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 9.4×10^3 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]

Markscheme

a. gravitational provides centripetal force / gravitational provides force towards centre; (because radius is implied constant) (centripetal) force is constant;

at 90° to velocity (vector)/orbit/direction / *OWTTE* / $\frac{GmM}{r^2} = \frac{mv^2}{r}$ (or re-arranged) and therefore speed is constant (and motion is uniform); } *(do not allow "inwards/centripetal" for this mark. The right angle must be explicit)*

b. $v = \omega r$ and $\omega = \frac{2\pi}{T}$ combined; } *(allow approach from speed* $= \frac{s}{T}$, *do not allow approach from* $v^2 = ar$ or $f = \frac{1}{T}$)

$v = \left(\frac{2\pi r}{T} =\right) \frac{2\pi \times 9.4 \times 10^6}{7.7 \times 3600}$ ***or*** $2.1(3) \times 10^3\ (\mathrm{m\,s^{-1}})$;

c. $m\frac{v^2}{r} = G\frac{mM}{r^2}$ ***or*** $F_\mathrm{c} = F_\mathrm{G}$;

$M = \frac{v^2 r}{G}$ ***or*** $\frac{(2.13\times10^3)^2 \times 9.4 \times 10^6}{6.67 \times 10^{-11}}$; *(allow power of ten error in this mark)*

$M = 6.4 \times 10^{23}\ (\mathrm{kg})$ from 2.13 ***or*** $5.6 \times 10^{23}\ (\mathrm{kg})$ from 2;

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

Examiners report

a. Candidates were asked to outline the real meaning of "uniform circular motion". They were required to link the gravitational force acting on Phobos due to Mars (and the constancy of this force) to the dynamics of the force direction associated with the orbit and its consequences for the change in velocity (and lack of change in speed). Few managed to score all points with the majority managing to score 2 out of the 3 available.

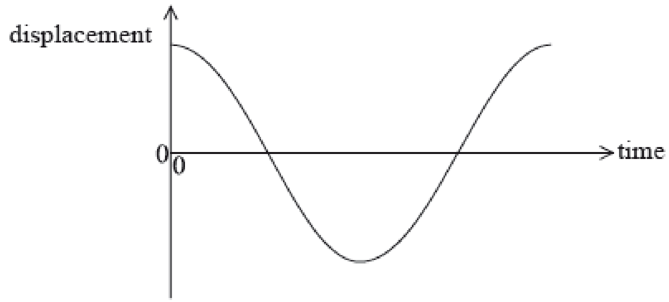
b. This was a particularly simple "show that" question. Once again, examiners saw considerable numbers of answers that gave little information about the origin of the solution. As in past examinations, examiners saw much pure substitution without any explanation of its origin. This does not score well. It is best practice for candidates to present a full argument in calculations, and in "show that" and "deduce" questions it is essential.

c. Candidates were on surer ground with the deduction of the mass of Mars. An algebraic starting point was allowed and many scored all 3 marks. However, a very large number failed to arrive at the correct numerical answer due to errors in powers of ten from the data provided.

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

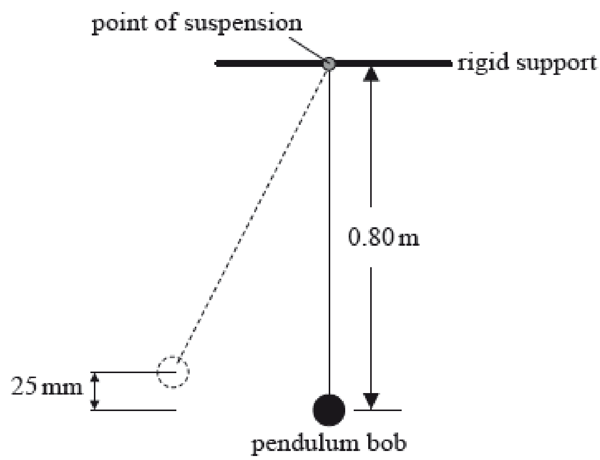
Part 1 Simple pendulum

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.

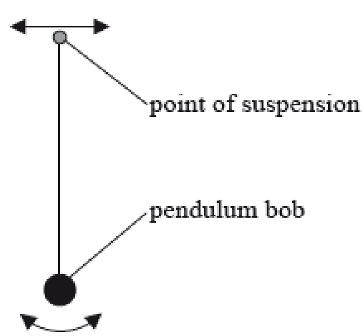


On the sketch graph above,

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]

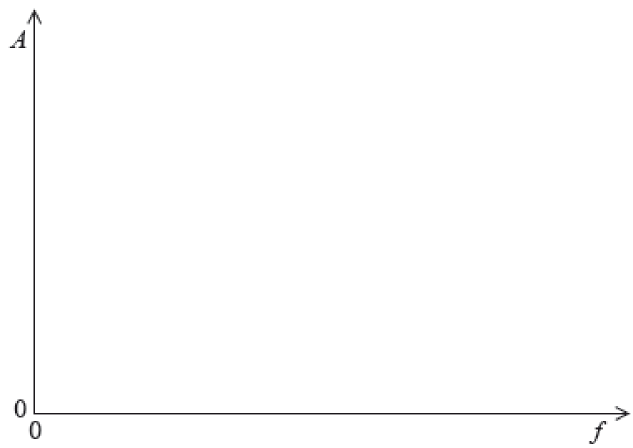
(ii) label with the letter V a point at which the speed of the pendulum bob is a maximum.

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 1.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]

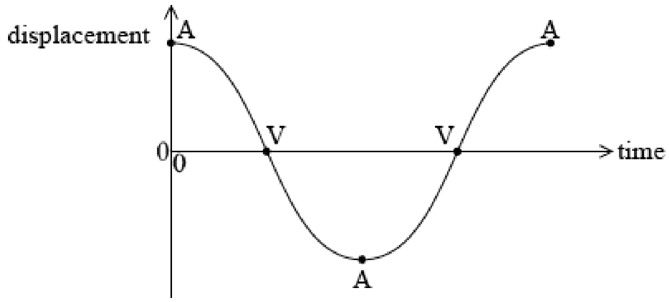
Part 2.b. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. [4]

(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.

Markscheme

Part 1.a. (i) one A correctly shown;

(ii) one V correctly shown;



Part1.b. pendulum bob accelerates towards centre of circular path / *OWTTE*;

therefore force upwards;

that <u>adds</u> to tension produced by the weight;

Part1.c. (i) evidence shown of equating kinetic energy and gravitational potential energy;

$v = \sqrt{(2 \times 9.8 \times 0.025)}$;

$= 0.70 \text{ m s}^{-1}$

Allow g = 10 m s^{-2} answer 0.71 m s^{-2}.

(ii) centripetal acceleration $\left(= \frac{v^2}{r}\right) \left[= \frac{0.7^2}{0.8}\right] = 0.61 \ (\text{m s}^{-2})$;

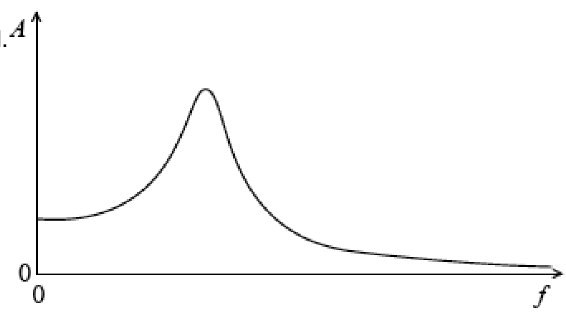
net acceleration $= (9.81 + 0.61 =)\ 10.4 \ (\text{m s}^{-2})$ ***or*** $T - mg = m \times 0.61$;

tension $= (ma =)\ 0.59 \text{ N}$;

Allow g = 10 m s^{-2} answer 0.60 N.

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

Part1.d.



(i)

one maximum shown and curve broadly similar to example above;

amplitude falls on each side by lower amount on low driving frequency side;

(ii) resonance is where driving frequency equals/close to natural frequency;

the frequency at the maximum amplitude of the graph;

Part1.e. lower amplitude everywhere on graph;

with a much broader resonance peak;

maximum moves to left on graph;

*Award **[2]** for a sketch graph.*

Part2.a. most of the atom is empty space;

most of the mass/(protonic) charge of the atom is concentrated in the nucleus/nucleus is dense;

$$\left.\begin{array}{c}\text{nucleus is positively charged;}\\ \text{(most) alphas not close enough to nuclei to be deflected;}\\ \text{(very few) alphas (are) close enough to nuclei to be deflected;}\end{array}\right\}\begin{array}{c} These points can \\ be awarded to a \\ labelled diagram.\end{array}$$

To award the last two marking points for a diagram response the candidate must show that a non-deflected alpha is well away from a nucleus and a strongly deflected alpha is aimed very close or head-on.

Part 2.b. (i) mention of Coulomb repulsion between protons;

mention of strong (nuclear) force (between nucleons);

overall balance must be correct (and more neutrons needed for this);

*Award **[0]** for a statement that neutron is negative.*

(ii) anti neutrino / $\bar{v}$;

Examiners report

Part 1.a. Identifications of points A and V were mixed. About half the candidates received both marks here.

Part 1.b. This was poorly done with many misapprehensions evident. The main problem was that candidates failed to associate the effect with the presence of a centripetal force and also unable to consider it in terms of the directions and additions of the various forces in the situation.

Part 1.c. (i) This was well done by many. However a use of a *suvat* equation is not appropriate in this case as the acceleration is not uniform.

(ii) Candidates who kept a clear head were able to arrive at a correct answer even if they had failed in part (b)

Part 1.d. (i) Graphs were poor in general with few gaining both marks and many candidates unable to make any progress. Graphs often showed a decreasing amplitude against time despite the frequency label on the *x*-axis.

(ii) Few understood the meaning of the term “resonance” sufficiently to be able to describe it in terms of the graph.

Part 1.e. Again, few candidates referred their answer to the graph. Some were able to gain credit for discussing changes in amplitude.

Part 2.a. Candidates who rely on a diagram rather than a written description must ensure that their sketches give all the required information unambiguously. In this type of question it is also common to see candidates repeating part of the question itself back to the examiner; this will not gain credit. Candidates needed to distinguish between those alpha particles passing close to and those far away from a nucleus, and then to give the deduced properties of the nucleus from these observations. Descriptions were often illogical and repetitive.

Part 2.b. Most candidates could write with confidence about the repulsive nature of the proton-proton interaction and the attractive nature of the strong nuclear force. Few gave good accounts of the balance between these two forces or described the energy situation (a better way to answer). Weak candidates could not name the strong nuclear force adequately.

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.

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

Markscheme

a. (i) the force exerted on a small/test/point mass;

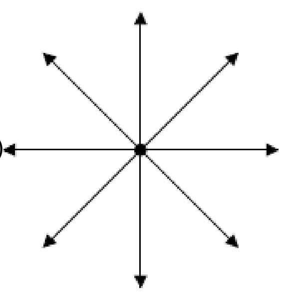
Do not allow bald "gravitational force".

(ii) the force exerted on a small/point/test positive charge;
*To award **[1]** "positive" is required.*
Do not allow bald "electric force".

(iii) the size/magnitude/value of the small/point mass;
Do not accept bald "mass".

(iv) the magnitude/size/value of the small/point/test (positive) charge;
Do not accept bald "charge".

b.

(i) 

pattern correct with at least 8 symmetrical lines as shown;
direction correct;

(ii) $E_p = \frac{e}{4\pi\varepsilon_0 r^2}$ and $g_p = \frac{Gm_p}{r^2}$; *(both needed)*
$\frac{e}{4\pi\varepsilon_0 Gm_p}\left(= \frac{9\times10^{9}\times1.6\times10^{-19}}{6.7\times10^{-11}\times1.7\times10^{-27}}\right)$;
□10^{28};

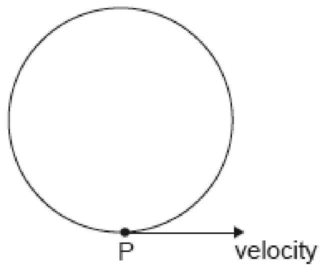
Examiners report

a. In this part candidates were completely at a loss and could not state the meanings of the symbols in the definitions of gravitational or electric field strengths. This was a disappointing failure in what was meant to be an easy opener to the whole question.

b. (i) The diagrams presented to examiners frequently gave a clear indication of the direction and shape of the field pattern. This was well done.

(ii) Following(a) candidates failed widely on this part too. They often had little idea which data to use (mass and charge were frequently confused) and sometimes the meaning of the constants in the equations failed them too. This was compounded by arithmetic errors to make a straightforward calculation very hard for many.

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]

Markscheme

a. out of the page plane / ⊙

Do not accept just “up” or “outwards”.

