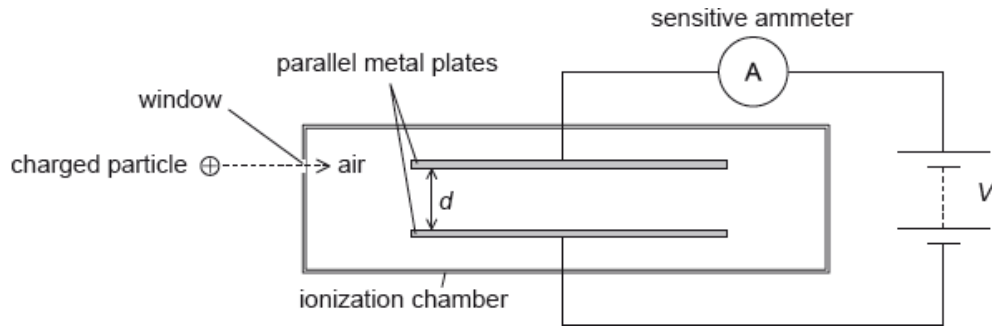


HL Paper 2

This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about waves.

Part 1 Electric fields and radioactive decay

An ionization chamber is a device which can be used to detect charged particles.

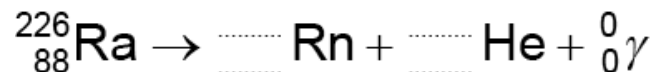


The charged particles enter the chamber through a thin window. They then ionize the air between the parallel metal plates. A high potential difference across the plates creates an electric field that causes the ions to move towards the plates. Charge now flows around the circuit and a current is detected by the sensitive ammeter.

The separation of the plates d is 12 mm and the potential difference V between the plates is 5.2 kV. An ionized air molecule M with charge $+2e$ is produced when a charged particle collides with an air molecule.

Radium-226 (${}^{226}_{88}\text{Ra}$) decays into an isotope of radon (Rn) by the emission of an alpha particle and a gamma-ray photon. The alpha particle may be detected using the ionization chamber but the gamma-ray photon is unlikely to be detected.

- a. On the diagram, draw the shape of the electric field between the plates. [2]
- b.i. Calculate the electric field strength between the plates. [1]
- b.ii. Calculate the force on M . [2]
- b.iii. Determine the change in the electric potential energy of M as it moves from the positive to the negative plate. [3]
- c.ii. Construct the nuclear equation for the decay of radium-226. [2]



- c.iii. Radium-226 has a half-life of 1600 years. Determine the time, in years, it takes for the activity of radium-226 to fall to 5% of its original activity. [3]

Markscheme

- a. minimum of three lines equally spaced and distributed, perpendicular to the plates and downwards; edge effect shown; } (condone lines that do not touch plates)

b.i. $4.3 \times 10^5 \text{ (NC}^{-1}\text{)}$

b.ii. ($F = Eq \Rightarrow$) $4.3 \times 10^5 \times 2 \times 1.6 \times 10^{-19}$; (allow ECF from (b)(i))

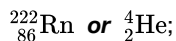
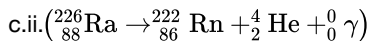
$1.4 \times 10^{-13} \text{ (N)}$;

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

b.iii. $\Delta E_P = q\Delta V$ or $3.2 \times 10^{-19} \times 5.2 \times 10^3$;

$1.7 \times 10^{-15} \text{ (J)}$;

negative/loss;



numbers balance top and bottom on right-hand side;

c.iii. $\lambda = \frac{\ln 2}{1600} = 4.33 \times 10^{-4} \text{ (yr}^{-1}\text{)}$;

$0.05 = e^{-\lambda t}$;

6900 (years);

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

Award **[2 max]** for 2.18×10^{11} (s).

Award **[1 max]** to a candidate who identifies time as about 4.3 half-lives but cannot get further or gives an approximate reasoned answer.

However award **[3]** if number n of half-lives is calculated from $0.05 = 2^{-n}$ (= 4.32 usually from use of \log_2 working) and time shown.

Examiners report

a. Field patterns were often negligently drawn. Lines did not meet both plates, edge effects were ignored, and the (vital) equality of spacing between drawn lines was not considered. Candidates continue to show their inadequacy in responding to questions that demand a careful and accurate diagram.

b.i. This sequence of calculations was often undertaken well with appropriate figures carried through from part to part.

b.ii. This sequence of calculations was often undertaken well with appropriate figures carried through from part to part.

b.iii. This sequence of calculations was often undertaken well with appropriate figures carried through from part to part. The only common error was the omission of a consideration of the gain or loss of the energy change in part (iii).

c.ii. As one of the easiest questions on the paper this was predictably well done.

c.iii. In the past candidates have found calculation involving exponential change difficult. On this occasion, however examiners saw a large number of correct and well explained solutions from candidates.

This question is in **two** parts. **Part 1** is about gravitational force fields. **Part 2** is about properties of a gas.

