the ball. [2]



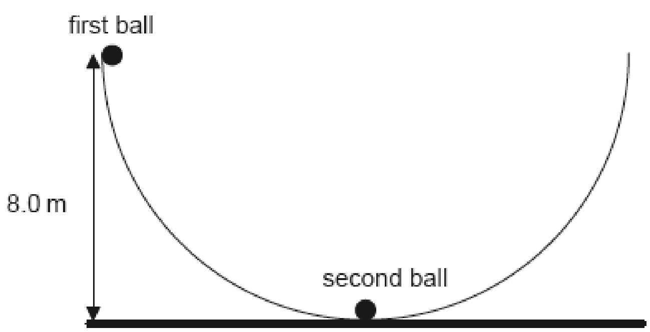
a.iiiShow that the magnitude of the net force *F* on the ball is given by the following equation. [3]

$$F = \frac{mg}{\tan\theta}$$

b. The radius of the bowl is 8.0 m and θ = 22°. Determine the speed of the ball. [4]

c. Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl. [2]

d. A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m. [3]



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Determine, in m, the maximum height reached by the two balls.

This question is in **two** parts. **Part 1** is about the motion of a car. **Part 2** is about electricity.

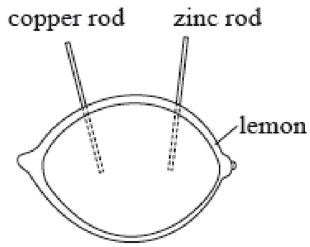
Part 1 Motion of a car

A car is travelling along the 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 the 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.

Part 2 Electricity

A lemon can be used to make an electric cell by pushing a copper rod and a zinc rod into the lemon.



A student constructs a lemon cell and connects it in an electrical circuit with a variable resistor. The student measures the potential difference *V* across the lemon and the current *I* in the lemon.

a. 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]

b. 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. [5]

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

(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 (b)(i), determine the maximum theoretical acceleration of the car at a speed of $28\ \mathrm{m\,s^{-1}}$.

c. (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.

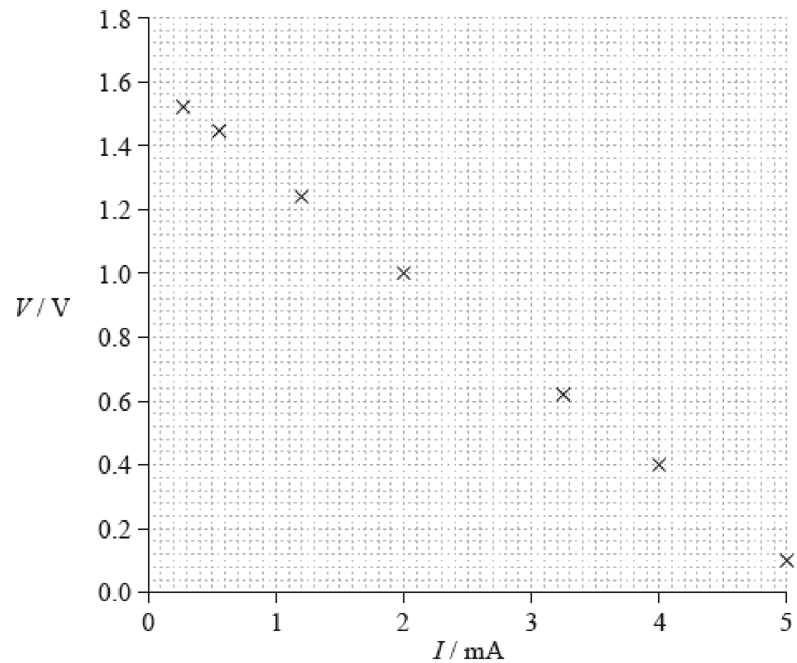
d. (i) Draw a circuit diagram of the experimental arrangement that will enable the student to collect the data for the graph. [10]

(ii) Show that the potential difference V across the lemon is given by

$$V = E - Ir$$

where E is the emf of the lemon cell and r is the internal resistance of the lemon cell.

(iii) The graph shows how V varies with I.

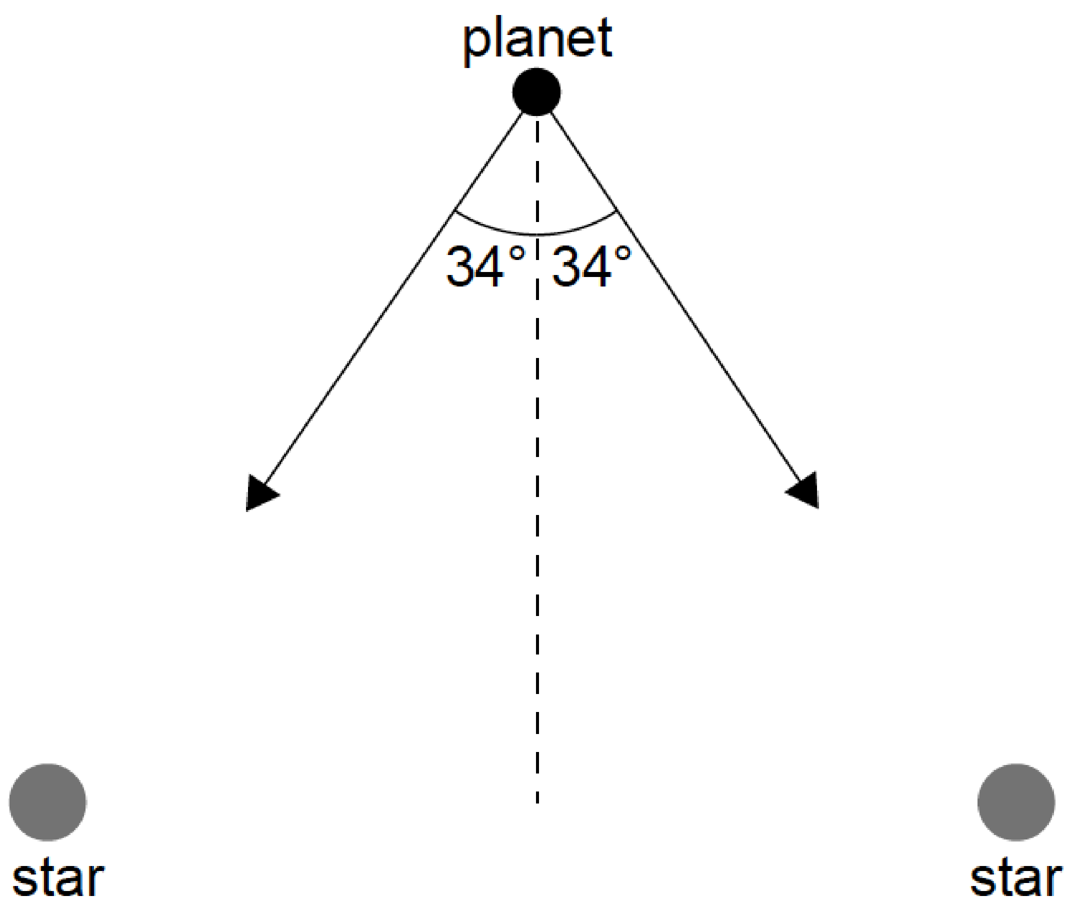


Using the graph, estimate the emf of the lemon cell.

(iv) Determine the internal resistance of the lemon cell.