[1 mark]

b. $1.60 \times 10^{-19} \times 6.8 \times 10^5 \times 8.5 = 9.2 \times 10^{-13}$ «N»

[1 mark]

c.i. the magnetic force does not do work on the electron hence does not change the electron’s kinetic energy

OR

the magnetic force/acceleration is at right angles to velocity

[1 mark]

c.ii. the velocity of the electron is at right angles to the magnetic field

(therefore) there is a centripetal acceleration / force acting on the charge

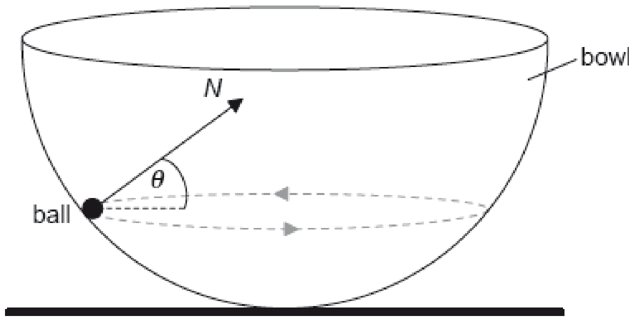
OWTTE

[2 marks]

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]

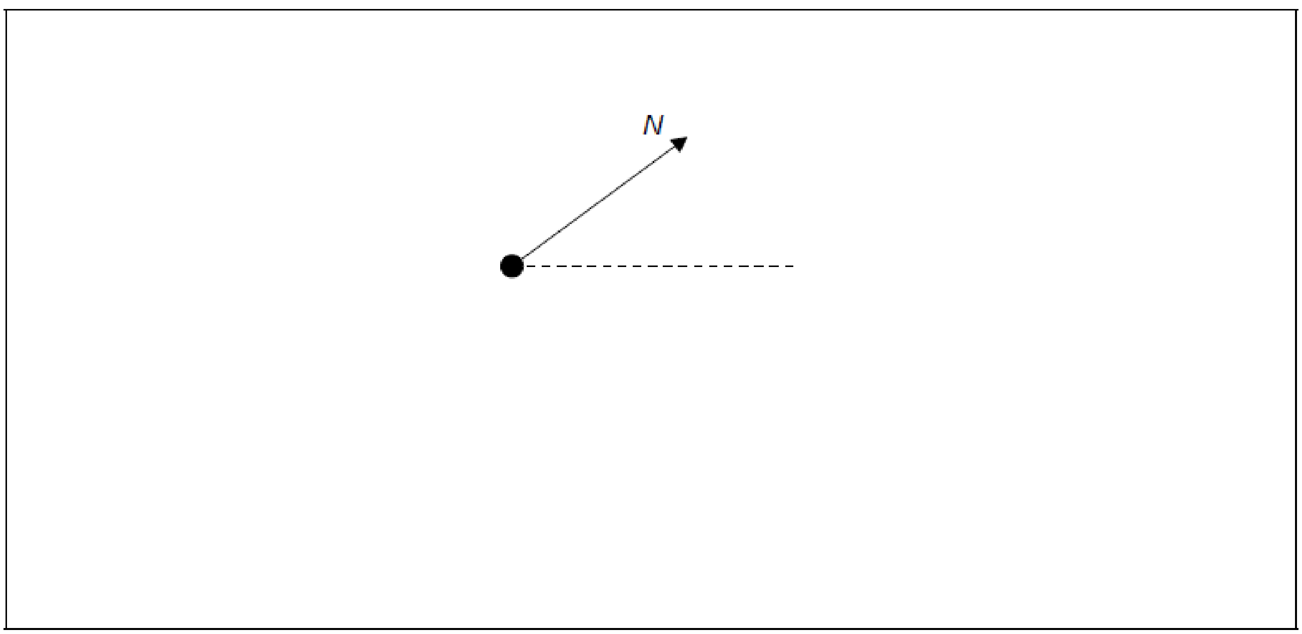
A small ball of mass *m* is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.



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]



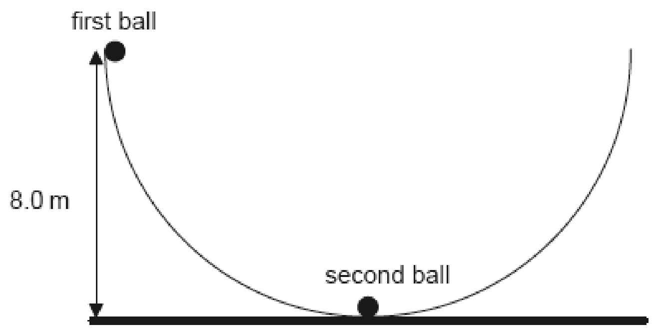
a.iii Show that the magnitude of the net force *F* on the ball is given by the following equation. [3]

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

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.

Markscheme

a.i. towards the centre «of the circle» / horizontally to the right

Do not accept towards the centre of the bowl

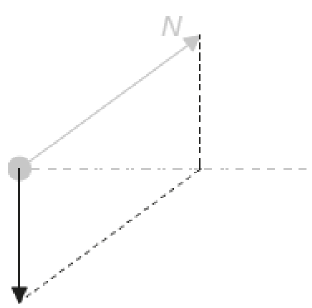
[1 mark]

a.ii. downward vertical arrow of any length

arrow of correct length

Judge the length of the vertical arrow by eye. The construction lines are not required. A label is not required

eg:



[2 marks]

a.iii. ***ALTERNATIVE 1***

$F = N \cos \theta$

$mg = N \sin \theta$

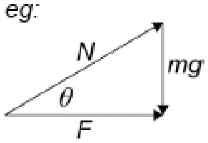
dividing/substituting to get result

ALTERNATIVE 2

right angle triangle drawn with *F*, *N* and *W*/*mg* labelled

angle correctly labelled and arrows on forces in correct directions

correct use of trigonometry leading to the required relationship *eg:*



tan θ = $\frac{O}{A} = \frac{mg}{F}$

[3 marks]

b. $\frac{mg}{\tan\theta} = m\frac{v^2}{r}$

r = *R* cos *θ*

v = $\sqrt{\frac{gR\cos^2\theta}{\sin\theta}} / \sqrt{\frac{gR\cos\theta}{\tan\theta}} / \sqrt{\frac{9.81\times8.0\cos22}{\tan22}}$

v = 13.4/13 «*ms* $^{-1}$»

*Award **[4]** for a bald correct answer*

*Award **[3]** for an answer of 13.9/14 «ms $^{-1}$». MP2 omitted*

[4 marks]

c. there is no force to balance the weight/N is horizontal

so no / it is not possible

Must see correct justification to award MP2

[2 marks]

d. speed before collision *v* = «$\sqrt{2gR}$ =» 12.5 «ms^{-1}»

«from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed «$v_c = \frac{12.5}{2}$ = 6.25 ms^{-1}»

h = «$\frac{v_c{}^2}{2g} = \frac{6.25^2}{2\times9.81}$» 2.0 «m»

Allow 12.5 from incorrect use of kinematics equations

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

*Award **[0]** for mg(8) = 2mgh leading to h = 4 m if done in one step.*

Allow ECF from MP1

Allow ECF from MP2

[3 marks]

Examiners report

a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

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

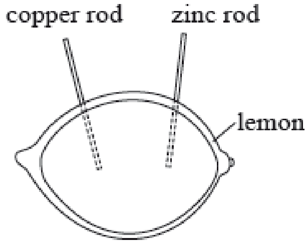
Part 1 Motion of a car

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.

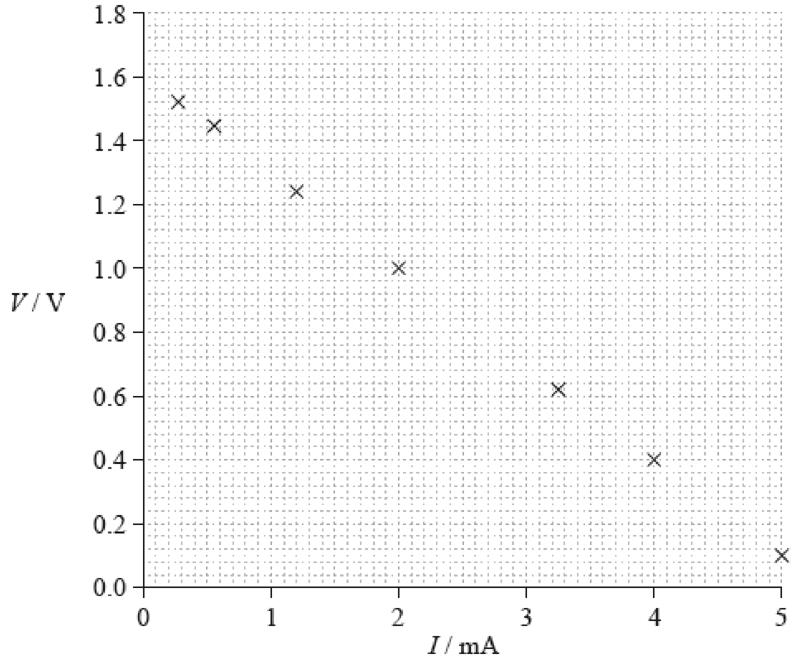
d. (i) Draw a circuit diagram of the experimental arrangement that will enable the student to collect the data for the graph. [10]

(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.

Markscheme

a. use of a kinematic equation to determine motion time $(= 12.5\text{ s})$;

change in kinetic energy $= \frac{1}{2} \times 1200 \times \left[28^2 - 12^2\right]\ (= 384\text{ kJ})$;

rate of change in kinetic energy $= \frac{384000}{12.5}$; } *(allow ECF of 162 from (28 – 12)^2 for this mark)*

31 (kW);

or

use of a kinematic equation to determine motion time $(= 12.5\text{ s})$;

use of a kinematic equation to determine acceleration $(= 1.28\text{ m s}^{-2})$;

work done $= \frac{F \times s}{\text{time}} = \frac{1536 \times 250}{12.5}$;

31 (kW);

b. (i) $\text{force} = \frac{\text{power}}{\text{speed}}$;

2300 ***or*** 2.3k (N);

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

(ii) resistive force $= \frac{2300}{4}$ ***or*** $\frac{2321}{4}$ $(= 575)$; *(allow ECF)*

so accelerating force = $(2300 - 580 =)\ 1725\ (\text{N})$ ***or*** 1741 (N);

$a = \frac{1725}{1200} = 1.44\ (\text{ms}^{-2})$ ***or*** $a = \frac{1741}{1200} = 1.45\ (\text{m s}^{-2})$;

*Award **[2 max]** for an answer of 0.49 (m s^{-2}) (omits 2300 N).*

c. (i) centripetal force must be $< 6000\ (\text{N})$; *(allow force = 6000 N)*

$v^2 = F \times \frac{r}{m}$;

$31.6\ (\text{m s}^{-1})$;

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

*Allow **[2 max]** if 4× is omitted, giving 15.8 (m s^{-1}).*

(ii) statement of Newton's first law;

(hence) without car wall/restraint/friction at seat, the people in the car would move in a straight line/at a tangent to circle;

(hence) seat/seat belt/door exerts centripetal force;

(in frame of reference of the people) straight ahead movement is interpreted as "outwards";

d. (i) voltmeter in parallel with cell; *(allow ammeter within voltmeter leads)*

ammeter in series with variable resistor; } *(must draw as variable arrangement or as potential divider)*

Allow cell symbol for lemon/cell/box labelled "lemon cell".

*Award **[1 max]** if additional cell appears in the circuit.*

(ii) $E = I(R + r)$ and $V = IR$ used; *(must state both explicitly)*

re-arrangement correct *ie* $E = V + Ir$; } *(accept any other correct re-arrangement eg. involving energy conversion)*

(iii) line correctly extrapolated to *y*-axis; *(judge by eye)*

1.6 ***or*** 1.60 (V); *(allow ECF from incorrect extrapolation)*

(iv) correct read-offs from large triangle greater than half line length;

gradient determined;

290 to 310 (Ω);

*Award **[2 max]** for the use of one point on line and equation.*

(v) 0.35 (C);

Examiners report

a. There were at least two routes to tackle this problem. Some solutions were so confused that it was difficult to decide which method had been used. Common errors included: forgetting that the initial speed was $12\ \mathrm{m\,s^{-1}}$ not zero, power of ten errors, and simple mistakes in the use of the kinematic equations, or failure to evaluate work done = force × distance correctly. However, many candidates scored partial credit. Scores of two or three out of the maximum four were common showing that many are persevering to get as far as they can.

b. (i) Many correct solutions were seen. Candidates are clearly comfortable with the use of the equation force = power/speed.

(ii) The method to be used here was obvious to many. What was missing was a clear appreciation of what was happening in terms of resistive force in the system. Many scored two out of three because they indicated a sensible method but did not use the correct value for the force. Scoring two marks does require that the explanation of the method is at least competent. Those candidates who give limited explanations of their method leading to a wrong answer will generally accumulate little credit. A suggestion (never seen in answers) is that candidates should have begun from a free-body force diagram which would have revealed the relationship of all the forces.

c. (i) The major problem here was that most candidates did not recognise that 1500 N of force acting at each of four wheels will imply a total force of 6 kN. Again, partial credit was available only if it was clear what the candidate was doing and what the error was.

(ii) Statements of Newton's first law were surprisingly poor. As in previous examinations, few candidates appear to have learnt this essential rule by heart and they produce a garbled and incomplete version under examination pressure. The first law was then only loosely connected to the particular context of the question. Candidates have apparently not learnt to relate the physics they learn to everyday contexts.

d. (i) Circuit diagrams continue to be a particular issue for many candidates. Neat, well-drawn diagrams are rarely seen. Some diagrams had two cells, the lemon cell and another. Variable resistors were sometimes absent (or were drawn as fixed). Potential dividers were often attempted usually unsuccessfully. Generally candidates gained an average one mark for what should have been a familiar task.