Part 1 Gravitational force fields

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

b. A satellite of mass m orbits a planet of mass M . Derive the following relationship between the period of the satellite T and the radius of its orbit R (Kepler's third law). [3]

$$T^2 = \frac{4\pi^2 R^3}{GM}$$

c. A polar orbiting satellite has an orbit which passes above both of the Earth's poles. One polar orbiting satellite used for Earth observation has an orbital period of 6.00×10^3 s. [8]

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

$$\text{Average radius of Earth} = 6.37 \times 10^6 \text{ m}$$

(i) Using the relationship in (b), show that the average height above the surface of the Earth for this satellite is about 800 km.

(ii) The satellite moves from an orbit of radius 1200 km above the Earth to one of radius 2500 km. The mass of the satellite is 45 kg.

Calculate the change in the gravitational potential energy of the satellite.

(iii) Explain whether the gravitational potential energy has increased, decreased or stayed the same when the orbit changes, as in (c)(ii).

Markscheme

a. the (attractive) force between two (point) masses is directly proportional to the product of the masses;
and inversely proportional to the square of the distance (between their centres of mass);

Use of equation is acceptable:

Award [2] if all five quantities defined. Award [1] if four quantities defined.

b. $G \frac{Mm}{R^2} = \frac{mv^2}{R}$ so $v^2 = \frac{Gm}{R}$;

$$v = \frac{2\pi R}{T};$$

$$v^2 = \frac{4\pi^2 R^2}{T^2} = \frac{Gm}{R};$$

or

$$G \frac{Mm}{R^2} = m\omega^2 R;$$

$$\omega^2 = \frac{4\pi^2}{T^2};$$

$$\frac{4\pi^2}{T^2} = \frac{GM}{R^3};$$

Award [3] to a clear response with a missing step.

c. (i) $R^3 = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 6000^2}{4 \times \pi^2}$;

$$R = 7.13 \times 10^6 \text{ (m)};$$

$$h = (7.13 \times 10^6 - 6.37 \times 10^6) = 760 \text{ (km)};$$

Award [3] for an answer of 740 with π taken as 3.14.

(ii) clear use of $\Delta V = \frac{\Delta E}{m}$ and $V = -\frac{Gm}{r}$ **or** $\Delta E = GMm \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$;

one value of potential energy calculated (2.37×10^9 **or** 2.02×10^9);

$$3.5 \times 10^8 \text{ (J)};$$

Award [3] for a bald correct answer.

Award [2] for 7.7×10^9 . Award [1] for 7.7×10^{12} .

Award [0] for answers using $mg\Delta h$.

(iii) increased;
further from Earth / closer to infinity / smaller negative value;
Award [0] for a bald correct answer.

Examiners report

- a. (a) Many candidates stated that the Newton's law force is proportional to the masses of the objects in question, rather than the product of the masses.
- b. This part was generally well done with most candidates coming to the correct outcome; too often steps were missed out in the derivations and this cost candidates mark. It is essential that they realise that a derivation must include every step. The presentation of this part left much to be desired in quite a large minority with mathematically incorrect statements being given.
- c. (i) Most candidates were able to substitute values into the equation and rearrange it to find a value for R. Many then fail to subtract the radius of the Earth.
- (ii) Very few candidates completed this part correctly. Confusion between potential and potential energy was common as were adding the height in kilometres to the radius of the Earth in metres. A sizeable minority of candidates attempted to use the mgh equation.
- (iii) This part was quite well answered with most candidates realising that the increase in height meant an increase in potential energy. Several argued that the magnitude decreased but being a negative quantity this meant an increase.

This question is in **two** parts. **Part 1** is about the use of renewable energy sources. **Part 2** is about the gravitational potential of the Earth.

Part 2 Gravitational potential of the Earth

A satellite of mass 780 kg is put into circular orbit 4.0×10^3 km above the surface of the Earth. It is then moved to a higher orbit 3.2×10^4 km above the surface.

Calculate, for the satellite as it is moved from the lower orbit to the higher orbit, the change in

- d. The table gives the gravitational potential V for various distances r from the **surface** of Earth. The radius of Earth is 6.4×10^3 km. [3]

$V / 10^7 \text{ J kg}^{-1}$	$r / 10^3 \text{ km}$
-6.24	0
-3.84	4.0
-1.04	32

Show that the data are consistent with Earth acting as a point mass with its mass concentrated at its centre.

- e. (i) the gravitational potential energy. [7]
(ii) kinetic energy
(iii) total energy.

Markscheme

d. recognize that $V \times a$ distance is constant / $\frac{V_1}{V_2} = \frac{R_2}{R_1}$ ($= 1.625$);

use of $R_E + r$;

evaluates at least two data points 4.0×10^{14} ; } (allow $V \times R$ to be expressed in any consistent unit)

Award [2 max] if answer fails to use radius of Earth but infers wrong conclusion from correct evaluation of two or more data points.

Award [3 max] if answer evaluates mass of Earth and shows that it is the same for two or more data points.

e. (i) change in gravitational potential = $(+)$ 28 (MJ kg⁻¹);

change in gravitational potential energy = $(28 \times 10^6 \times 780 =) 2.2 \times 10^{10}$ (J);

Award [2] for a bald correct answer.

(ii) (change in) $\frac{1}{2}mv^2 =$ (change in) $\frac{GMm}{2}$ ($=$ -change in $\frac{mV}{2}$);

$(-)$ 1.1 $\times 10^{10}$ (J);

Award [2] for a bald correct answer.