(v) The lemon cell is used to supply energy to a digital clock that requires a current of $6.0\ \mu\text{A}$. The clock runs for 16 hours. Calculate the charge that flows through the clock in this time.

The two arrows in the diagram show the gravitational field strength vectors at the position of a planet due to each of two stars of equal mass *M*.



Each star has mass M=2.0×10^{30}kg. The planet is at a distance of 6.0×10^{11}m from each star.

a. Show that the gravitational field strength at the position of the planet due to **one** of the stars is g=3.7×10^{-4}Nkg^{-1}. [1]

b. Calculate the magnitude of the resultant gravitational field strength at the position of the planet. [2]

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a. (i) Define *gravitational field strength.* [2]

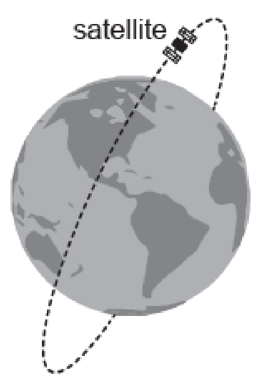
(ii) State the SI unit for gravitational field strength.

b. A planet orbits the Sun in a circular orbit with orbital period T and orbital radius R. The mass of the Sun is M. [4]

(i) Show that $T = \sqrt{\frac{4\pi^2 R^3}{GM}}$.

(ii) The Earth's orbit around the Sun is almost circular with radius 1.5×10^{11} m. Estimate the mass of the Sun.

A satellite powered by solar cells directed towards the Sun is in a polar orbit about the Earth.



The satellite is orbiting the Earth at a distance of 6600 km from the centre of the Earth.

The satellite carries an experiment that measures the peak wavelength emitted by different objects. The Sun emits radiation that has a peak wavelength λ_S of 509 nm. The peak wavelength λ_E of the radiation emitted by the Earth is 10.1 μm.

a. Determine the orbital period for the satellite. [3]

Mass of Earth = 6.0 x 10^{24} kg

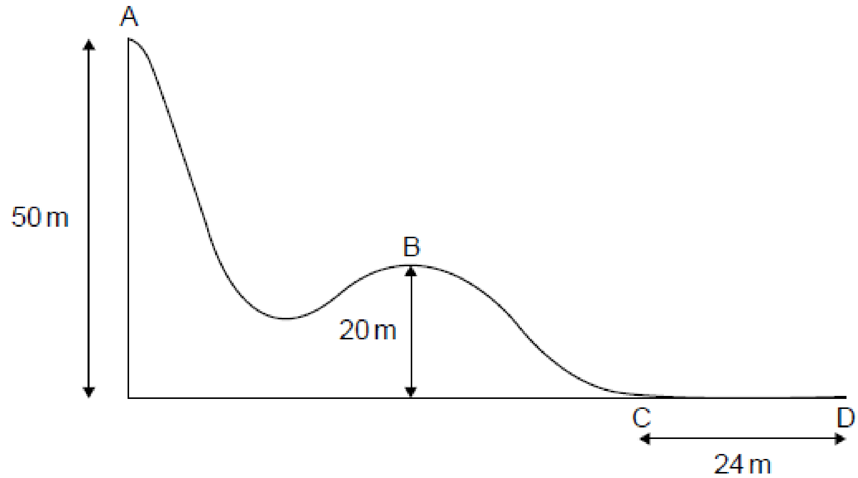
b.i. Determine the mean temperature of the Earth. [2]

b.ii. Suggest how the difference between λ_S and λ_E helps to account for the greenhouse effect. [3]

c. Not all scientists agree that global warming is caused by the activities of man. [1]

Outline how scientists try to ensure agreement on a scientific issue.

The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

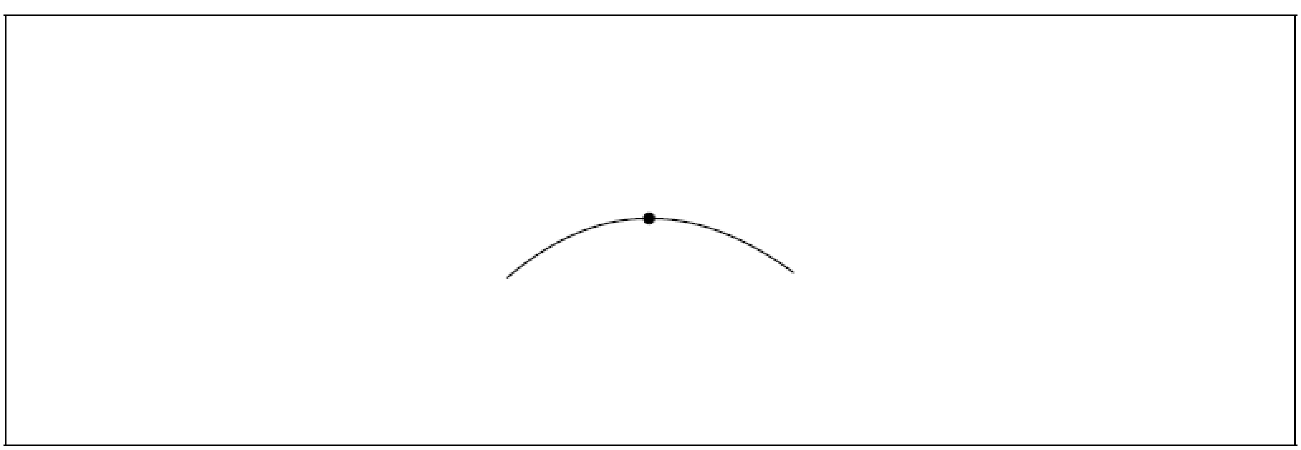
At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

a.i. From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 m s^{-1}. [2]

a.ii. Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. [2]

b.i. The dot on the following diagram represents the skier as she passes point B. [2]

Draw and label the vertical forces acting on the skier.



b.ii. The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. [3]

c. The skier reaches point C with a speed of 8.2 m s^{-1}. She stops after a distance of 24 m at point D. [3]

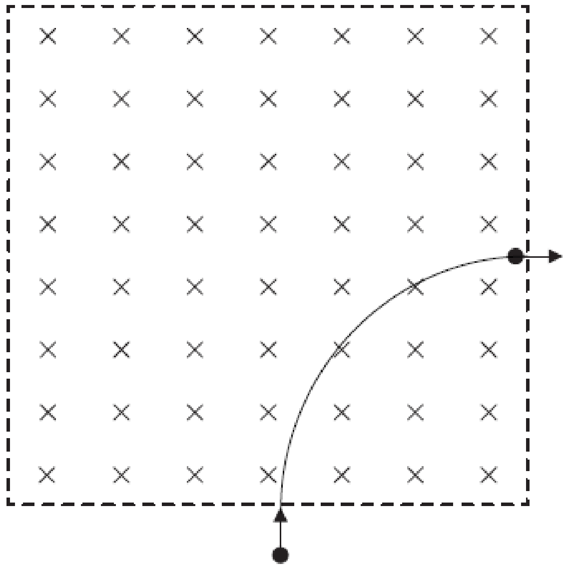
Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

d.i. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. [2]

d.ii. Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. [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.