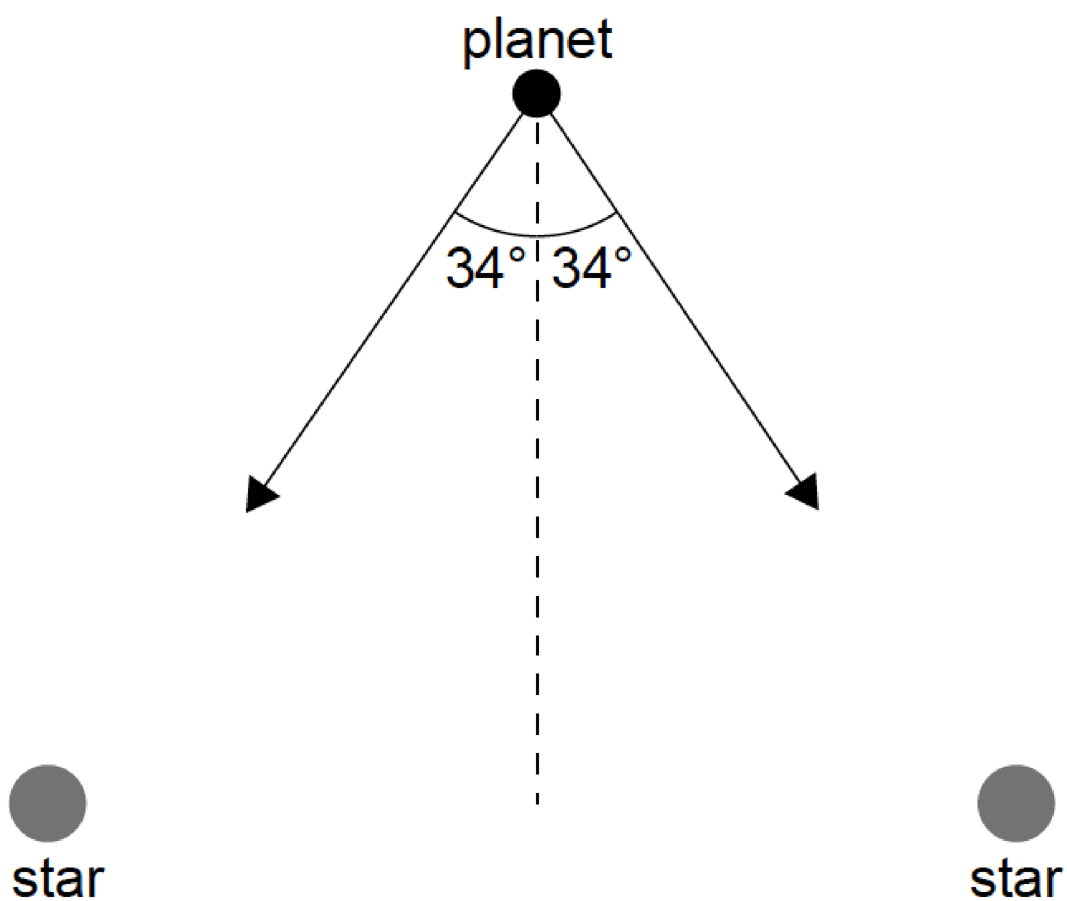
(ii) Those who quoted the data booklet equation and the definition of resistance were generally able to show the final expression. Some however could not convince the examiners that they knew what they were doing.

(iii) Candidates were expected to understand the physical point that the emf can be determined when the current in the cell is zero. For many, an extrapolation of the obvious straight line to the emf axis and a correct read-off gave an easy couple of marks. Some however did not understand the physics of the circuit and gave poorly described solutions.

(iv) The internal resistance was best obtained from a large triangle drawn on the graph. Many however gained two of the three marks because they engendered power of ten errors or because they used only one point, or because their triangle was too small.

(v) Only a minority were able to use the data to calculate the charge transferred correctly.

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 $M = 2.0\times10^{30}$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 $g = 3.7\times10^{-4}\,\text{Nkg}^{-1}$. [1]

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

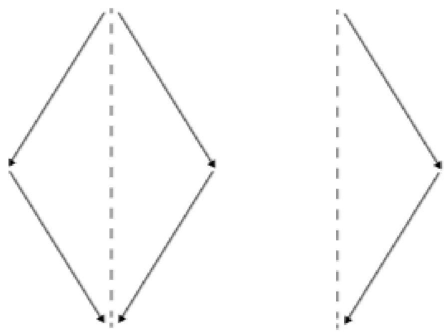
Markscheme

a. $g = \frac{GM}{r^2} = \frac{6.67\times10^{-11}\times2.0\times10^{30}}{\left(6.0\times10^{11}\right)^2}$

OR

$3.71\times10^{-4}\,\text{Nkg}^{-1}$

b. «g_{net} = 2cos34» 2g ***OR*** $g$cos34 ***OR*** $g$sin56 ***OR*** vector addition diagram shown



«g_{net} =«2×3.7×10^{-4} ×cos34° =» 6.1×10^{-4} Nkg^{-1}

Examiners report

a. [N/A]
b. [N/A]

---

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.

Markscheme

a. (i) «gravitational» force per unit mass on a «small **or** test» mass

(ii) N kg^{-1}

Award mark if N kg^{-1} is seen, treating any further work as neutral.
Do not accept bald m s^{-2}

b. i

clear evidence that *v* in $v^2 = \frac{4\pi^2 R^2}{T^2}$ is equated to orbital speed $\sqrt{\frac{GM}{R}}$

OR

clear evidence that centripetal force is equated to gravitational force

OR

clear evidence that *a* in $a = \frac{v^2}{R}$ etc is equated to *g* in $g = \frac{GM}{R^2}$ with consistent use of symbols

Minimum is a statement that $\sqrt{\frac{GM}{R}}$ is the orbital speed which is then used in $v = \frac{2\pi R}{T}$

Minimum is $F_c = F_g$ ignore any signs.

Minimum is g = a.

substitutes and re-arranges to obtain result
Allow any legitimate method not identified here.
Do not allow spurious methods involving equations of shm etc

$$\ll T = \sqrt{\frac{4\pi^2 R}{\left(\frac{GM}{R^2}\right)}} = \sqrt{\frac{4\pi^2 R^3}{GM}} \gg$$

ii
«T = 365 × 24 × 60 × 60 = 3.15 × 10^7 s»

$$M = \ll \frac{4\pi^2 R^3}{GT^2} = \gg = \frac{4\times3.14^2\times\left(1.5\times10^{11}\right)^3}{6.67\times10^{-11}\times\left(3.15\times10^7\right)^2}$$

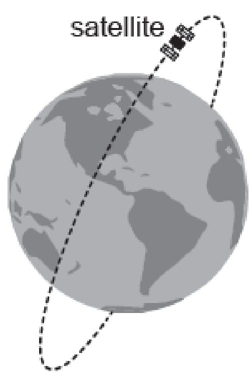
2×10^{30}«kg»

Allow use of 3.16 x 10^7 s for year length (quoted elsewhere in paper).
Condone error in power of ten in MP1.
*Award **[1 max]** if incorrect time used (24 h is sometimes seen, leading to 2.66 x 10^{35} kg).*
Units are not required, but if not given assume kg and mark POT accordingly if power wrong.
*Award **[2]** for a bald correct answer.*
No sf penalty here.

Examiners report

a. [N/A]
b. [N/A]

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.

Markscheme

a. $\frac{mv^2}{r} = G\frac{Mm}{r^2}$

leading to $T^2 = \frac{4\pi^2 r^3}{GM}$

T = 5320 «s»

Alternative 2

«$v = \sqrt{\frac{GM_E}{r}}$» = $\sqrt{\frac{6.67\times10^{-11}\times6.0\times10^{24}}{6600\times10^3}}$ ***or*** 7800 «ms^{-1}»

distance = $2\pi r$ = 2π x 6600 x 10^3 «m» or 4.15 x 10^7 «m»

«$T = \frac{d}{v} = \frac{4.15\times10^7}{7800}$» = 5300 «s»

Accept use of ω instead of v

b.i. T = «$\frac{2.90\times10^{-3}}{\lambda_{\max}}$ =» $\frac{2.90\times10^{-3}}{10.1\times10^{-6}}$

= 287 «K» ***or*** 14 «°C»

*Award **[0]** for any use of wavelength from Sun*

Do not accept 287 °C

b.ii. wavelength of radiation from the Sun is shorter than that emitted from Earth «and is not absorbed by the atmosphere»

infrared radiation emitted from Earth is absorbed by greenhouse gases in the atmosphere

this radiation is re-emitted in all directions «including back to Earth»

c. peer review

international collaboration

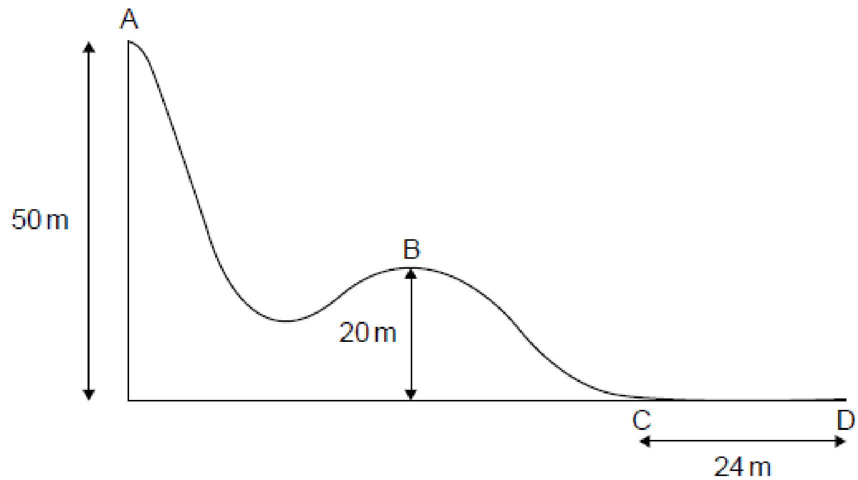
full details of experiments published so that experiments can repeated

[Max 1 Mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

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.

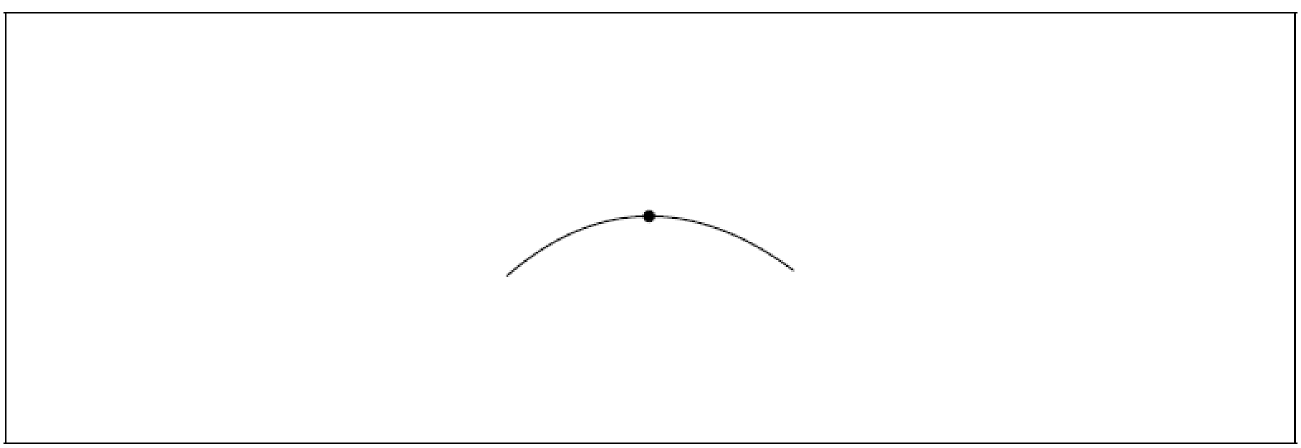
At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

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]

Markscheme

a.i. $\frac{1}{2}v^2 = 0.24\,\mathrm{gh}$

$v = 11.9$ «m s^{-1}»

Award GPE lost = 65 × 9.81 × 30 = «19130 J»

Must see the 11.9 value for MP2, not simply 12.

Allow g = 9.8 ms^{-2}.

a.ii. internal energy is the total KE «and PE» of the molecules/particles/atoms in an object

temperature is a measure of the average KE of the molecules/particles/atoms

*Award **[1 max]** if there is no mention of molecules/particles/atoms.*

b.i. arrow vertically downwards from dot labelled weight/W/mg/gravitational force/F_g/$F_{gravitational}$ ***AND*** arrow vertically upwards from dot labelled reaction force/R/normal contact force/N/F_N

W > R

Do not allow gravity.
Do not award MP1 if additional ‘centripetal’ force arrow is added.
Arrows must connect to dot.
Ignore any horizontal arrow labelled friction.
Judge by eye for MP2. Arrows do not have to be correctly labelled or connect to dot for MP2.

b.ii ***ALTERNATIVE 1***

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen

= 468 «N»

W/640 N (weight) is larger than the centripetal force required, so the skier does not lose contact with the ground

ALTERNATIVE 2

recognition that centripetal acceleration is required / $\frac{v^2}{r}$ seen

a = 7.2 «ms^{-2}»

g is larger than the centripetal acceleration required, so the skier does not lose contact with the ground

ALTERNATIVE 3

recognition that to lose contact with the ground centripetal force ≥ weight

calculation that v ≥ 14 «ms^{-1}»

comment that 12 «ms^{-1}» is less than 14 «ms^{-1}» so the skier does not lose contact with the ground

ALTERNATIVE 4

recognition that centripetal force is required / $\frac{mv^2}{r}$ seen

calculation that reaction force = 172 «N»

reaction force > 0 so the skier does not lose contact with the ground

Do not award a mark for the bald statement that the skier does not lose contact with the ground.

c. ***ALTERNATIVE 1***

$0 = 8.2^2 + 2 \times a \times 24$ therefore a = «–»1.40 «m s^{-2}»

friction force = ma = 65 × 1.4 = 91 «N»

coefficient of friction = $\frac{91}{65 \times 9.81}$ = 0.14

ALTERNATIVE 2

$KE = \frac{1}{2}mv^2 = 0.5 \times 65 \times 8.2^2 = 2185$ «J»

friction force = KE/distance = 2185/24 = 91 «N»

coefficient of friction = $\frac{91}{65 \times 9.81}$ = 0.14

Allow ECF from MP1.

d.i. «76 × 9.6»= 730

Ns ***OR*** kg ms^{-1}

d.ii. safety net extends stopping time

$F = \frac{\Delta p}{\Delta t}$ therefore F is smaller «with safety net»

OR

force is proportional to rate of change of momentum therefore F is smaller «with safety net»

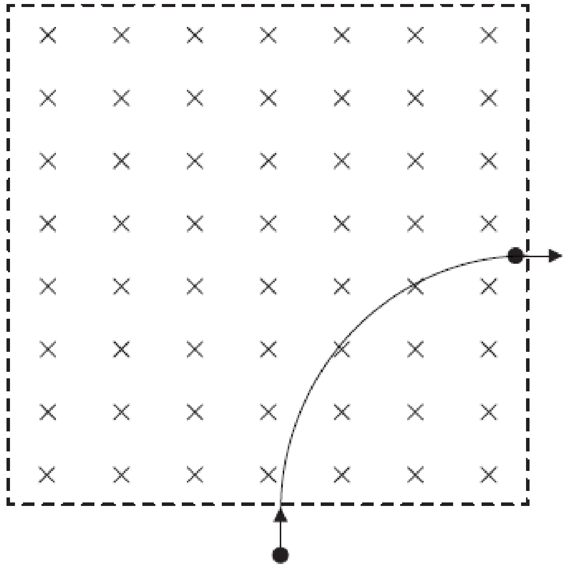
Accept reverse argument.