(iii) change in kinetic energy = -1.1×10^{10} (J); (recognition that KE is lost)

change in gravitational potential energy = $+2.2 \times 10^{10}$ (J); } recognition that gpe is gained)

$(+)$ 1.1 $\times 10^{10}$ (J); (direction of change required for this mark)

Award [1 max] for a bald correct answer with sign.

Award [0] for a bald correct answer with no sign.

or

change in total energy = change in potential energy + change in kinetic energy;

adds (e)(i) to (e)(ii); (allow ECF in value and sign)

$(+)$ 1.1 $\times 10^{10}$ (J); (do not allow negative answer)

Accept correct answer only without ECF for this approach.

Examiners report

d. This was a simple test to establish whether candidates could check the consistency of data. Most could not. The obvious solution (to evaluate Vr twice having first incorporated the radius of the Earth) was rare. Many candidates preferred to calculate the mass of the earth twice and check that the values obtained were similar. In principle this could have scored full marks but three marks were only rarely seen by examiners.

e. (i) It is quite clear that candidates do not understand the relationship between gravitational potential and gravitational potential energy. A consideration of units could have led them in the correct direction. Many could only tackle this by carrying out a full solution from the gravitational potential equation printed in the data booklet.

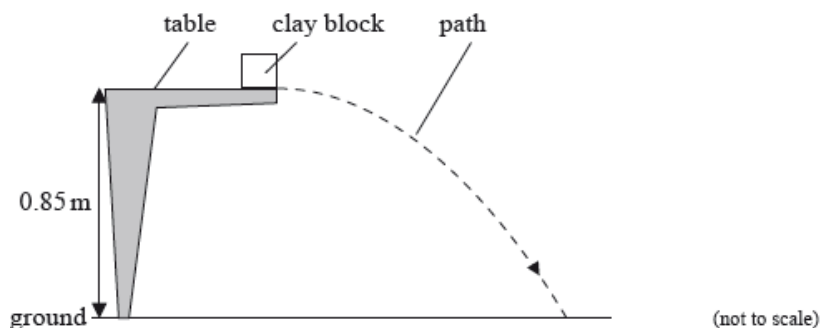
(ii) Similarly candidates were unable to use the known change in gravitational potential energy to establish the change in kinetic energy. Most felt that they had to calculate the kinetic energies from first principles and usually obtained the wrong answer.

(iii) Most candidates did not continue from (i) and (ii) to this part question; it was either left blank or an attempt was made at a statement of conservation of energy. This was another case where knowledge of a principle does not necessarily mean that a candidate can operate it effectively. Even the most able candidates seemed to struggle with this standard piece of bookwork.