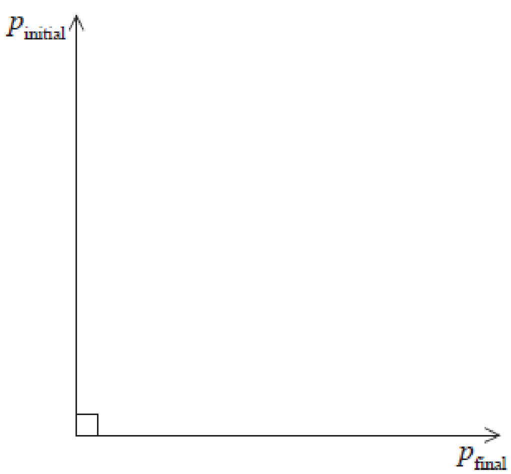


a. The electron's path while in the region of magnetic field is a quarter circle. Show that the [4]

(i) speed of the electron after acceleration is $9.4\times10^{6}\,ms^{-1}$.

(ii) radius of the path is 4.5×10^{-4}m.

b. The diagram below shows the momentum of the electron as it enters and leaves the region of magnetic field. The magnitude of the initial momentum and of the final momentum is 8.6×10^{-24}Ns. [3]



(i) On the diagram above, draw an arrow to indicate the vector representing the change in the momentum of the electron.

(ii) Show that the magnitude of the change in the momentum of the electron is 1.2×10^{-23}Ns.

(iii) The time the electron spends in the region of magnetic field is 7.5×10^{-11}s. Estimate the magnitude of the average force on the electron.

This question is in two parts. **Part 1** is about electric charge and electric circuits. **Part 2** is about momentum.

Part 1 Electric charge and electric circuits

a. State Coulomb’s law. [2]

b. In a simple model of the hydrogen atom, the electron can be regarded as being in a circular orbit about the proton. The radius of the orbit is 2.0×10^{-10} m. [7]

(i) Determine the magnitude of the electric force between the proton and the electron.

(ii) Calculate the magnitude of the electric field strength *E* and state the direction of the electric field due to the proton at a distance of 2.0×10^{-10} m from the proton.

(iii) The magnitude of the gravitational field due to the proton at a distance of 2.0×10^{-10} m from the proton is *H.*
Show that the ratio $\frac{H}{E}$ is of the order 10^{-28}C kg^{-1}.

(iv) The orbital electron is transferred from its orbit to a point where the potential is zero. The gain in potential energy of the electron is 5.4×10^{-19}J. Calculate the value of the potential difference through which the electron is moved.

c. An electric cell is a device that is used to transfer energy to electrons in a circuit. A particular circuit consists of a cell of emf ε and internal resistance *r* connected in series with a resistor of resistance 5.0 Ω. [6]

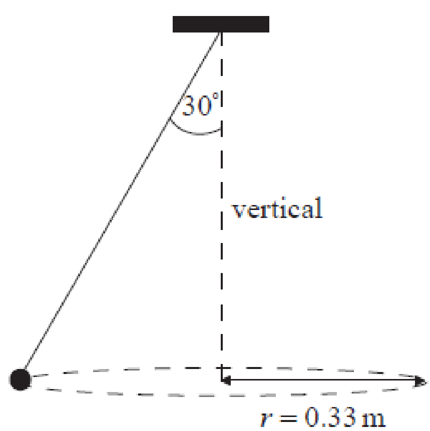
(i) Define *emf of a cell.*

(ii) The energy supplied by the cell to one electron in transferring it around the circuit is 5.1×10^{-19}J. Show that the emf of the cell is 3.2V.

(iii) Each electron in the circuit transfers an energy of 4.0×10^{-19} J to the 5.0 Ω resistor. Determine the value of the internal resistance *r.*

This question is about circular motion.

A ball of mass 0.25 kg is attached to a string and is made to rotate with constant speed *v* along a horizontal circle of radius *r* = 0.33m. The string is attached to the ceiling and makes an angle of 30 ° with the vertical.



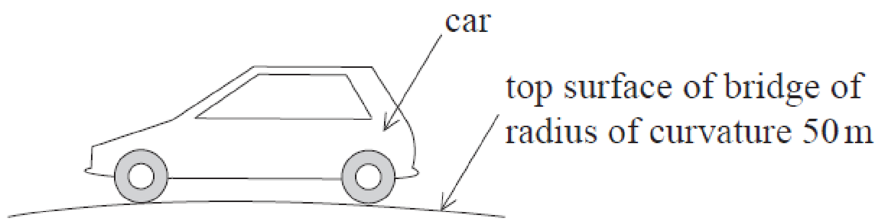
a. (i) On the diagram above, draw and label arrows to represent the forces on the ball in the position shown. [4]

(ii) State and explain whether the ball is in equilibrium.

b. Determine the speed of rotation of the ball. [3]

This question is about circular motion.

The diagram shows a car moving at a constant speed over a curved bridge. At the position shown, the top surface of the bridge has a radius of curvature of 50 m.



a. Explain why the car is accelerating even though it is moving with a constant speed. [2]

b. On the diagram, draw and label the vertical forces acting on the car in the position shown. [2]

c. Calculate the maximum speed at which the car will stay in contact with the bridge. [3]

Part 2 Gravitational fields

a. State Newton's universal law of gravitation. [3]

b. Deduce that the gravitational field strength g at the surface of a spherical planet of uniform density is given by [2]

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

where M is the mass of the planet, R is its radius and G is the gravitational constant. You can assume that spherical objects of uniform density act as point masses.

c. The gravitational field strength at the surface of Mars g_M is related to the gravitational field strength at the surface of the Earth g_E by [2]