Examiners report

a.i. [N/A]
a.ii. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]

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.

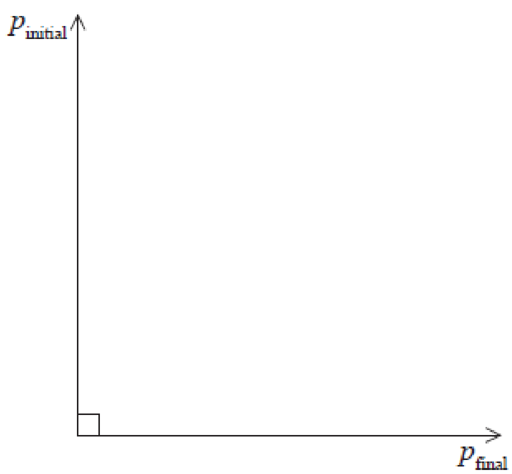


a. The electron's path while in the region of magnetic field is a quarter circle. Show that the [4]

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

(ii) radius of the path is $4.5\times10^{-4}m$.

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 $8.6\times10^{-24}Ns$. [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 $1.2\times10^{-23}Ns$.

(iii) The time the electron spends in the region of magnetic field is $7.5\times10^{-11}s$. Estimate the magnitude of the average force on the electron.

Markscheme

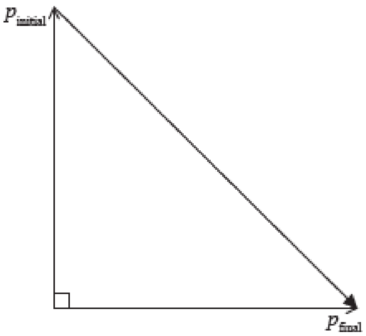
a. (i) $v=\sqrt{\frac{2eV}{m}}$;

$v=\sqrt{\frac{2\times1.6\times10^{-19}\times250}{9.1\times10^{-31}}}$;

$=9.4\times10^{6}ms^{-1}$

(ii) $evB = m\frac{v^2}{r}$;
$r = \frac{9.1\times10^{-31}\times9.4\times10^{6}}{1.6\times10^{-19}\times0.12}$;
$=4.5\times10^{-4}$m

b. (i) vector as shown;



(ii) $\Delta p = \sqrt{\left[8.6\times10^{-24}\right]^2 + \left[8.6\times10^{-24}\right]^2}$;
$=1.2\times10^{-23}$Ns

(iii) $F\left(=\frac{\Delta p}{\Delta t} = \frac{1.2\times10^{-23}}{7.5\times10^{-11}}\right) = 1.6\times10^{-13}\text{N}$;

Examiners report

a. [N/A]
b. [N/A]

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.*

Markscheme

a. the force between two (point) charges;

is inversely proportional to the square of their separation and (directly) proportional to (the product of) their magnitudes;

*Allow **[2]** for equation with F, Q and r defined.*

b. (i) $F = \left(k\frac{q_1 q_2}{r^2} =\right) \frac{9\times10^9 \times \left[1.6\times10^{-19}\right]^2}{4\times10^{-20}}$;

$=5.8\times10^{-9}$(N);

*Award **[0]** for use of masses in place of charges.*

(ii) ($\frac{(b)(i)}{1.6\times10^{-19}}$ **or** 3.6 x 10^{10} (NC^{-1}) **or** (Vm^{-1});
(directed) away from the proton;
Allow ECF from (b)(i).
Do not penalize use of masses in both (b)(i) and (b)(ii) – allow ECF.

(iii) $H = \left(G\frac{m}{r^2} =\right) \frac{6.67\times10^{-11}\times1.673\times10^{-27}}{4\times10^{-20}} = 2.8\times10^{-18}\ (\text{Nkg}^{-1})$;

$\frac{H}{E} = \frac{2.8\times10^{-18}}{3.6\times10^{10}}$ **or** 7.8×10^{-29}(Ckg^{-1});
($\approx10^{28}Ckg^{-1}$)
Allow ECF from (b)(i).

(iv) 3.4(V);

c. (i) power supplied per unit current / energy supplied per unit charge / work done per unit charge;

(ii) energy supplied per coulomb=$\frac{5.1\times10^{-19}}{1.6\times10^{-19}}$ ***or*** 3.19(V);
(≈3.2V)

(iii) pd across 5.0Ω resistor=$\left(\frac{4.0\times10^{-19}}{1.6\times10^{-19}} =\right) 2.5\ (\text{V})$;
pd across *r*=(3.2-2.5=)0.70(V);

and

either

current in circuit=$\left(\frac{2.5}{5.0} =\right) 0.5\ (\text{A})$;
resistance of *r*=$\left(\frac{0.70}{0.50} =\right) 1.4\ (\Omega)$;

or

resistance of *r*=$\frac{0.70}{2.5}\times 5.0$;
=1.4(Ω);

or

3.2=0.5(R+*r*);
resistance of *r*=1.4(Ω);
*Award **[4]** for alternative working leading to correct answer.*
*Award **[4]** for a bald correct answer.*

Examiners report

a. Many were able to state Coulomb's law or to give the equation with explanations of the symbols. Some candidates however failed to define their symbols and lost marks.

b. (i) The electric force was calculated well by many.

(ii) The answer to (i) was well used to determine the magnitude of *E*. However, many candidates did not read the question and failed to state the direction of the field or gave it in an ambiguous way.

(iii) Calculations to show the order of magnitude of *H*/*E* were generally well done. The last step was often missing with the answer simply given as a fraction.

(iv) Many obtained this simple mark.

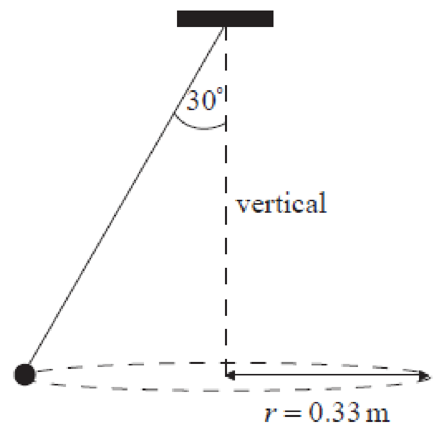
c. (i) Many candidates gave confused or incorrect definitions of the emf of a cell. Previous comments in this report on the memorizing of definitions apply. Too many had recourse to the next part and used this idea in their answer.

(ii) This was well done.

(iii) A large number of candidates completed this calculation stylishly, generally explaining steps (or at least writing down the algebra) in a logical way. There were many correct and original solutions that gained full marks.

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.



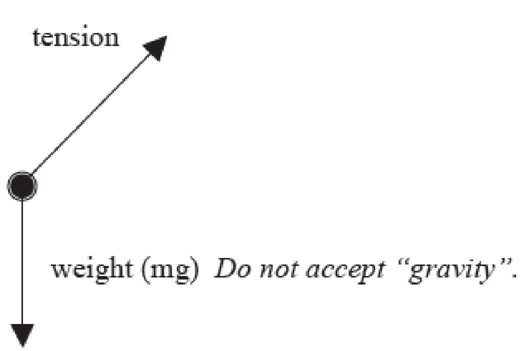
a. (i) On the diagram above, draw and label arrows to represent the forces on the ball in the position shown. [4]

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

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

Markscheme

a. (i) ***[1]*** each for correct arrow <u>and</u> (any reasonable) labelling;



*Award **[1 max]** for arrows in correct direction but not starting at the ball.*

(ii) no;
because the two forces on the ball can never cancel out / there is a net force on the ball / the ball moves in a circle / the ball has acceleration/it is changing direction;
*Award **[0]** for correct answer with no or wrong argument.*

b. $T\left(=\frac{mg}{\cos 30^\circ}\right)=2.832\text{N}$;
$\frac{mv^2}{r}=T\sin 30^\circ$;
$v=\left(\sqrt{\frac{Tr\sin 30^\circ}{m}}=\sqrt{\frac{2.832\times 0.33\times \sin 30^\circ}{0.25}}\right)=1.4\text{ms}^{-1}$;

or

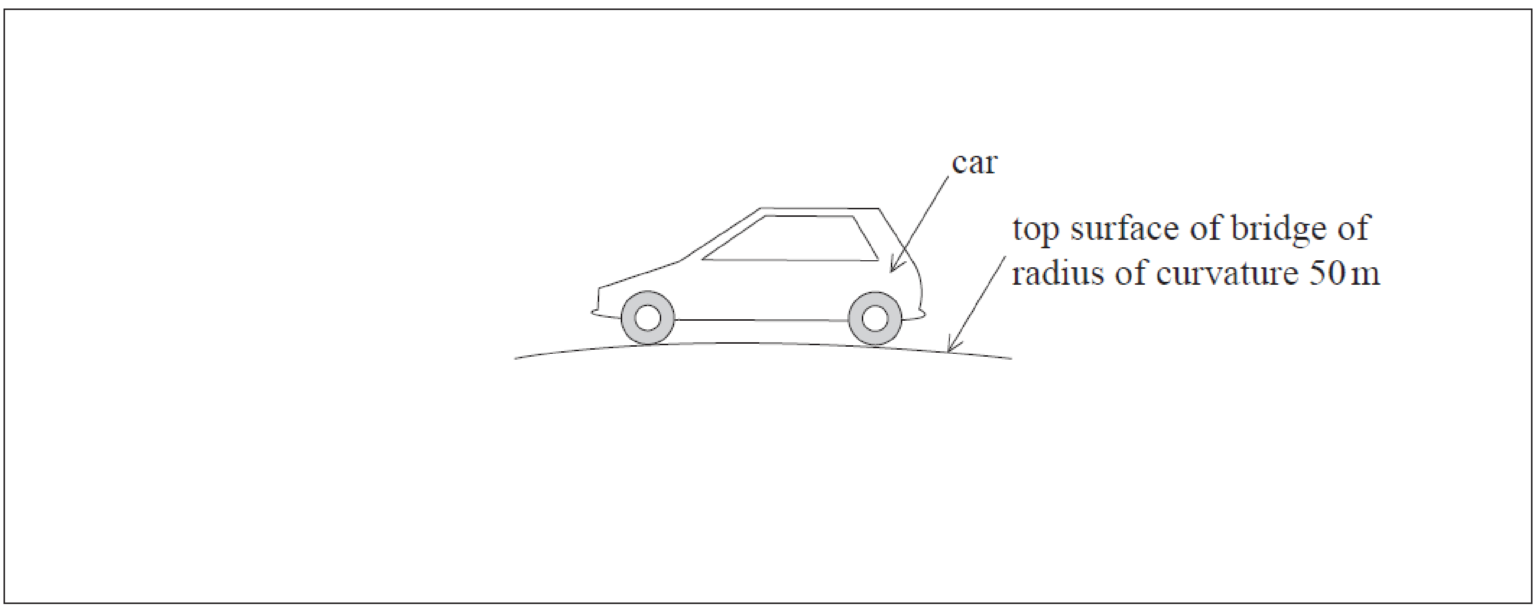
$T\cos 30^\circ=mg$;
$T\sin 30^\circ=\frac{mv^2}{r}$;
$v=\left(\sqrt{gr\tan 30^\circ}=\sqrt{9.81\times 0.33\times \tan 30^\circ}\right)=1.4\text{ms}^{-1}$;

Examiners report

a. [N/A]
b. [N/A]

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]

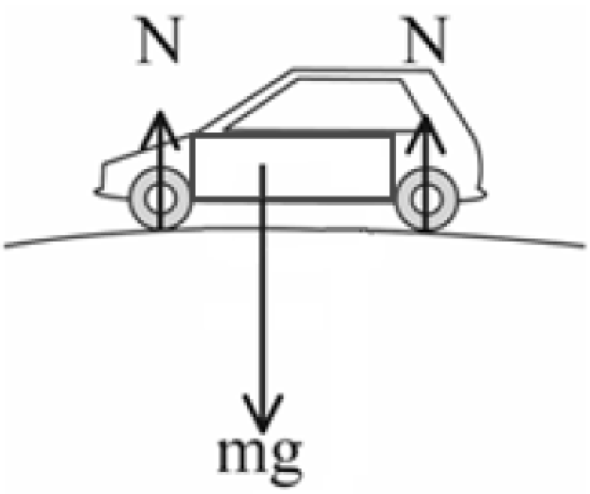
c. Calculate the maximum speed at which the car will stay in contact with the bridge. [3]

Markscheme

a. direction changing;

velocity changing so accelerating;

b.



weight/gravitational force/mg/w/F_w/F_g and reaction/normal reaction/perpendicular contact force/N/R/F_N/F_R both labelled; *(do not allow "gravity" for "weight".)*

weight between wheels (in box) from centre of mass and reactions at both wheels / single reaction acting along same line of action as the weight;

Judge by eye. Look for reasonably vertical lines with weight force longer than (sum of) reaction(s). Extra forces (eg centripetal force) loses the second mark.

c. $g = \frac{v^2}{r}$;

$v = \sqrt{50 \times 9.8}$;

22(ms^{-1});

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

Examiners report

a. Most candidates failed to state that acceleration is the rate of change of velocity and that as velocity is a vector it has both magnitude and direction. With there being a change in direction the car accelerates. Many erroneously talked about there being a change of direction of the acceleration – the direction is always centripetal.

b. Few marked in reaction acting at each wheel and the weight acting from the centre of gravity. The weight needed to be larger than the combined reaction to give a resultant centripetal force (this is shown by the relative length of the lines). Most candidates were unconcerned about the point of application of the forces and often added spurious horizontal and/or centripetal forces. Centripetal forces, being the resultant of the other force, should not be marked in on free body diagrams like this.

c. The majority of candidates made a good attempt at calculating the maximum speed by equating the weight to the centripetal force (that is, in the limit there is no reaction force).