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

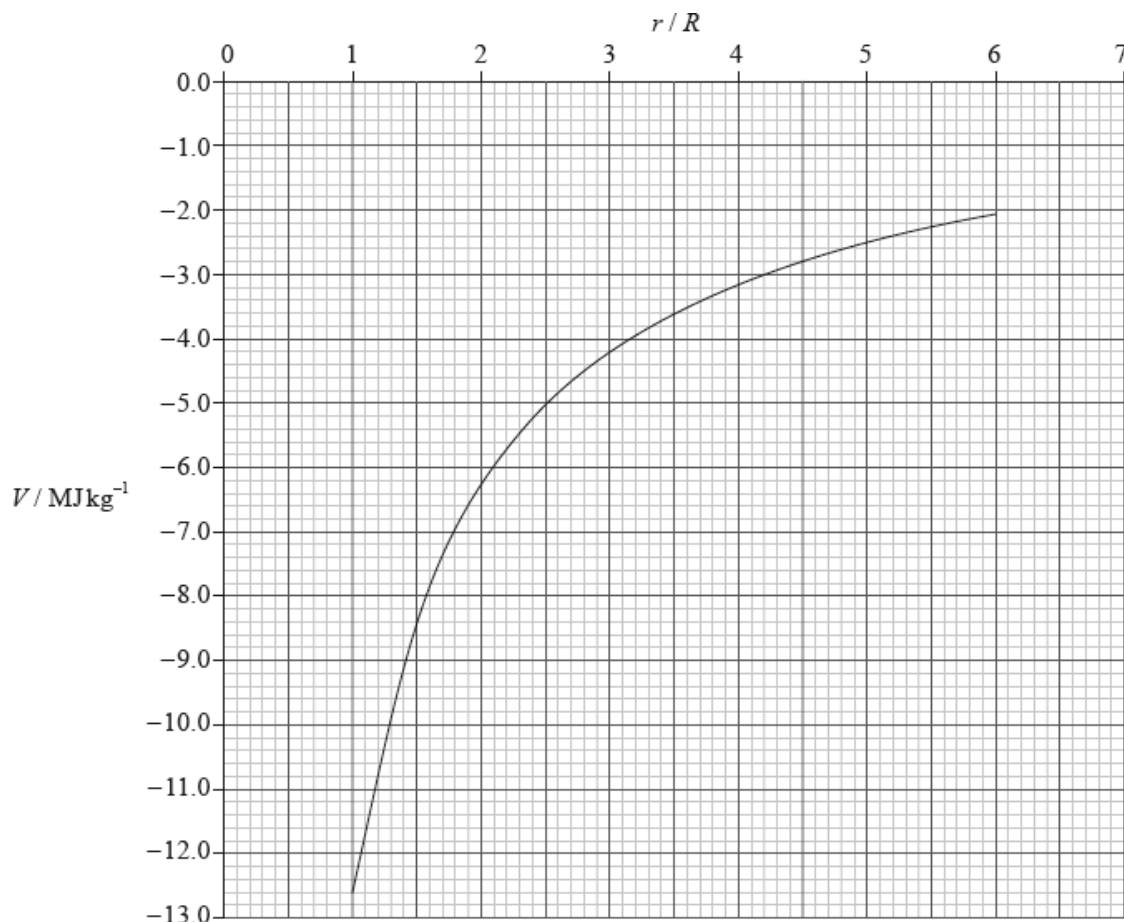
Part 1 Collisions

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



Part 2 Gravitational field of Mars

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



A rocket of mass $1.2 \times 10^4 \text{ kg}$ lifts off from the surface of Mars. Use the graph to

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

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

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

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

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

Markscheme

Part 1.c. use of kinematic equation to yield time;

$$t = \sqrt{\frac{2s}{g}} (= 0.42 \text{ s});$$

$s = \text{horizontal speed} \times \text{time};$

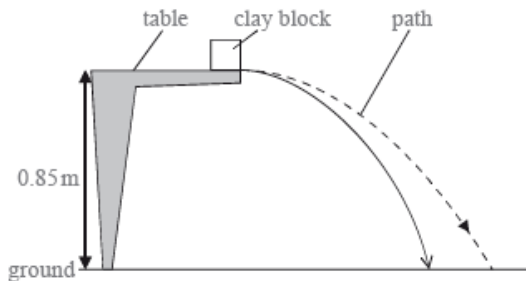
$$= 1.8 \text{ m};$$

Accept $g = 10 \text{ m s}^{-2}$ equivalent answers 1.79 from 9.8, 1.77 from 10.

- (ii) initial drawn velocity horizontal; (*judge by eye*)

reasonable shape; (*i.e. quasi-parabolic*)

horizontal distance moved always decreasing when compared to given path / range less than original;



Part 2.a. work done in moving mass from infinity to a point;

Part 2.b. read offs -12.6 and -3.2 ;

gain in gpe $1.2 \times 10^4 \times [12.6 - 3.2]$ **or** gain in g potential $[12.6 \times 10^6 - 3.2 \times 10^6]$;

$$= 1.13 \pm 0.05 \times 10^5 \text{ MJ } \mathbf{or} \ 1.13 \pm 0.05 \times 10^{11} \text{ J};$$

- (ii) use of gradient of graph to determine g ;

values substituted from drawn gradient (typically $\frac{6.7 \times 10^6}{7 \times 3.3 \times 10^6}$);

$$= 0.23 \text{ N kg}^{-1} \text{ (allow answers in the range of } 0.20 \text{ to } 0.26 \text{ N kg}^{-1}\text{)}$$

Award **[0]** for solutions from $\frac{V}{r}$.

Examiners report

Part 1.c. Candidates were required to determine the time taken to fall to the floor and then use this time to evaluate the distance travelled horizontally.

Many managed this with more or less success.

- (ii) Many candidates produced poor attempts at the sketch. Initial trajectories were not horizontal and the general shapes of the curves were usually not quasi-parabolic.

Part 5 Some candidates gave a definition of gravitational potential, i.e. they related the energy to that of a unit mass.

Part 6 Throughout this part candidates were instructed to use the graph, those who used other non-graphical methods were penalised.

- (i) There were many good evaluations with complete and well presented solutions.
- (ii) Use of the Data Booklet equation for gravitational field strength without reference to the graph was common.

The gravitational potential due to the Sun at its surface is $-1.9 \times 10^{11} \text{ J kg}^{-1}$. The following data are available.

Mass of Earth	= $6.0 \times 10^{24} \text{ kg}$
Distance from Earth to Sun	= $1.5 \times 10^{11} \text{ m}$
Radius of Sun	= $7.0 \times 10^8 \text{ m}$

- a. Outline why the gravitational potential is negative. [2]
- b.i. The gravitational potential due to the Sun at a distance r from its centre is V_S . Show that [1]
$$rV_S = \text{constant.}$$
- b.ii. Calculate the gravitational potential energy of the Earth in its orbit around the Sun. Give your answer to an appropriate number of significant [2]
figures.
- b.iii. Calculate the total energy of the Earth in its orbit. [2]
- b.iv. An asteroid strikes the Earth and causes the orbital speed of the Earth to suddenly decrease. Suggest the ways in which the orbit of the Earth [2]
will change.
- c. Outline, in terms of the force acting on it, why the Earth remains in a circular orbit around the Sun. [2]

Markscheme

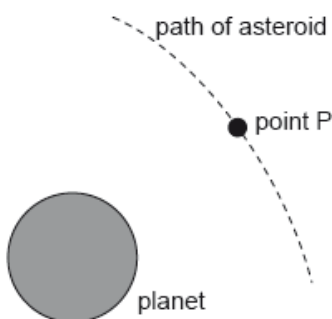
- a. potential is defined to be zero at infinity
so a positive amount of work needs to be supplied for a mass to reach infinity
- b.i. $V_S = -\frac{GM}{r}$ so $r \times V_S = -GM = \text{constant}$ because G and M are constants
- b.ii. $GM = 1.33 \times 10^{20} \text{ «J m kg}^{-1}\text{»}$
GPE at Earth orbit $= -\frac{1.33 \times 10^{20} \times 6.0 \times 10^{24}}{1.5 \times 10^{11}} = -5.3 \times 10^{33} \text{ «J»}$