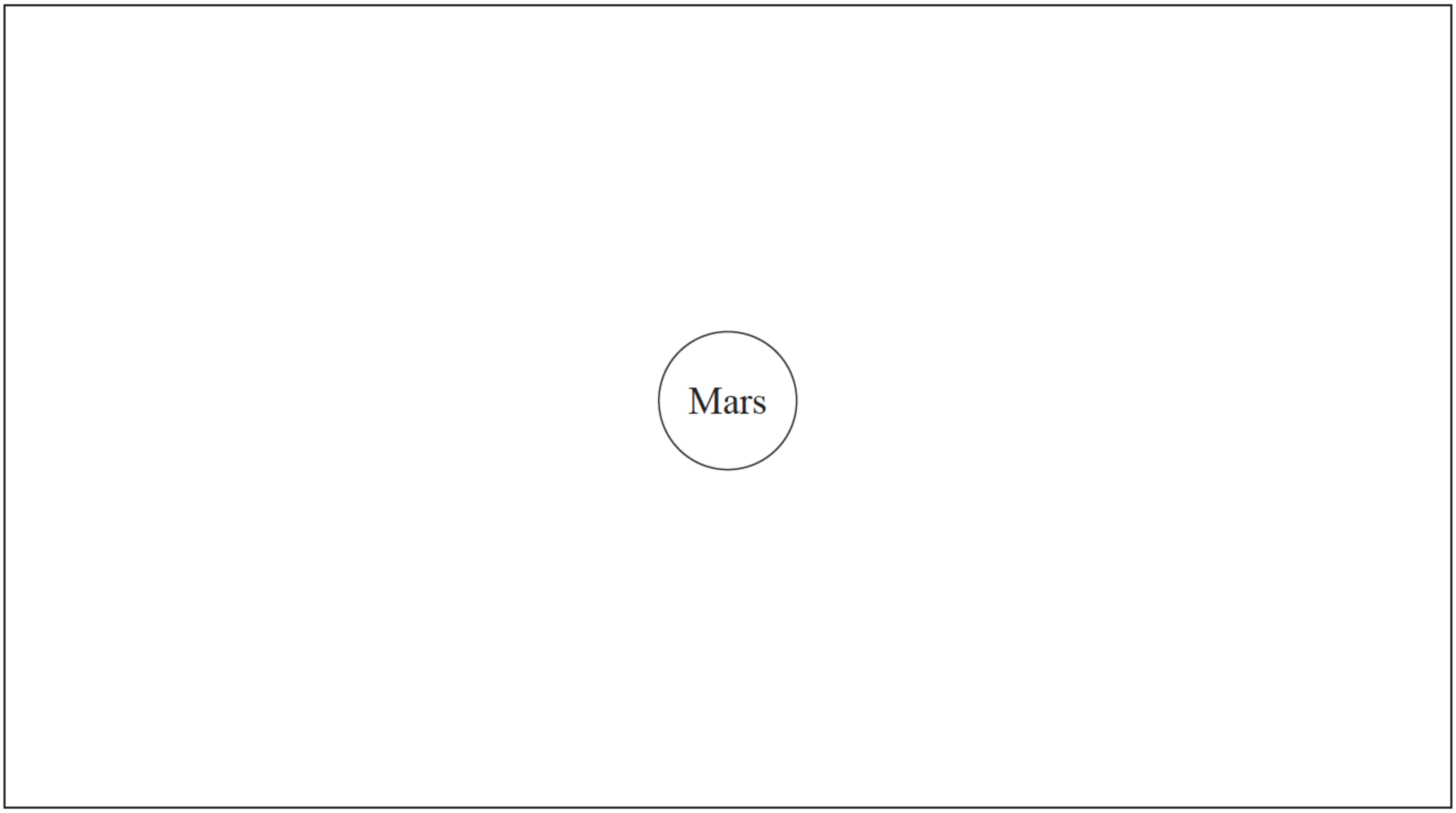
$$g_M = 0.38 \times g_E.$$

The radius of Mars R_M is related to the radius of the Earth R_E by

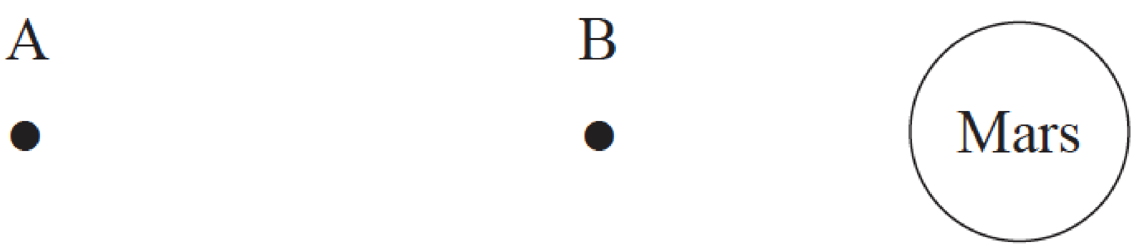
$$R_M = 0.53 \times R_E.$$

Determine the mass of Mars M_M in terms of the mass of the Earth M_E.

d. (i) On the diagram below, draw lines to represent the gravitational field around the planet Mars. [3]



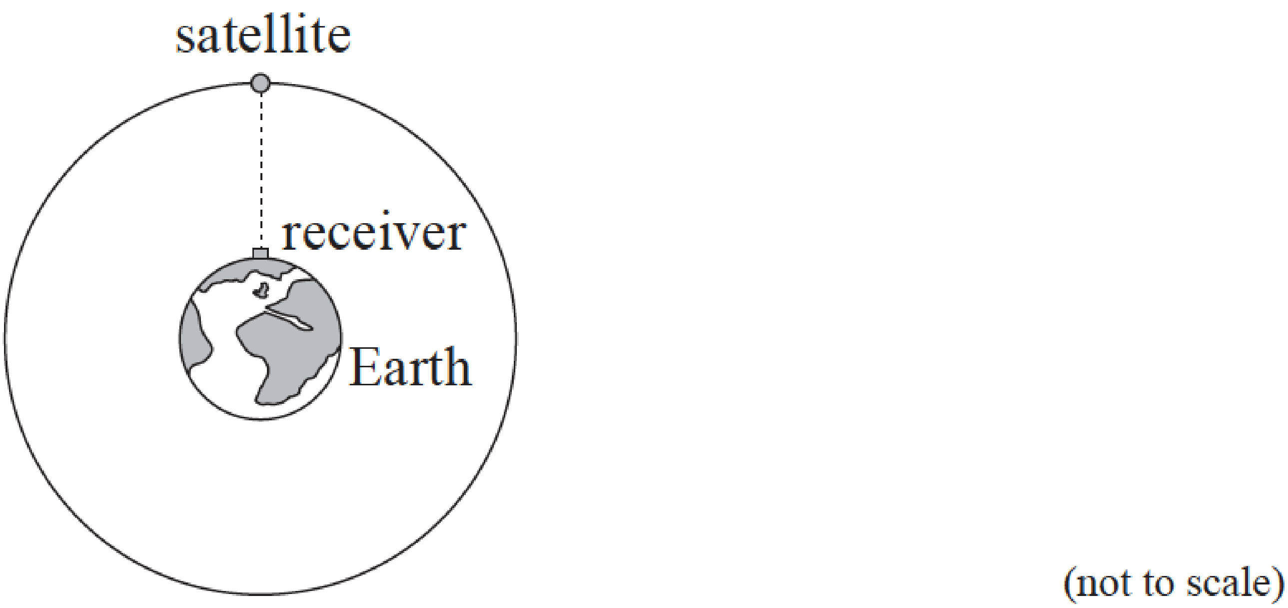
(ii) An object falls freely in a straight line from point A to point B in time t. The speed of the object at A is u and the speed at B is v. A student suggests using the equation $v=u+g_Mt$ to calculate v. Suggest **two** reasons why it is not appropriate to use this equation.



Part 2 Satellite

a. State, in words, Newton's universal law of gravitation. [2]

b. The diagram shows a satellite orbiting the Earth. The satellite is part of the network of global-positioning satellites (GPS) that transmit radio signals used to locate the position of receivers that are located on the Earth. [3]



When the satellite is directly overhead, the microwave signal reaches the receiver 67ms after it leaves the satellite.

(i) State the order of magnitude of the wavelength of microwaves.

(ii) Calculate the height of the satellite above the surface of the Earth

c. (i) Explain why the satellite is accelerating towards the centre of the Earth even though its orbital speed is constant. [8]

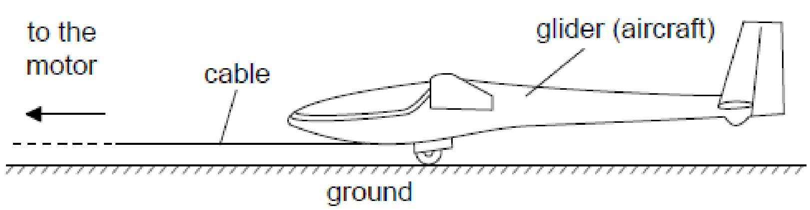
(ii) Calculate the gravitational field strength due to the Earth at the position of the satellite.

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

(iii) Determine the orbital speed of the satellite.

(iv) Determine, in hours, the orbital period of the satellite.