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]

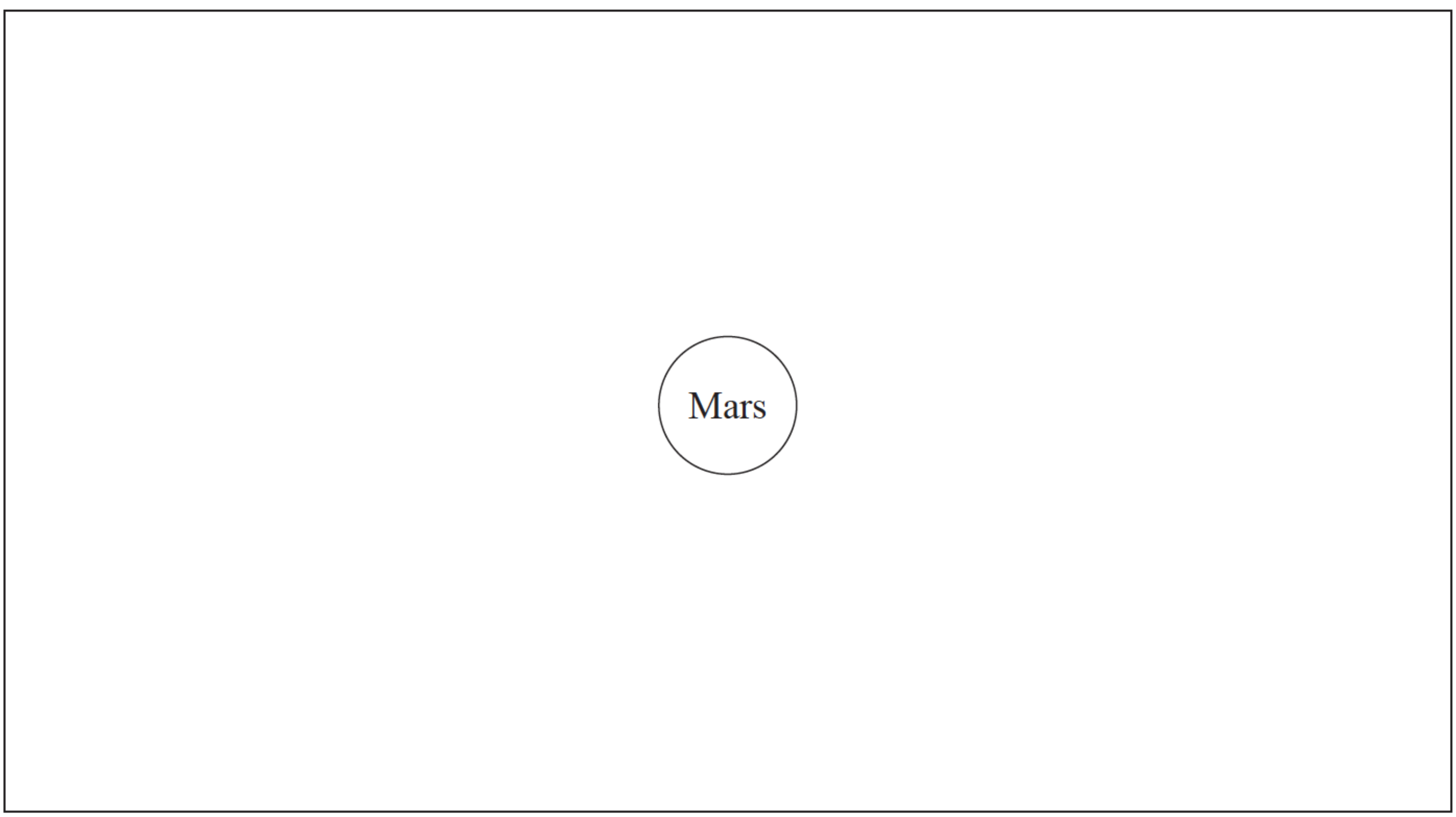
$$g_M = 0.38 \times g_E.$$

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

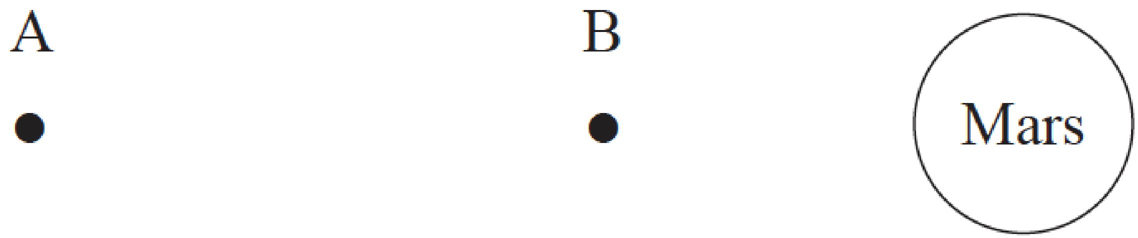
$$R_M = 0.53 \times R_E.$$

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 $v=u+g_M t$ to calculate v. Suggest **two** reasons why it is not appropriate to use this equation.



Markscheme

a. there is an attractive force;

between any two point/small masses;

proportional to the product of their masses;

and inversely proportional to the square of their separation;

Accept formula with all terms defined.

b. use of $g = \frac{F}{m}$ and $F = \frac{GmM}{R^2}$;

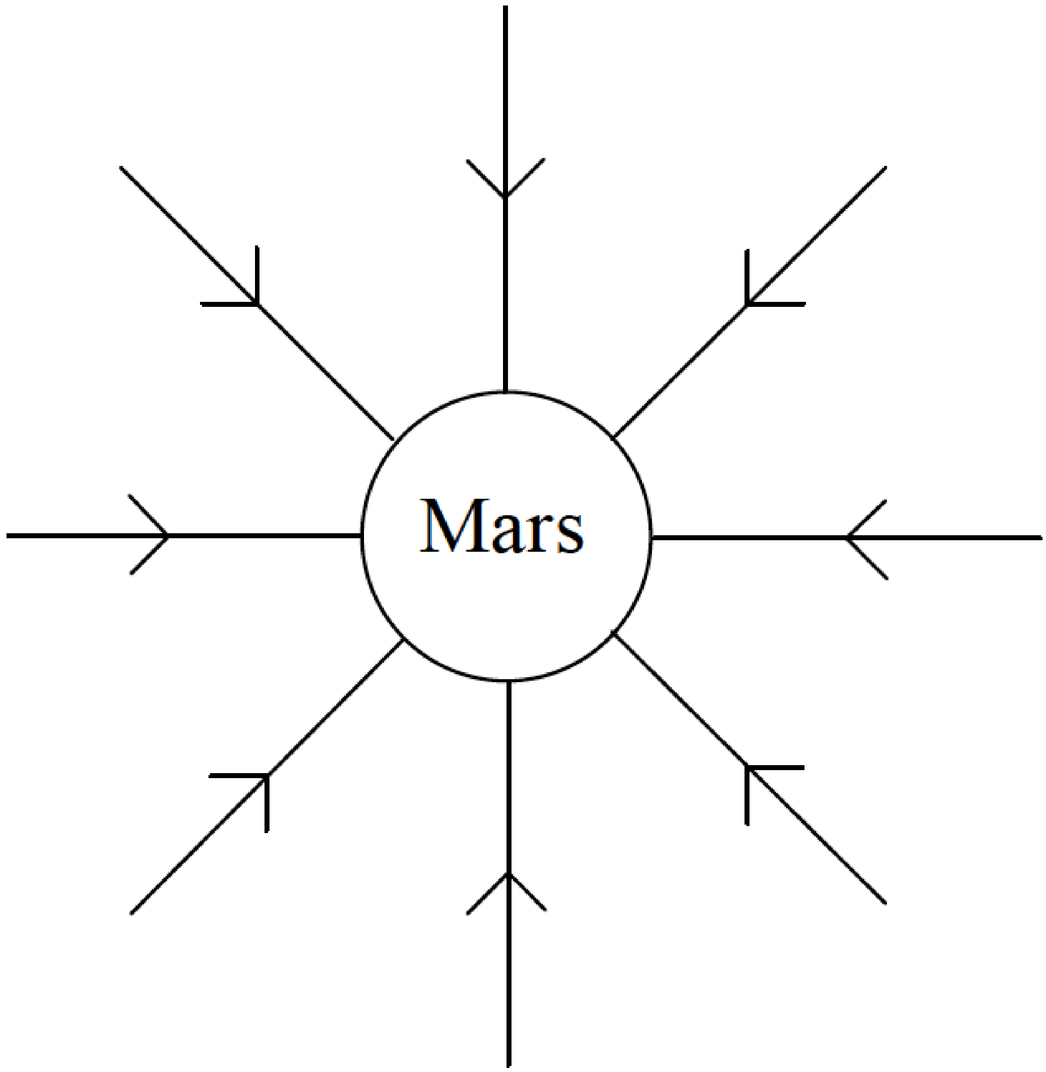
evidence of substitution/manipulation;

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

c. $\frac{g_M}{g_E} = \frac{\frac{M_M}{R_M^2}}{\frac{M_E}{R_E^2}} \Rightarrow \frac{M_M}{M_E} = \frac{g_M}{g_E} \times \left[\frac{R_M}{R_E}\right]^2$;

$M_{\mathrm{M}} \left(= 0.38 \times 0.53^2 M_{\mathrm{E}}\right) = 0.11 M_{\mathrm{E}}$;

d. (i) radial field with arrows pointing inwards;



(ii) field between A and B is not equal to field at surface;
acceleration is not constant between these two points;

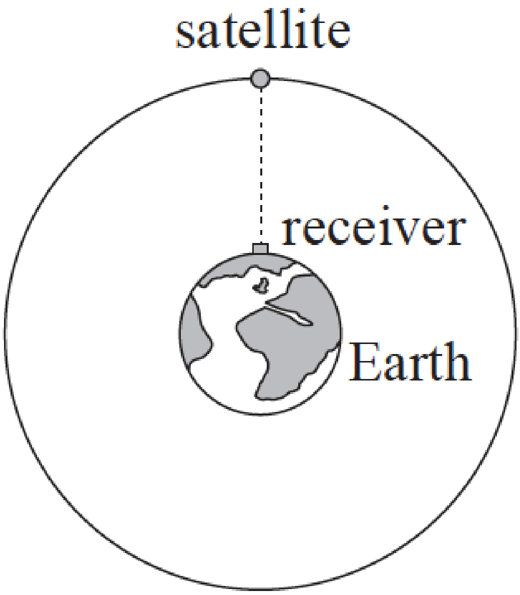
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

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.

Markscheme

a. force is proportional to product of masses and inversely proportional to square of distance apart;

reference to point masses;

b. (i) order of 1 cm;

(ii) $3\times10^{8}\times67\times10^{-3}$;
2.0×10^{7}m;

c. (i) force required towards centre of Earth to maintain orbit;

force means that there is an acceleration / *OWTTE*;

or

direction changes;
a change in velocity therefore acceleration;

(ii) uses=$\frac{GM}{r^2}$ ***or*** $\frac{6.7\times10^{-11}\times6.0\times10^{24}}{\left[2.6\times10^{7}\right]^{2}}$;
0.57Nkg^{-1}; (allow ms^{-2})

(iii) $v=\sqrt{0.57\times\left(2.0\times10^{7}+6.4\times10^{6}\right)}$ by equating $\frac{v^2}{r}$ and g;
3900ms^{-1};

(iv) $T = 2\pi \frac{2.6 \times 10^7}{3900}$;

11.9 hours;

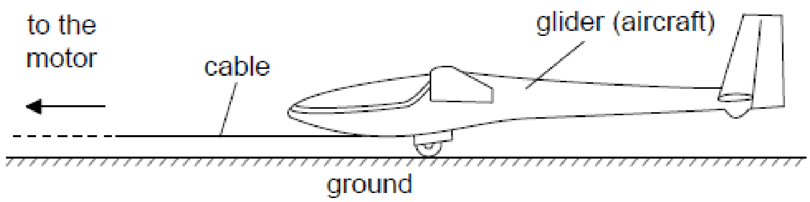
Examiners report

a. [N/A]

b. [N/A]

c. [N/A]

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.