Award [1 max] unless answer is to 2 sf.
Ignore addition of Sun radius to radius of Earth orbit.
- b.iii. **ALTERNATIVE 1**
work leading to statement that kinetic energy $\frac{GMm}{2r}$, **AND** kinetic energy evaluated to be $+2.7 \times 10^{33} \text{ «J»}$
energy $= \text{PE} + \text{KE} = \text{answer to (b)(ii)} + 2.7 \times 10^{33} = -2.7 \times 10^{33} \text{ «J»}$



b. A planet has a radius of 3.1×10^6 m. At a point P a distance 2.4×10^7 m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1} . Calculate the gravitational potential at point P, include an appropriate unit for your answer. [1]

c. The diagram shows the path of an asteroid as it moves past the planet. [3]



When the asteroid was far away from the planet it had negligible speed. Estimate the speed of the asteroid at point P as defined in (b).

d. The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the **planet** when the asteroid is at point P. [2]

Markscheme

a.i. the «gravitational» force per unit mass exerted on a point/small/test mass

[1 mark]

a.ii. at height h potential is $V = -\frac{GM}{(R+h)}$

$$\text{field is } g = \frac{GM}{(R+h)^2}$$

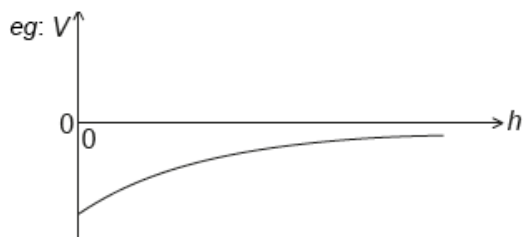
«dividing gives answer»

Do not allow an answer that starts with $g = -\frac{\Delta V}{\Delta r}$ and then cancels the deltas and substitutes $R + h$

[2 marks]

a.iii. correct shape and sign

non-zero negative vertical intercept



[2 marks]

b. $V = \left\langle -2.2 \times (3.1 \times 10^6 + 2.4 \times 10^7) \right\rangle \Rightarrow \left\langle - \right\rangle 6.0 \times 10^7 \text{ J kg}^{-1}$

Unit is essential

Allow eg MJ kg⁻¹ if power of 10 is correct

Allow other correct SI units eg m²s⁻², N m kg⁻¹

[1 mark]

c. total energy at P = 0 / KE gained = GPE lost

$$\left\langle \frac{1}{2}mv^2 + mV = 0 \Rightarrow v = \sqrt{-2V} \right\rangle$$

$$v = \left\langle \sqrt{2 \times 6.0 \times 10^7} \Rightarrow 1.1 \times 10^4 \text{ ms}^{-1} \right\rangle$$

Award [3] for a bald correct answer

Ignore negative sign errors in the workings

Allow ECF from 6(b)

[3 marks]

d. **ALTERNATIVE 1**

$$\text{force on asteroid is } \left\langle 6.2 \times 10^{12} \times 2.2 \Rightarrow 1.4 \times 10^{13} \text{ N} \right\rangle$$

«by Newton's third law» this is also the force on the planet

ALTERNATIVE 2

$$\text{mass of planet} = 2.4 \times 10^{25} \text{ kg} \left\langle \text{from } V = -\frac{GM}{(R+h)} \right\rangle$$

$$\text{force on planet } \left\langle \frac{GMm}{(R+h)^2} \right\rangle = 1.4 \times 10^{13} \text{ N}$$

MP2 must be explicit

[2 marks]

Examiners report

a.i. [N/A]

a.ii. [N/A]

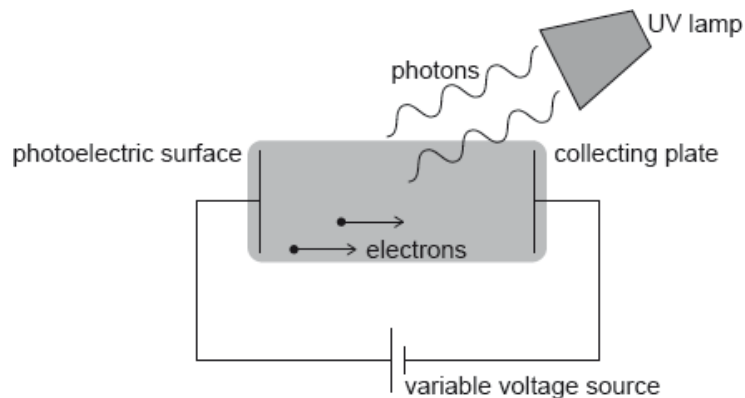
a.iii. [N/A]

b. [N/A]

c. [N/A]