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.



a. 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]

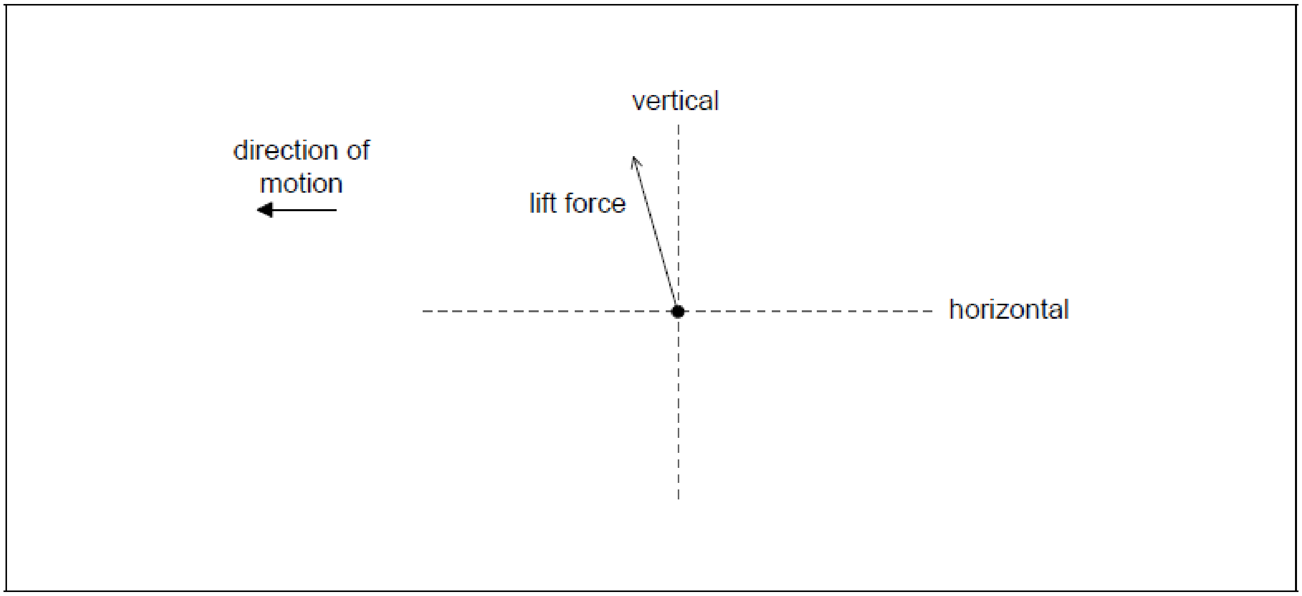
b. The glider and pilot have a total mass of 492 kg. During the acceleration the glider is subject to an average resistive force of 160 N. Determine the average tension in the cable as the glider accelerates. [3]

c. 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]

d. 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]

e. After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. [2]

The diagram shows the lift force acting on the glider and the direction of motion of the glider.



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

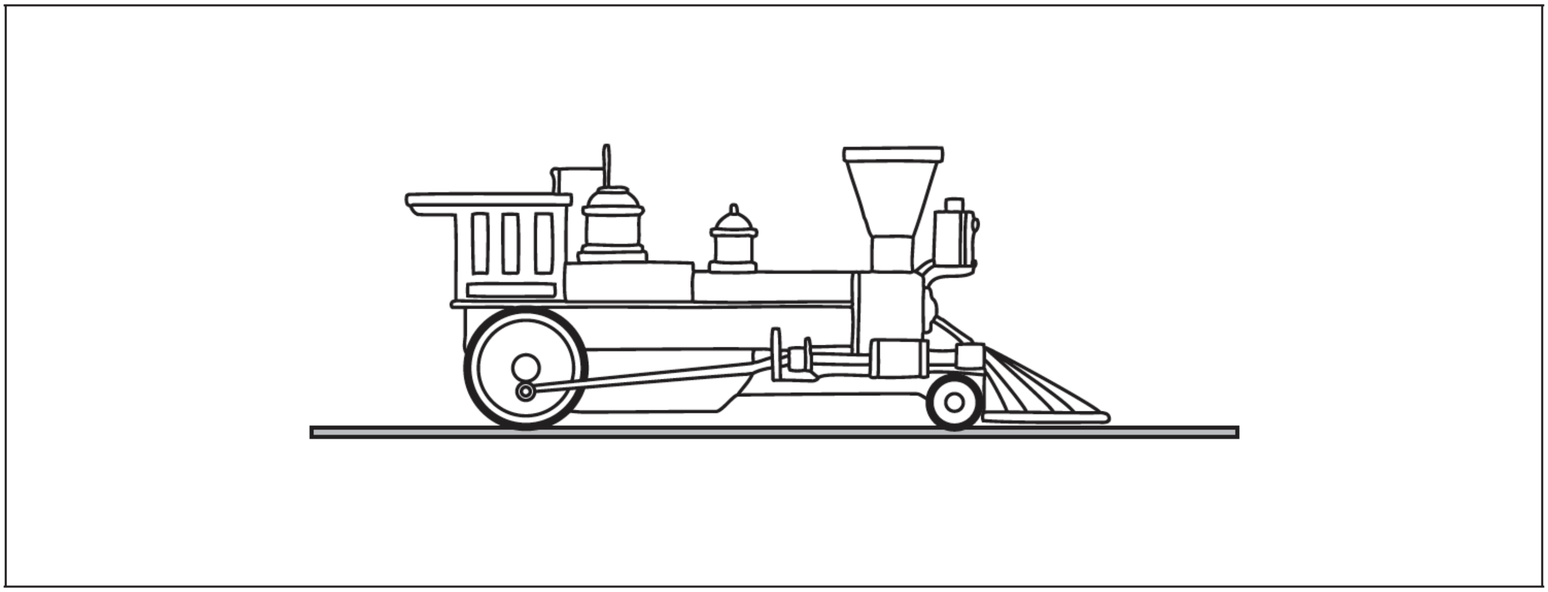
f. Explain, using appropriate laws of motion, how the forces acting on the glider maintain it in level flight. [2]

g. 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]

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.



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

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

c. 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]

Calculate the useful power output of the railway engine.

d. 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]

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

e. 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 t o v^3. [5]