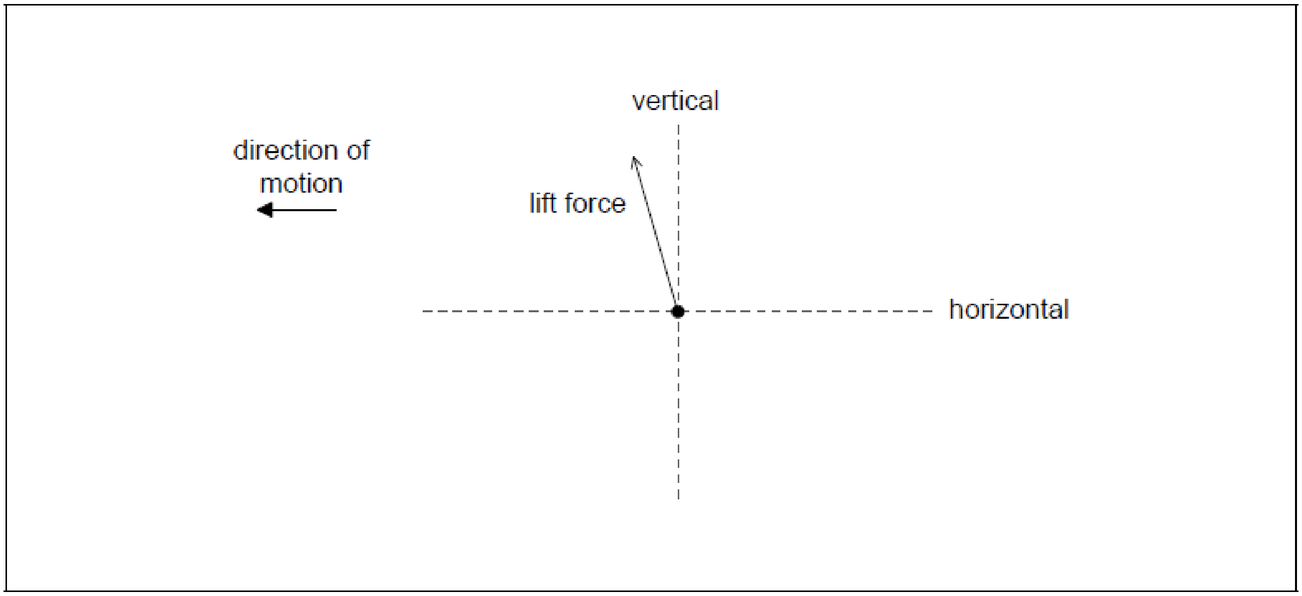
a. The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. [2]

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. The diagram shows the lift force acting on the glider and the direction of motion of the glider. [2]



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]

Markscheme

a. correct use of kinematic equation/equations

148.5 ***or*** 149 ***or*** 150 «m»

Substitution(s) must be correct.

b. $a = \frac{27}{11}$ ***or*** 2.45 «m s^{-2}»

$F - 160 = 492 \times 2.45$

1370 «N»

Could be seen in part (a).
*Award **[0]** for solution that uses a = 9.81 m s^{-2}*

c. ***ALTERNATIVE 1***

«work done to launch glider» = 1370 x 149 «= 204 kJ»

«work done by motor» $= \frac{204 \times 100}{23}$

«power input to motor» $= \frac{204 \times 100}{23} \times \frac{1}{11} = 80$ ***or*** 80.4 ***or*** 81 k«W»

ALTERNATIVE 2

use of average speed 13.5 m s^{-1}

«useful power output» = force x average speed «= 1370 x 13.5» power input = «$1370 \times 13.5 \times \frac{100}{23}$ =» 80 ***or*** 80.4 ***or*** 81 k«W»

ALTERNATIVE 3

work required from motor = KE + work done against friction «$= 0.5 \times 492 \times 27^2 + (160 \times 148.5)$» = 204 «kJ»

«energy input» $= \frac{\text{work required from motor} \times 100}{23}$

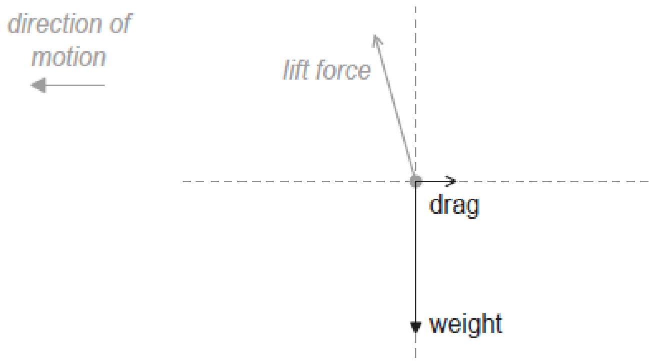
power input $= \frac{883000}{11} = 80.3$ k«W»

*Award **[2 max]** for an answer of 160 k«W».*

d. $\omega =$ «$\frac{v}{r}$ =» $\frac{27}{0.6} = 45$

rad s^{-1}

Do not accept Hz.
*Award **[1 max]** if unit is missing.*

e. 

drag correctly labelled and in correct direction

weight correctly labelled and in correct direction ***AND*** no other incorrect force shown

*Award **[1 max]** if forces do not touch the dot, but are otherwise OK.*

f. name Newton's first law

vertical/all forces are in equilibrium/balanced/add to zero
OR
vertical component of lift mentioned

as equal to weight

g. any speed and any direction quoted together as the answer

quotes their answer(s) to 3 significant figures

speed = 12.7 m s^{-1} ***or*** direction = 9.46° ***or*** 0.165 rad «below the horizontal» ***or*** gradient of $-\frac{1}{6}$

Examiners report

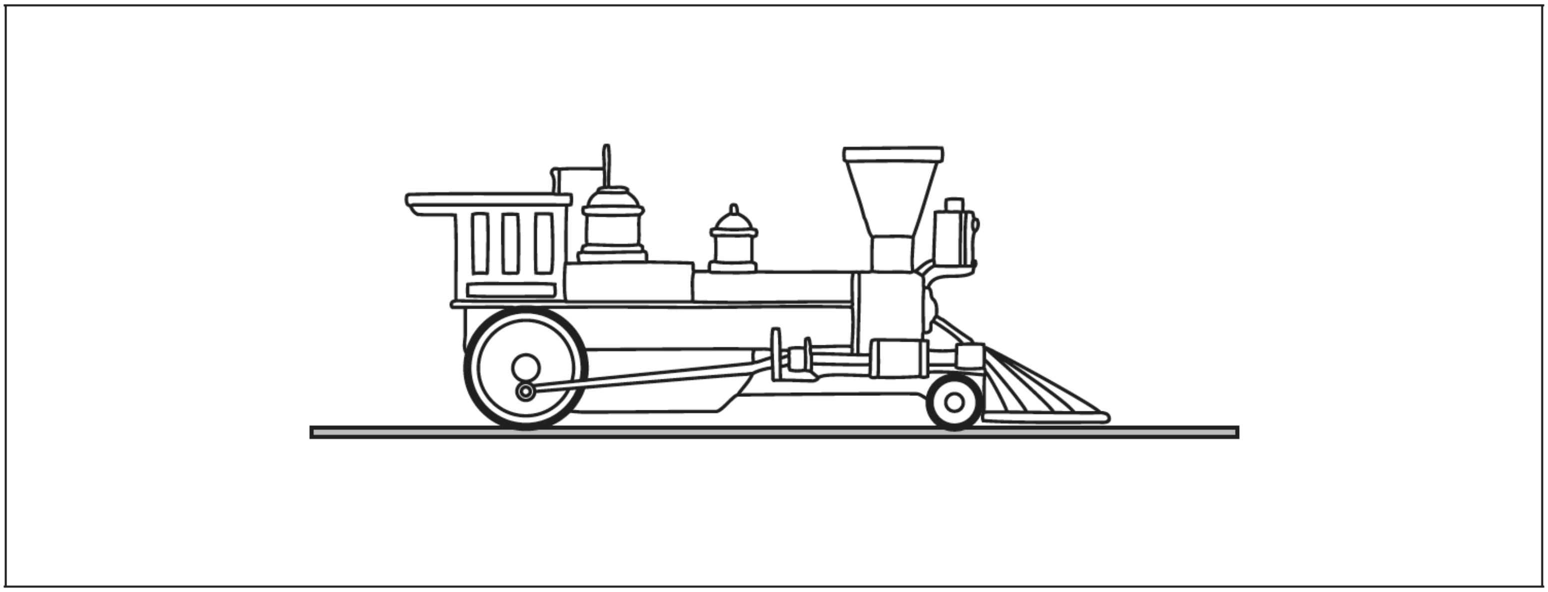
a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]

g. [N/A]

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]

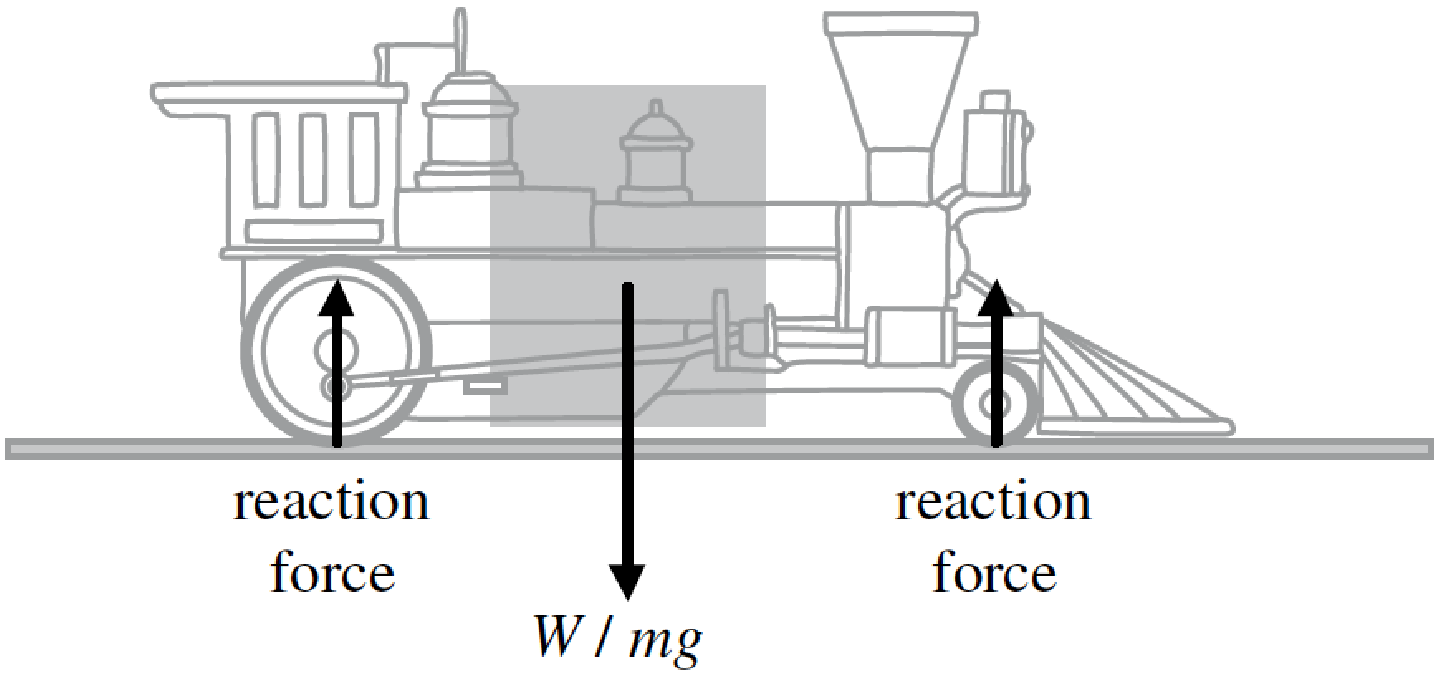
(i) State the value of the magnitude of F when the railway engine is travelling at 16 ms^{-1}.

(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]

Markscheme

a.