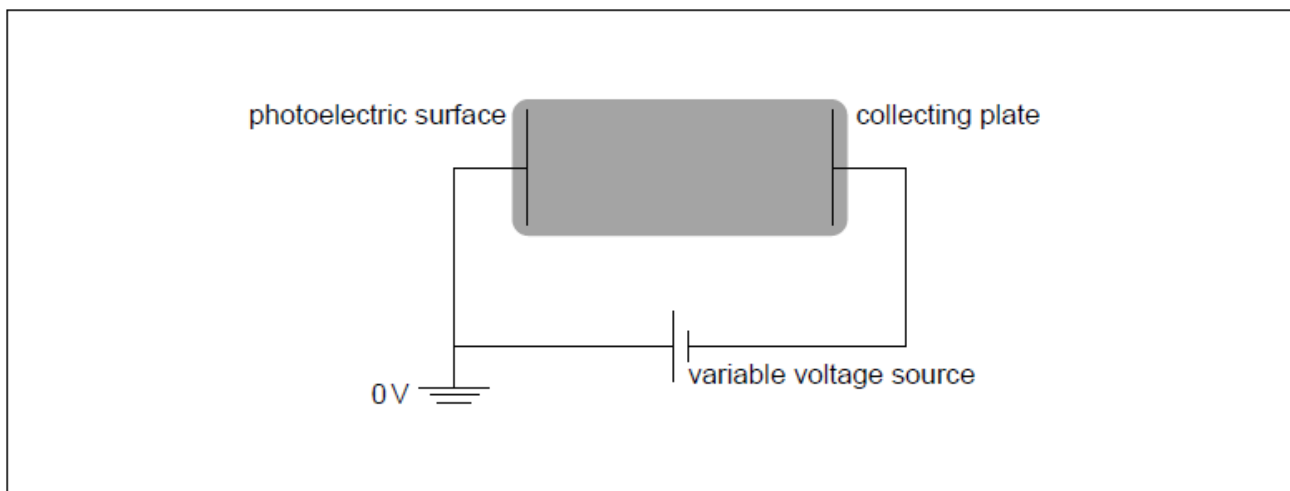
d. [N/A]

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



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

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



- a. Show that the energy of photons from the UV lamp is about 10 eV. [2]
- b.i. Calculate, in J, the maximum kinetic energy of the emitted electrons. [2]
- b.ii. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. [2]
- b.iii. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. [1]
- c.i. On the diagram, draw and label the equipotential lines at -0.4 V and -0.8 V. [2]
- c.ii. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. [2]

Markscheme

a. $E_1 = -13.6 \text{ eV}$ $E_2 = -\frac{13.6}{4} = -3.4 \text{ eV}$

energy of photon is difference $E_2 - E_1 = 10.2 \text{ eV}$

Must see at least 10.2 eV.

[2 marks]

b.i. $10 - 5.1 = 4.9 \text{ eV}$

$4.9 \times 1.6 \times 10^{-19} = 7.8 \times 10^{-19} \text{ J}$

Allow 5.1 if 10.2 is used to give $8.2 \times 10^{-19} \text{ J}$.

b.ii. EPE produced by battery

exceeds maximum KE of electrons / electrons don't have enough KE

For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.

[2 marks]

b.iii. 4.9 V

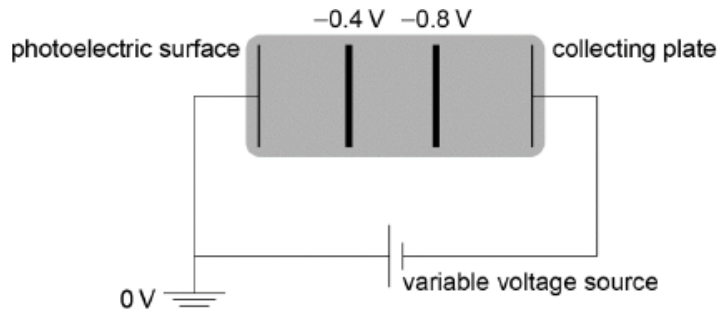
Allow 5.1 if 10.2 is used in (b)(i).

Ignore sign on answer.

[1 mark]

c.i. two equally spaced vertical lines (judge by eye) at approximately 1/3 and 2/3

labelled correctly



[2 marks]

c.ii. kinetic energy at collecting plate = 0.9 eV

speed = $\sqrt{\frac{2 \times 0.9 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} = 5.6 \times 10^5 \text{ ms}^{-1}$

Allow ECF from MP1

[2 marks]