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

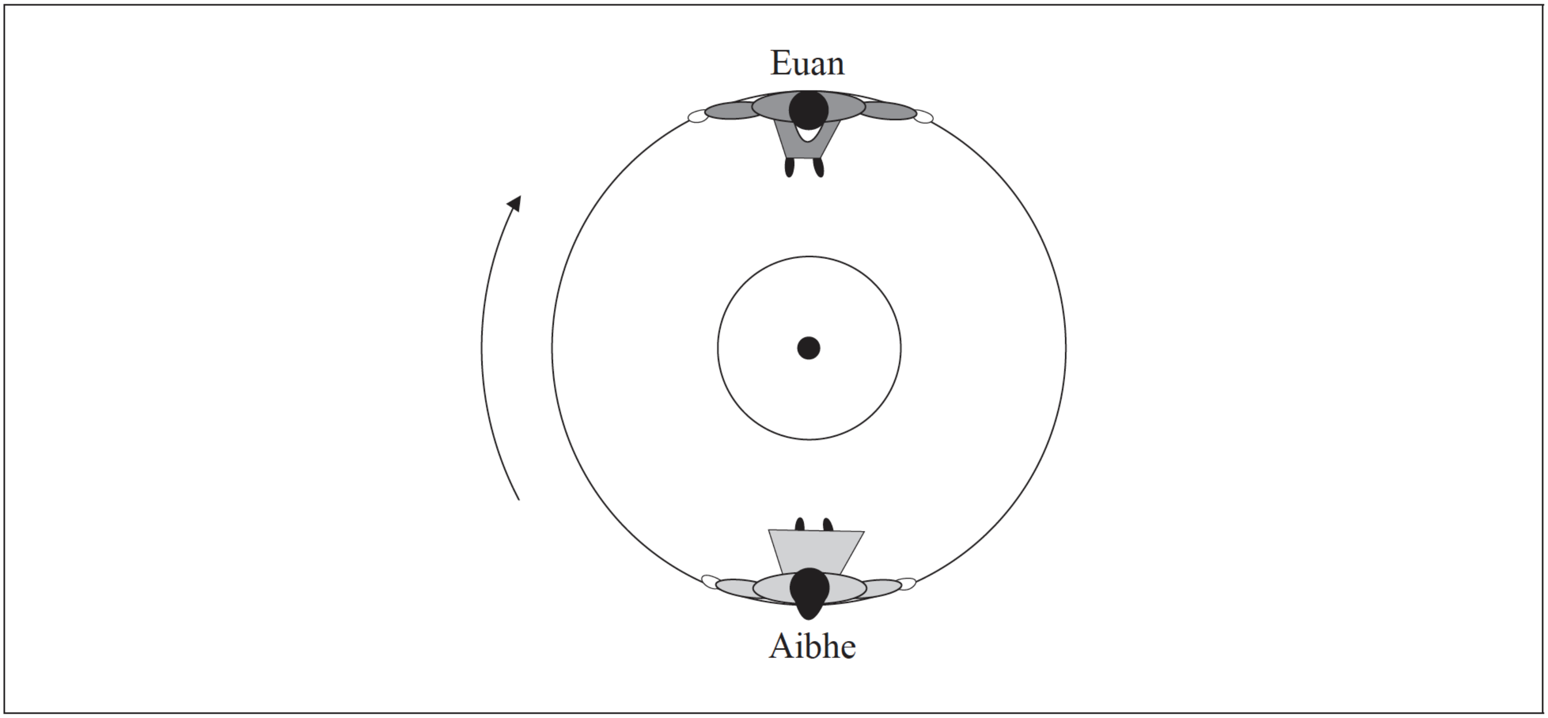
(ii) Determine the **total** horizontal resistive force when the railway engine is travelling at 8.0 ms^{-1}.

f. 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]

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

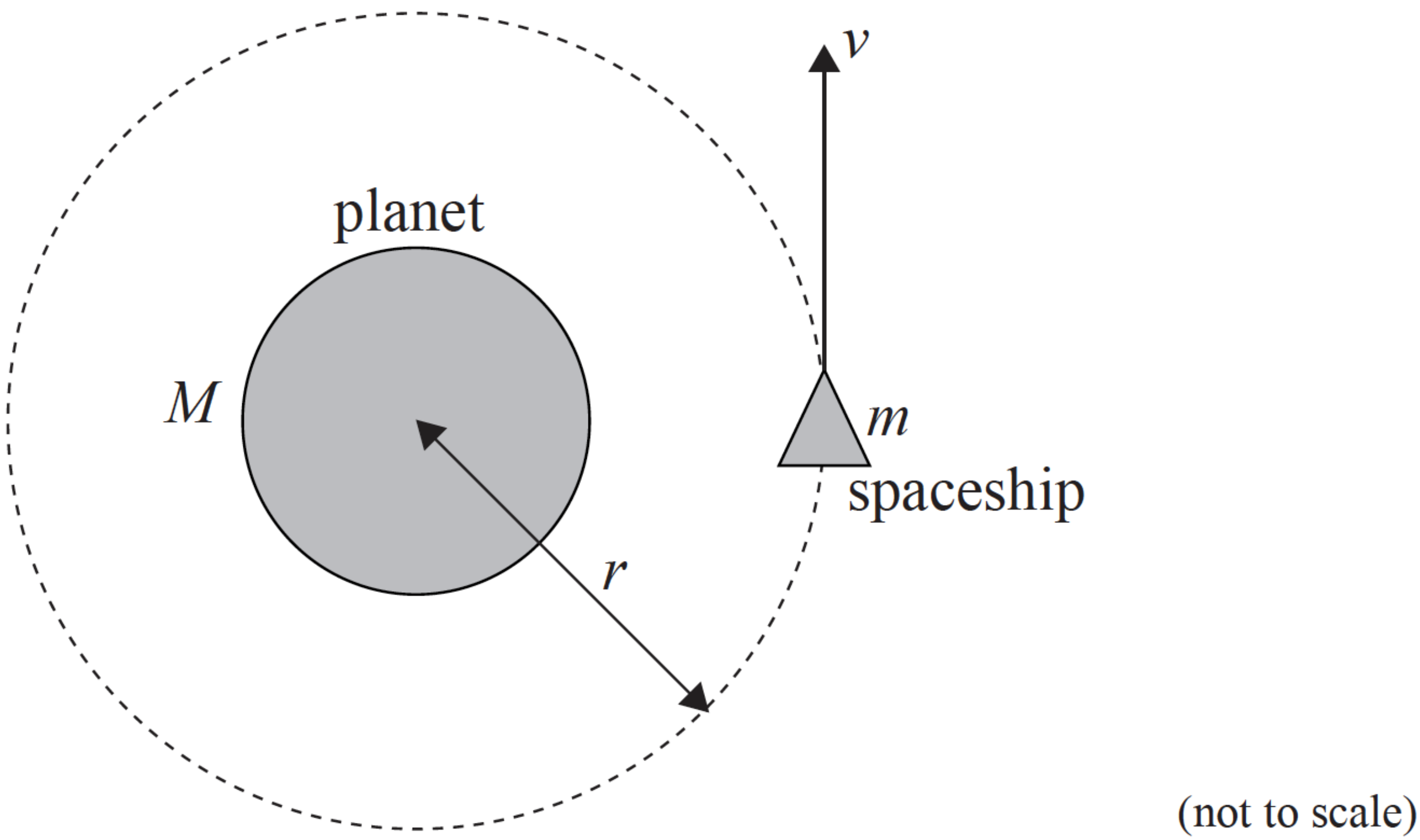
Aibhe and Euan are sitting on opposite sides of a merry-go-round, which is rotating at constant speed around a fixed centre. The diagram below shows the view from above.



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

Part 2 Orbital motion

A spaceship of mass *m* is moving at speed *v* in a circular orbit of radius *r* around a planet of mass *M*.



a. Determine the magnitude of the velocity of Aibhe relative to [2]

(i) Euan.

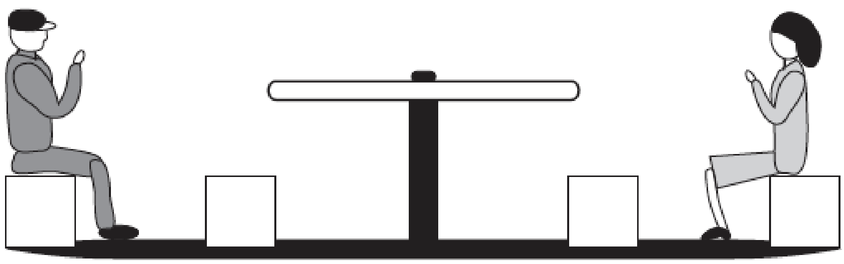
(ii) the centre of the merry-go-round.

b. (i) Outline why Aibhe is accelerating even though she is moving at constant speed. [6]

(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.