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;

b. 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;

c. power =16×76000;

1.2 MW;

d. acceleration= $\frac{16^2}{2\times1100}(=0.116)$;

$m=\left(\frac{7.6\times10^4}{0.116}=\right)6.5\times10^5\text{kg}$;

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

or

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

$m=\left(\frac{2\times7.6\times10^4\times1100}{16^2}=\right)6.5\times10^5\text{kg}$;

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

e. (i) 57 kN;

(ii) $F_8=\frac{F_{16}}{2^3}$;
F_8=7.1(kN);
total force =19+7.1(kN);
=26 kN;
*Award **[4]** for a bald correct answer.*

or

$k=\left(\frac{57\times10^3}{16^3}\right)=13.91$;
F_8=(13.91×8^3)=7.1(kN);
total force=19+7.1(kN);

=26 kN;
*Award **[4]** for a bald correct answer.*

f. 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.*

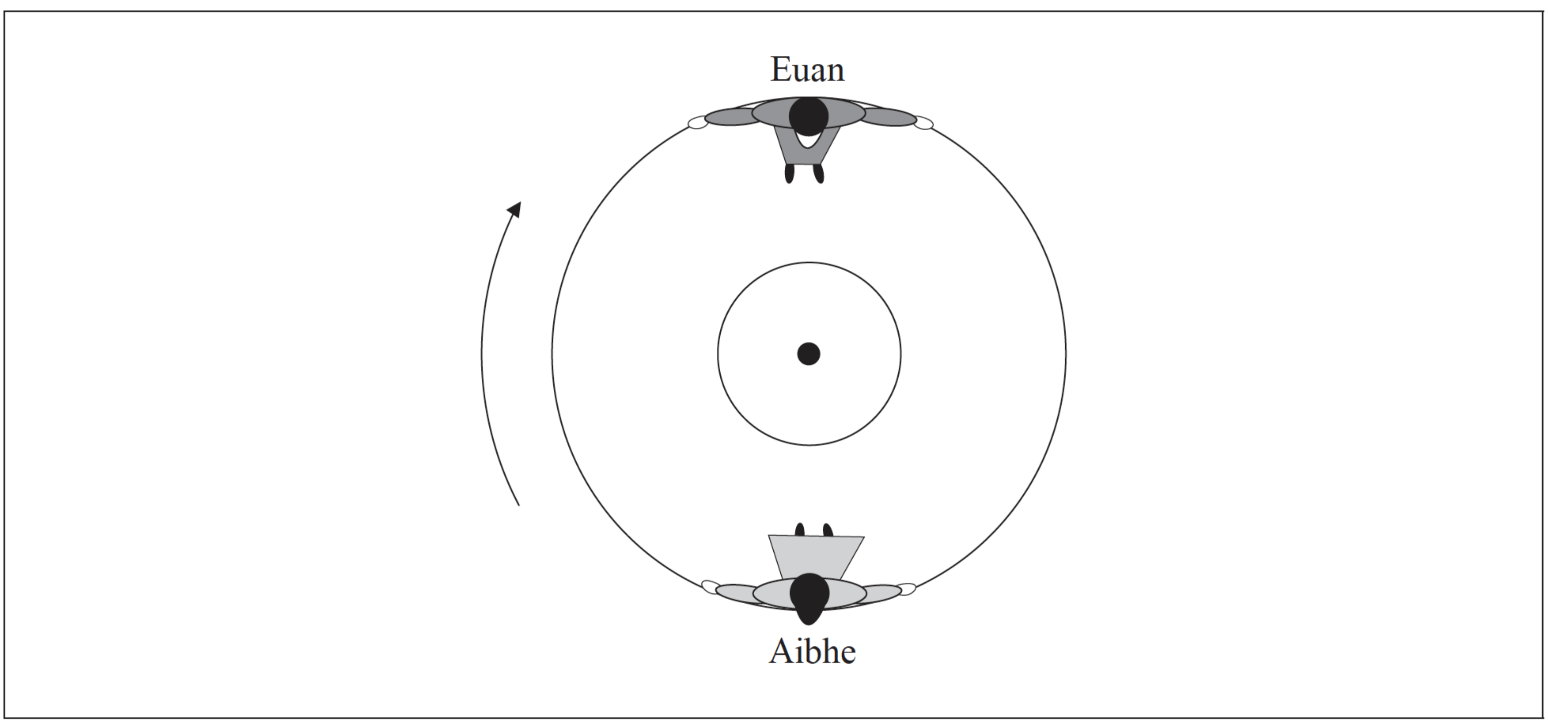
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]

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

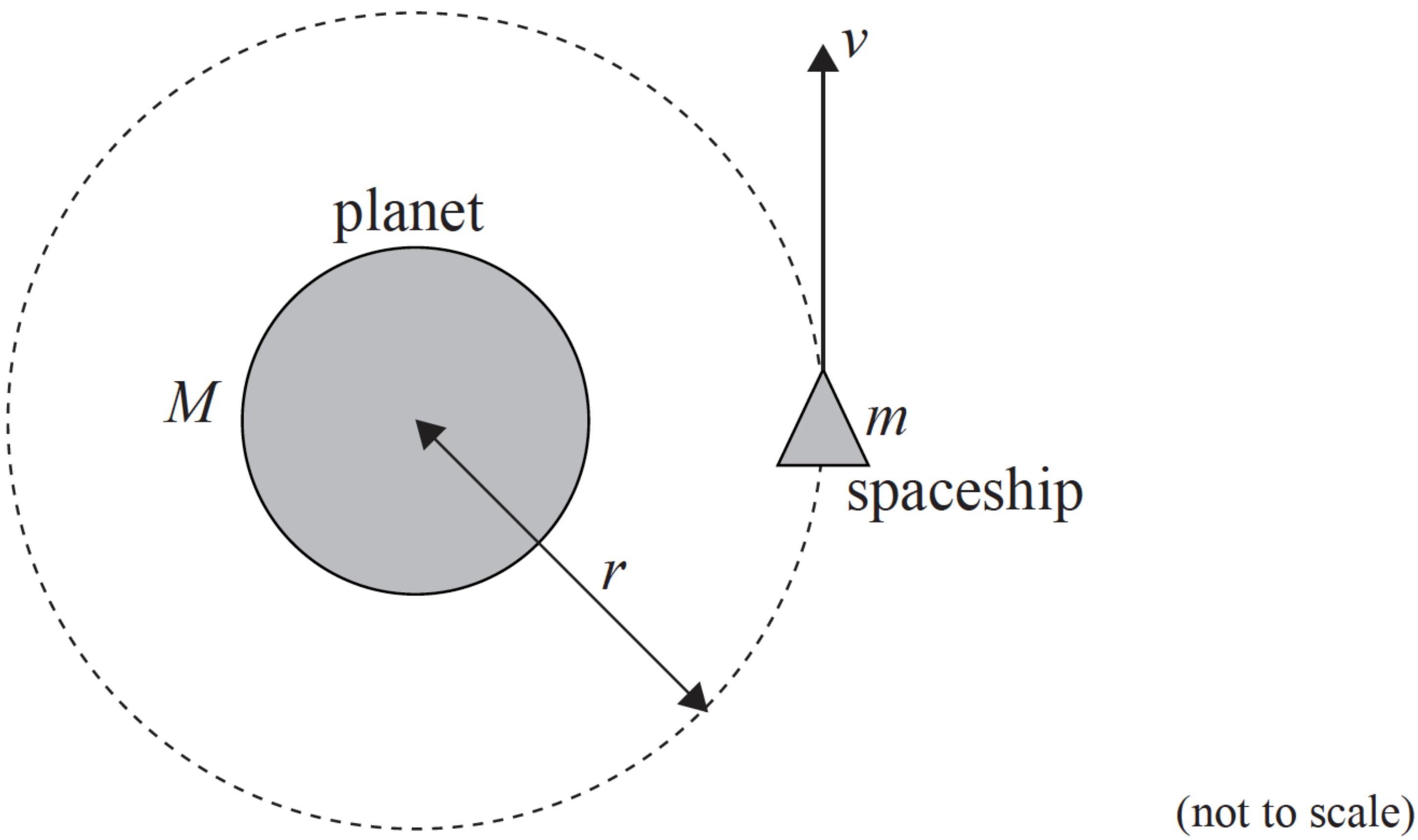
Aibhe and Euan are sitting on opposite sides of a merry-go-round, which is rotating at constant speed around a fixed centre. The diagram below shows the view from above.



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.

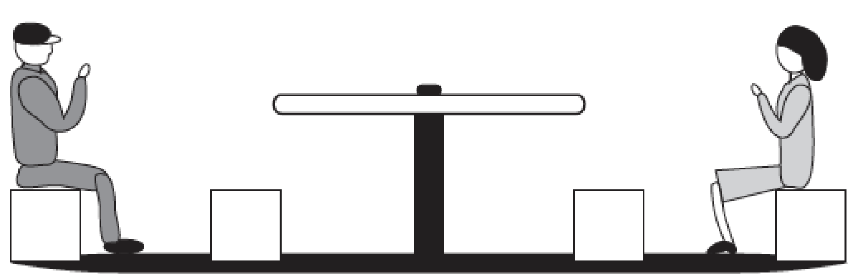
(ii) the centre of the merry-go-round.

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.

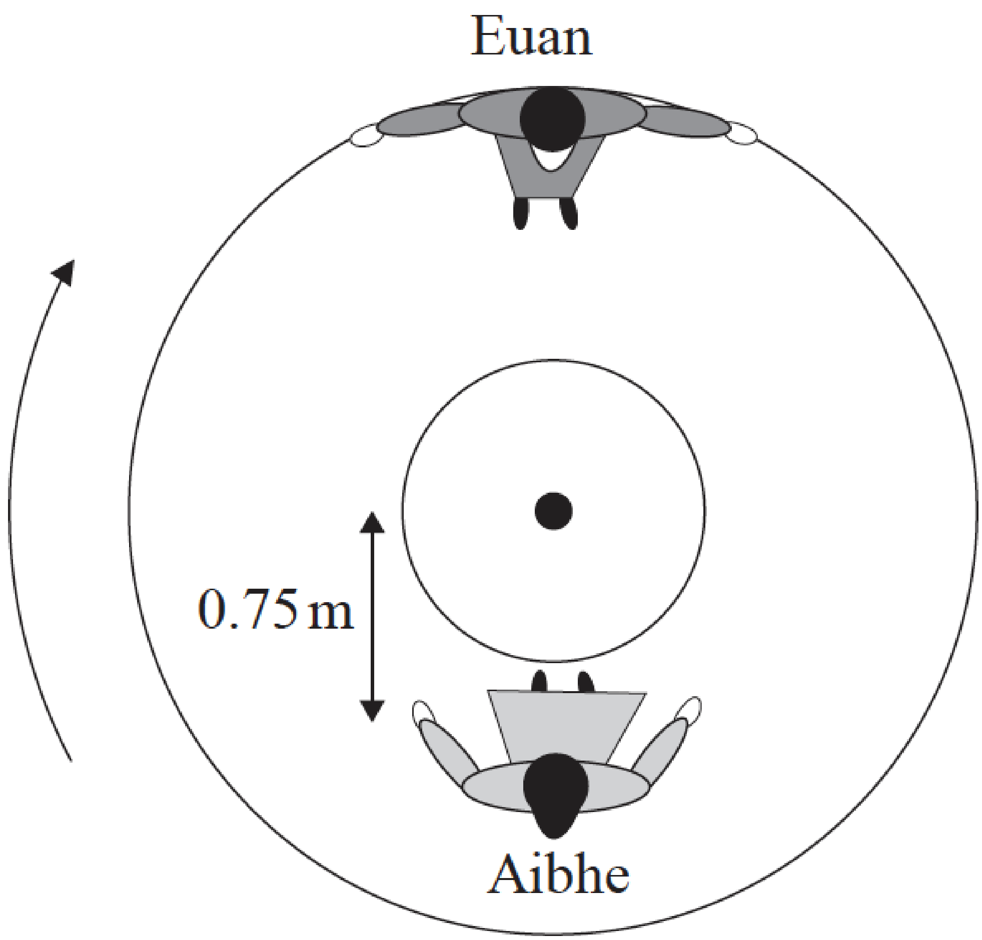
(iv) The diagram below shows a side view of Aibhe and Euan on the merry-go-round.



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.

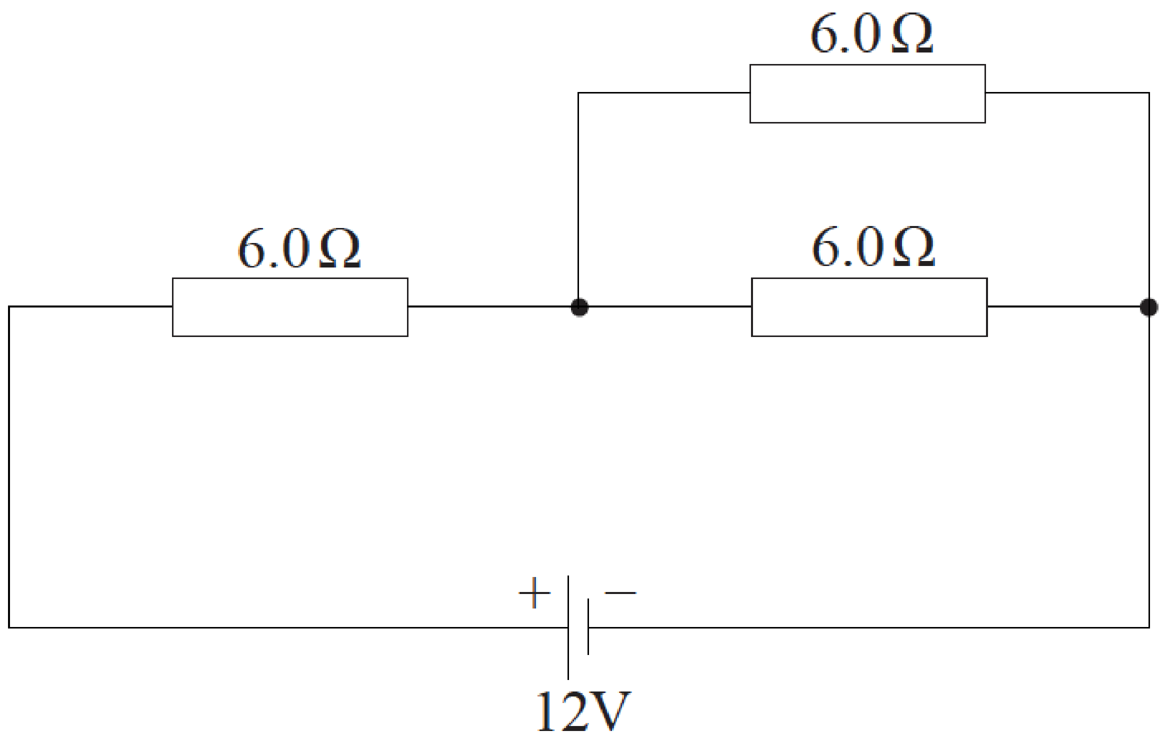
(ii) Calculate the magnitude of Aibhe's acceleration.