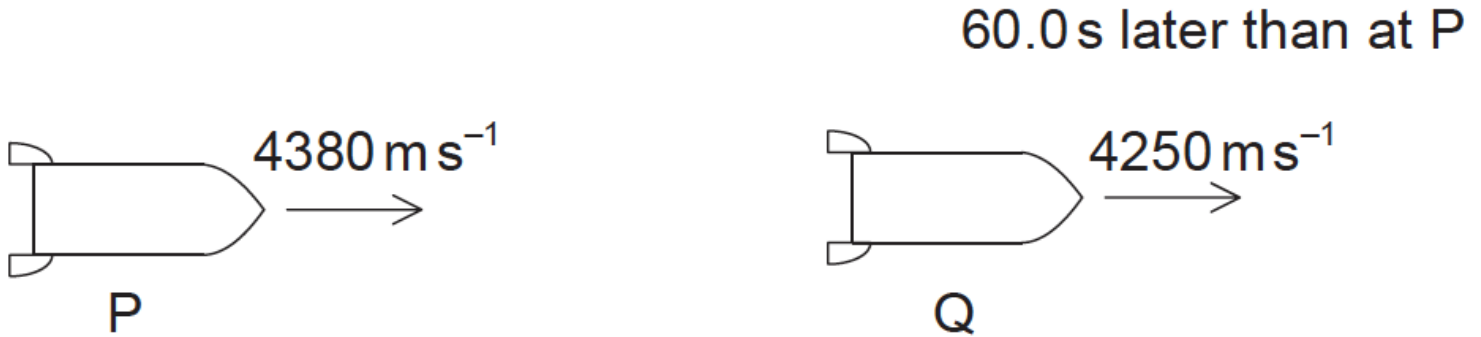
Examiners report

a. [N/A]

- b.i. [N/A]
- b.ii. [N/A]
- b.iii. [N/A]
- c.i. [N/A]
- c.ii. [N/A]

Part 2 Motion of a rocket

A rocket is moving away from a planet within the gravitational field of the planet. When the rocket is at position P a distance of $1.30 \times 10^7 \text{ m}$ from the centre of the planet, the engine is switched off. At P, the speed of the rocket is $4.38 \times 10^3 \text{ ms}^{-1}$.



At a time of 60.0 s later, the rocket has reached position Q. The speed of the rocket at Q is $4.25 \times 10^3 \text{ ms}^{-1}$. Air resistance is negligible.

- c. Outline, with reference to the energy of the rocket, why the speed of the rocket is changing between P and Q. [2]
- d. Estimate the average gravitational field strength of the planet between P and Q. [2]
- e. (i) An object is a distance r from the centre of a planet. Show that the minimum speed required to escape the gravitational field is equal to [5]

$$\sqrt{2g'r}$$

where g' is the gravitational field strength at distance r from the centre of a planet.

(ii) Discuss, using a calculation, whether the rocket at P can completely escape the gravitational field of the planet without further use of the engine.

- f. A space station is in orbit at a distance r from the centre of the planet in (e)(i). A satellite is launched from the space station so as just to escape from the gravitational field of the planet. The launch takes place in the same direction as the velocity of the space station. Outline why the launch velocity relative to the space station can be less than your answer to (e)(i). [1]

Markscheme

- c. gravitational potential energy is being gained;
this is at the expense of kinetic energy (and speed falls);
- d. $\left(\text{acceleration} = \frac{(v-u)}{t} = \frac{4.25 \times 10^3 - 4.38 \times 10^3}{60} = \right) (-) 2.17 \text{ (ms}^{-2}\text{)}$;

gravitational field strength = acceleration of rocket (=2.17 N kg⁻¹); } (allow $g = a$ in symbols)

or

computes potential difference from KE per unit mass change (5.61×10^5),

computes distance travelled (0.259 Mm), uses $g = \frac{(-)\Delta V}{\Delta r}$;

$g = (-)2.17(\text{ms}^{-2})$;

e. (i) (gravitational force) $= mg' = \frac{GMm}{r^2}$;

(kinetic energy) $= \frac{mv^2}{2} = \frac{GMm}{r}$;

$v^2 = 2\frac{GM}{r^2}r (= 2g'r)$;

Award [0] for centripetal force argument as rocket is not in orbit.

(ii) calculation of speed at a relevant distance eg: $\sqrt{2 \times g' \times 13 \times 10^6} = 7500 (\text{ms}^{-1})$;

speed is less than this so will not escape; } (allow ECF from (d) which could lead to rocket able to escape)

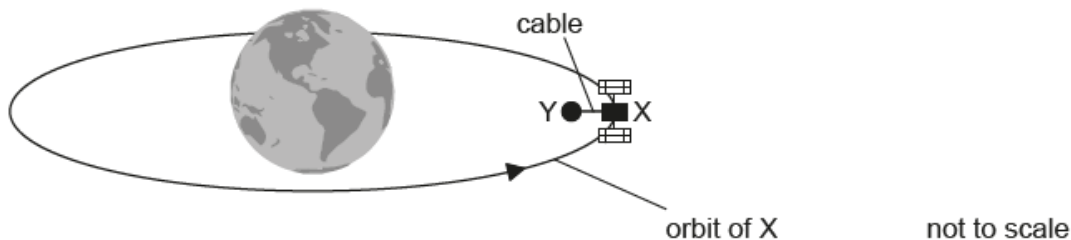
Award [1 max] for use of $g = 9.81$ and r which gives 16000ms^{-1} .

f. the satellite has velocity/kinetic energy as it is orbiting with the space station;

Examiners report

- c. [N/A]
- d. [N/A]
- e. [N/A]
- f. [N/A]

There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

The cable acts as a spring. Satellite Y has a mass m of 3.5×10^2 kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period T of 5.2 s.

a. Satellite X orbits 6600 km from the centre of the Earth.