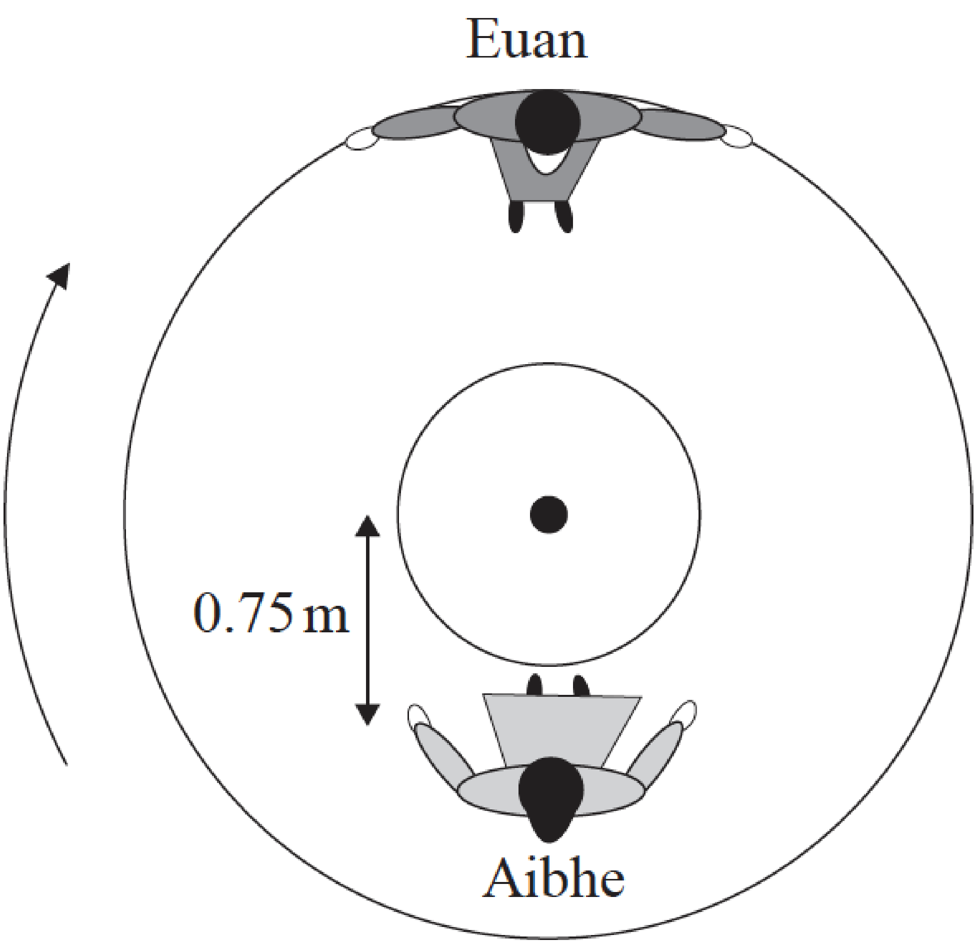
(iv) The diagram below shows a side view of Aibhe and Euan on the merry-go-round.



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

c. Euan is rotating on a merry-go-round and drags his foot along the ground 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. [2]

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



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.

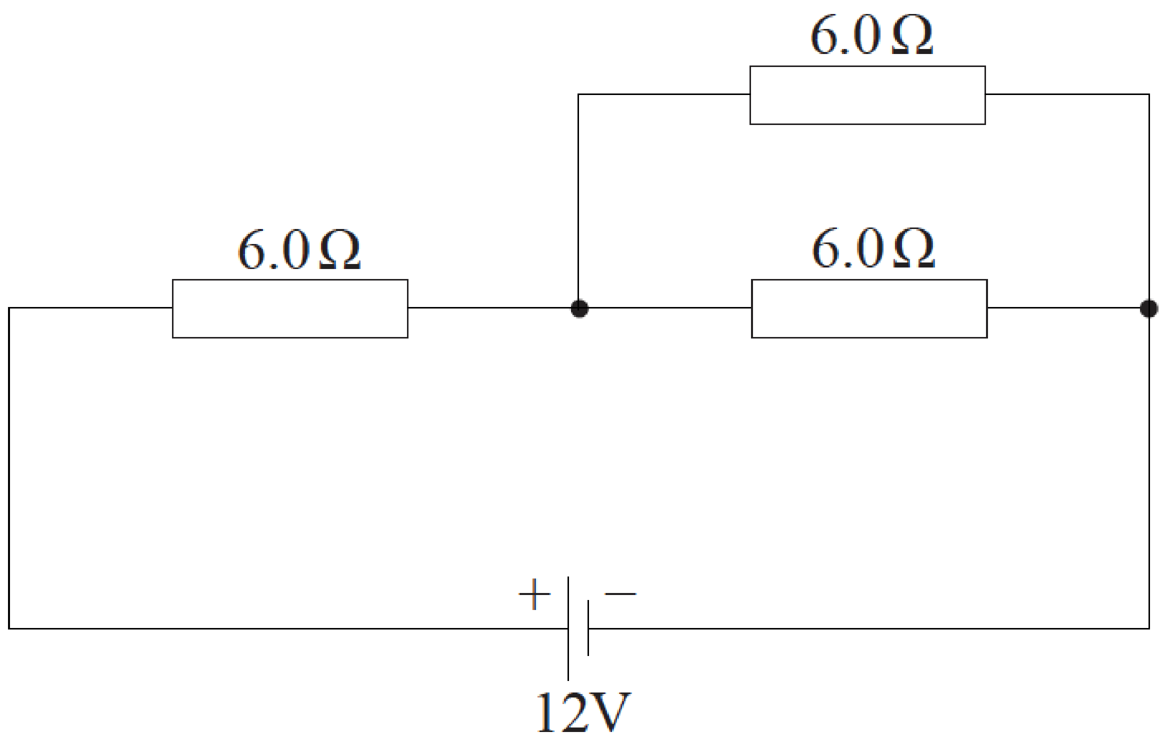
(ii) Calculate the magnitude of Aibhe's acceleration.

e. Define the *electric resistance* of a wire. [1]

f. Using the following data, calculate the length of constantan wire required to make a resistor with a resistance of 6.0Ω. [3]