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]

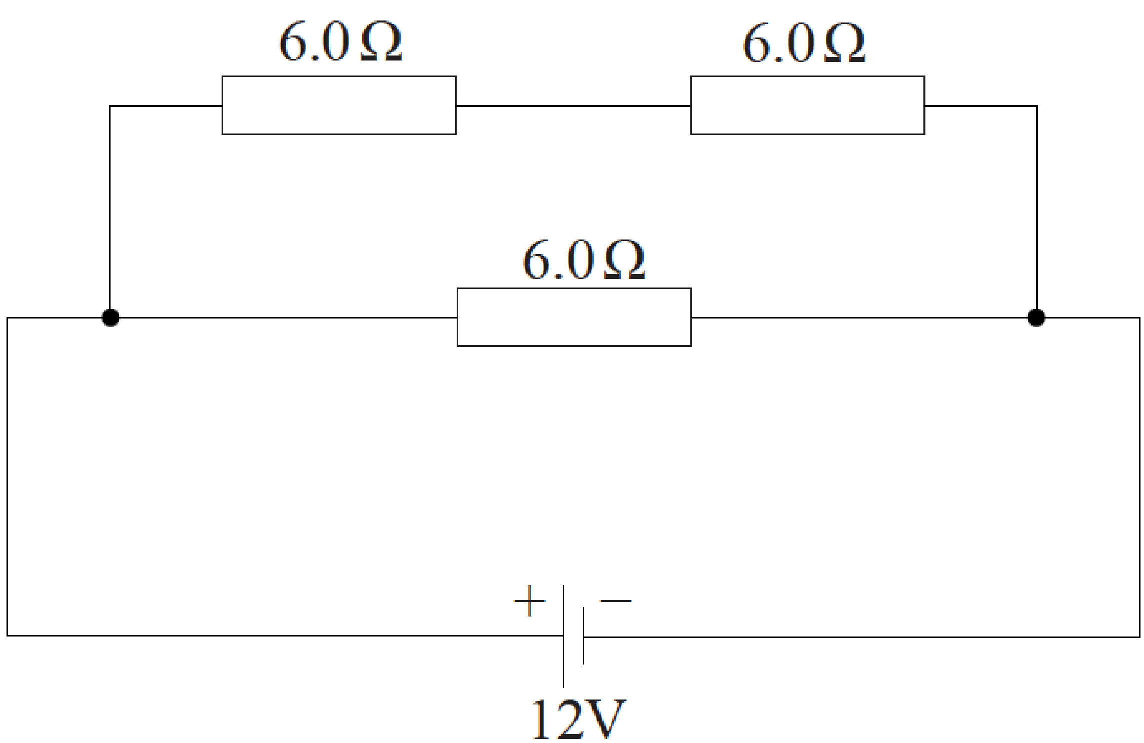
Resistivity of constantan = $5.0\times10^{-7}\Omega m$
Average radius of wire = $2.5\times10^{-5}m$

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).

Markscheme

a. (i) 2.0 ***or*** 0(ms^{-1});
(ii) 1.0 ***or*** 0(ms^{-1});

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

or

since her direction/velocity is changing;
a <u>resultant/unbalanced/net</u> 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 <u>Aibhe</u>/<u>her</u>;

(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;

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

d. (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(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(ms^{-2});
Allow ECF from (d)(i).
*Award **[2]** for a bald correct answer.*

e. $\frac{\text{potentialdifferenceacrossthewire}}{\text{currentthroughthewire}}$;
Accept equation with symbols defined. Accept p.d. Do not accept voltage.

f. $A = \left(\pi r^2 =\right) \pi \times \left[2.5 \times 10^{-5}\right]^2 \left(= 1.963 \times 10^{-9}\right)$;
$l = \left(\frac{RA}{\rho} =\right) \frac{6.0 \times 1.963 \times 10^{-9}}{5.0 \times 10^{-7}}$;
=2.4×10^{-2}(m);
*Award **[3]** for a bald correct answer.*

g. resistance of two resistors in parallel = 3.0(Ω), so total resistance = 6.0 + 3.0 = 9.0(Ω);

$I = \left(\frac{V}{R} =\right) \frac{12}{9.0} (= 1.333)\,(\text{A})$;

$P = (VI = 12 \times 1.333 =)\,16\,(\text{W})$;

or

resistance of two resistors in parallel = 3.0(Ω), so total resistance = 6.0 + 3.0 = 9.0(Ω);

$P = \left(\frac{V^2}{R} =\right) \frac{144}{9.0}$;

P =16 (W);

h. total resistance is smaller (=4.0Ω);

p.d./voltage is the same so current is greater (=3.0A);

since $P=VI$ ***or*** $P=I^2R$,power is greater (=36W);

or

total resistance is smaller (= 4.0Ω); p.d./voltage is the same;
since $P=\frac{V^2}{R}$, power is greater (=36W);

*Award **[1]** for a bald calculation of 36 (W). The marks are for an explanation.*

Examiners report

a. Most were able to identify the relative speeds. The markscheme was amended to also include answers in terms of velocity.

b. i) This was well-answered with most identifying a change in direction and a change in velocity.

ii) The majority were able to show the direction of the centripetal acceleration.

iii) Few identified a force that would act on Aibhe. They did not realize that the centripetal force is the resultant of the forces acting.

iv) Few realized from the diagram that it would be difficult provide an inward directed force on Aibhe's upper torso. The consequence of this is that it would tend to continue to move in a direction which is tangential to the circle.

c. This was well done by many.

d. i) Many scored three marks here.

ii) Most candidates were able to gain both marks.

e. The definition of resistance was poorly attempted with many describing some difficulty that a current has in travelling down a wire.

f. This calculation was generally well done although it was disappointing to see a significant proportion of candidates who did not know the formula for the area of a circle.

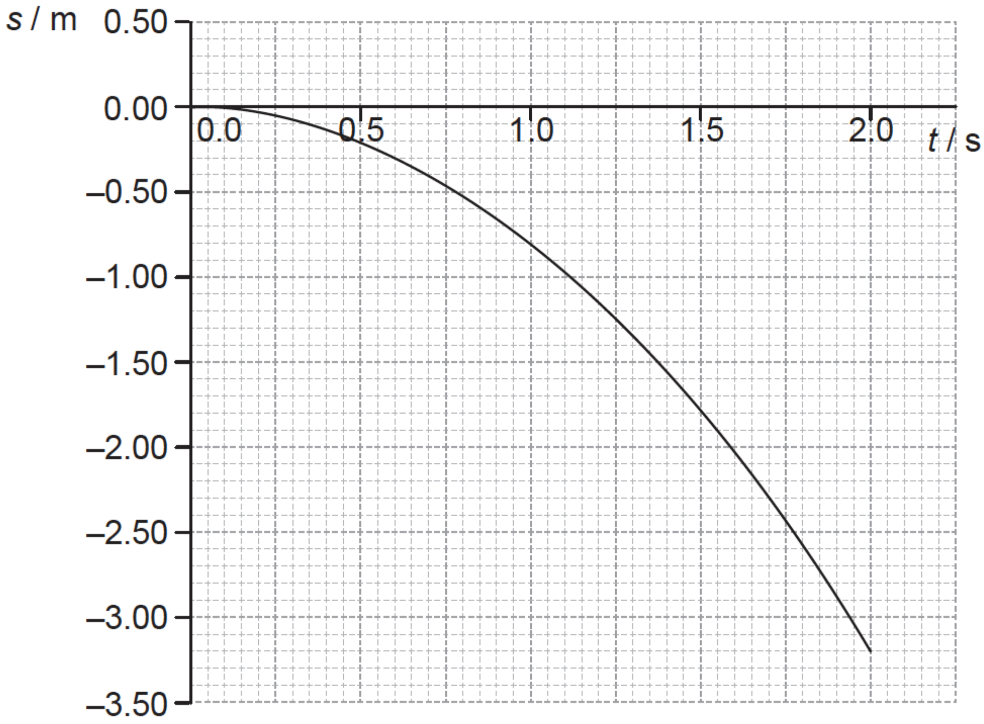
g. Most were able to calculate the equivalent resistance of the combination of resistors and progress successfully to find the power supplied by the cell.

h. Many recalculated the power but didn't provide an explanation and so consequently only scored one mark. Explanations were often detailed enough to score full marks.

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).

Markscheme

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

b. (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};

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

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

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

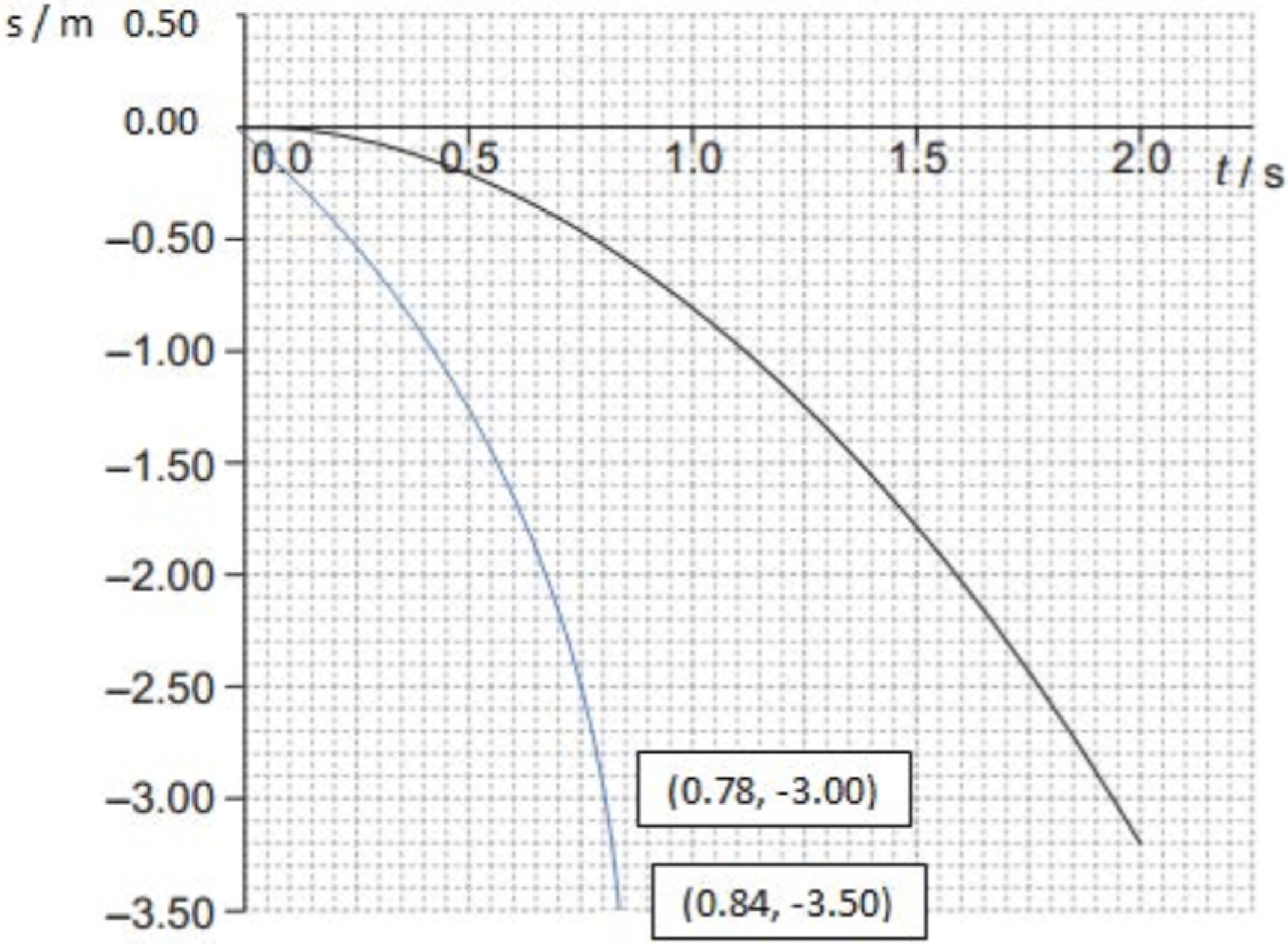
comment that it's insignificant compared with (0.2×1.63 =) 0.32 to 0.33 N / 1.63 m s^{-2};

d. 7.7 m s^{-1};

e. curve permanently below Moon curve;

smooth parabola; *(judge by eye)*

line passing through s = –3.00 m, t = 0.78 s ***or*** s = –3.50 m, t = 0.84 s (±1mm);



f. Ca-40 has 20 protons and 20 neutrons, Ca-47 has 20 protons and 27 neutrons / Ca-47 has 7 additional neutrons;

mention of strong/nuclear **and** coulomb/electrostatic/electromagnetic forces;

excess neutrons/too high a neutron-to-proton ration leads to the coulomb/electrostatic' electromagnetic force being greater than the strong/nuclear force (so the nucleus is unstable);

*Award **[1 max]** for an answer stating that Ca-47 has more neutrons so is bigger and less stable.*

g. six half-lives occurred;

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

98.4 / 98% decayed;

h. (i)(electron) anti-neutrino / $\overline{v}$;

(ii) 46.95455 u – (46.95241 u + 0.00055 u) = 0.00159 u;

1.48 MeV;

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

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]
g. [N/A]
h. [N/A]