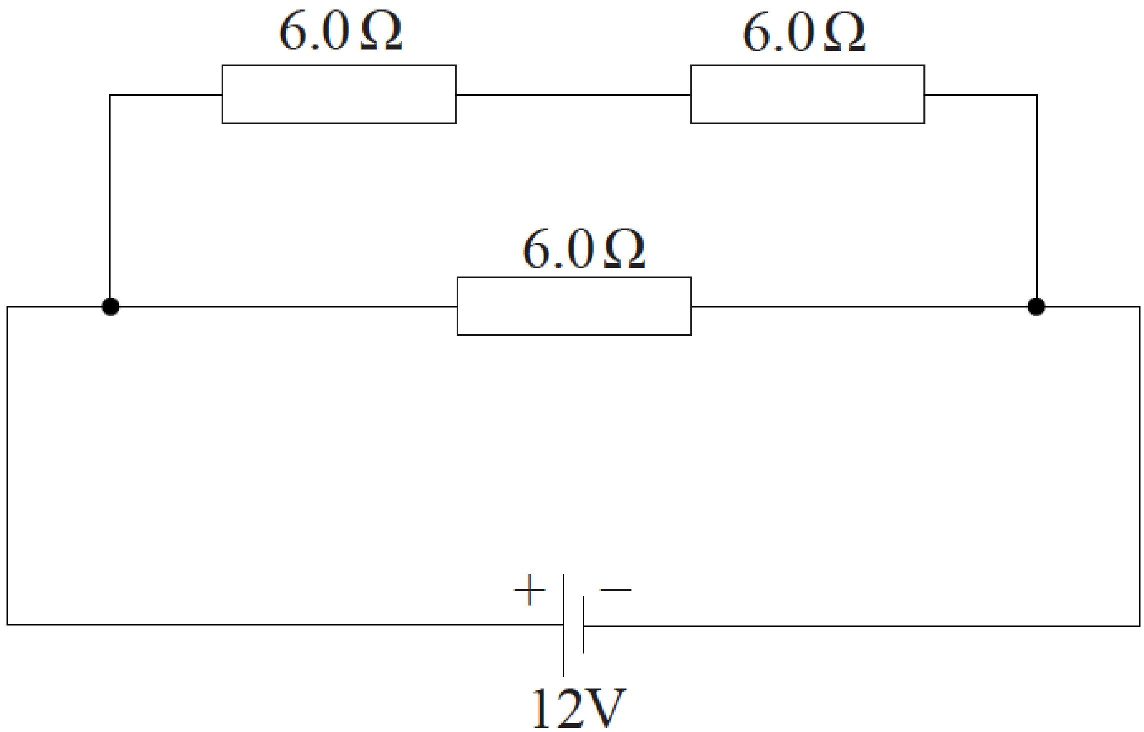
Resistivity of constantan = $5.0\times10^{-7}\Omega m$
Average radius of wire = $2.5\times10^{-5}m$

g. Three resistors, each of resistance 6.0Ω, are arranged in the circuit shown below. The cell has an emf of 12V and negligible internal resistance. [3]



Determine the total power supplied by the cell.

h. The same resistors and cell are now re-arranged into a different circuit, as shown below. [3]

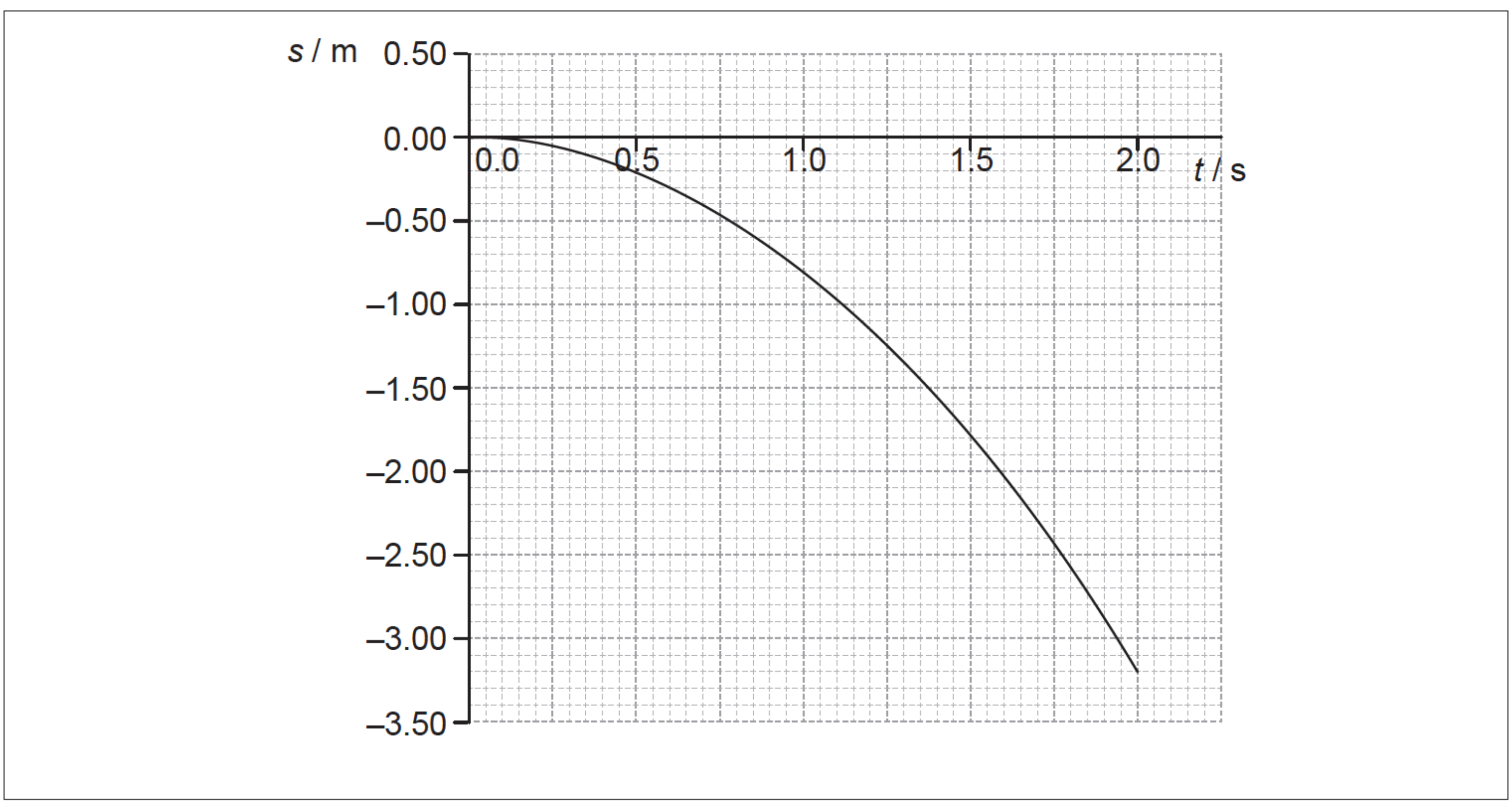


Explain why the total power supplied by the cell is greater than for the circuit in (g).

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.



Part 2 Radioactivity

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

a. State the significance of the negative values of *s*. [1]

b. Use the graph to [6]

(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.

c. The following data are available. [4]

Mass of the ball = 0.20 kg

Mean radius of the Moon = 1.74×10^6 m

Mean orbital radius of the Moon about the centre of Earth = 3.84×10^8 m

Mass of Earth = 5.97×10^{24} kg

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

d. 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]

e. Sketch, on the graph, the variation with time *t* of the displacement *s* from 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.) [3]

f. Explain, in terms of the number of nucleons and the forces between them, why calcium-40 is stable and calcium-47 is radioactive. [3]

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

h. The nuclear equation for the decay of calcium-47 into scandium-47 $\left({}^{47}_{21}\mathrm{Sc}\right)$ is given by [4]

$$ {}^{47}_{20}\mathrm{Ca} \rightarrow {}^{47}_{21}\mathrm{Sc} + {}^{0}_{-1}\mathrm{e} + \mathrm{X} $$

(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).