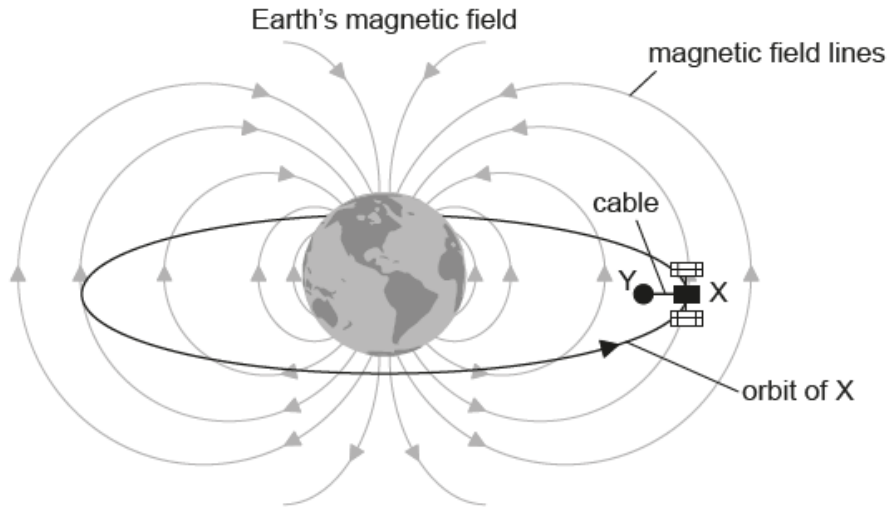
Mass of the Earth = 6.0×10^{24} kg

Show that the orbital speed of satellite X is about 8 km s^{-1} .

b.i.the orbital times for X and Y are different. [1]

b.ii.satellite Y requires a propulsion system. [2]

c. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. [3]



not to scale

Explain why satellite X becomes positively charged.

d. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. [3]

e. The magnetic field strength of the Earth is $31 \mu\text{T}$ at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]

f.i. Estimate the value of k in the following expression. [3]

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

f.ii. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. [2]

Markscheme

a. $\langle v = \sqrt{\frac{GM_E}{r}} \rangle = \sqrt{\frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{6600 \times 10^3}}$

7800 «m s⁻¹»

Full substitution required

Must see 2+ significant figures.

b.i.Y has smaller orbit/orbital speed is greater so time period is less

Allow answer from appropriate equation

Allow converse argument for X

b.ii.to stop Y from getting ahead

to remain stationary with respect to X

otherwise will add tension to cable/damage satellite/pull X out of its orbit

c. cable is a conductor and contains electrons

electrons/charges experience a force when moving in a magnetic field

use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive»

Alternative 2

cable is a conductor

so current will flow by induction flow when it moves through a B field

use of a suitable hand rule to show current to right so «X becomes positive»

Marks should be awarded from either one alternative or the other.

Do not allow discussion of positive charges moving towards X

d. electrons would build up at satellite Y/positive charge at X

preventing further charge flow

by electrostatic repulsion

unless a complete circuit exists

e. « $\mathcal{E} = Blv \Rightarrow 31 \times 10^{-6} \times 7990 \times 15000$

3600 «V»

Allow 3700 «V» from $v = 8000 \text{ m s}^{-1}$.

f.i. use of $k = \frac{4\pi^2 m}{T^2} \Rightarrow \frac{4 \times \pi^2 \times 350}{5.2^2}$

510

N m^{-1} **or** kg s^{-2}

Allow MP1 and MP2 for a bald correct answer

Allow 500

Allow N/m etc.

f.ii. E_p in the cable/system transfers to E_k of Y

and back again twice in each cycle

Exclusive use of gravitational potential energy negates MP1

Examiners report

a. [N/A]

b.i. [N/A]

b.ii. [N/A]

c. [N/A]

d. [N/A]

e. [N/A]

f.i. [N/A]

f.ii. [N/A]

This question is about the energy of an orbiting satellite.

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

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

a. The kinetic energy E_K given to the shuttle at its launch is given by the expression

[2]

$$E_K = \frac{7GMm}{8R_E}$$

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

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

[3]

b.ii. Using the expression for E_K in (a) and your answer to (b)(i), determine R in terms of R_E .

[3]

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

[2]

Markscheme

a. KE needs to be \geq (magnitude of) GPE at surface $\left(-\frac{GMm}{R_E}\right)$;

But KE is $\frac{7GMm}{8R_E} < \frac{GMm}{R_E}$ / OWTTE;

or

shows that total energy at launch = $-\frac{GMm}{8R_E}$; (appropriate working required)

this is < 0 , so escape impossible;

or

states that escape velocity needed is $\sqrt{\frac{2GM}{R_E}}$;

shows launch velocity is only $\sqrt{\frac{7GM}{4R_E}}$; (appropriate working required)

b.i. $E_{\text{tot}} = \text{PE} + \text{KE}$;

shows that kinetic energy = $\left(\frac{1}{2}mv^2 = \right) \frac{GMm}{2R}$; (appropriate working required)

adds PE $\left(-\frac{GMm}{R}\right)$ and KE to get given answer; (appropriate working required)

b.ii. $-\frac{GMm}{R_E} + \frac{7GMm}{8R_E} = -\frac{GMm}{2R}$; (equating total energy at launch and in orbit)

$$\frac{1}{8R_E} = \frac{1}{2R};$$

$$R = 4R_E;$$

Award **[0]** for an answer such as $R = \frac{4R_E}{7}$.

c. total energy decreases/becomes a greater negative value, so R decreases;

as R decreases kinetic energy increases;

speed increases;

Examiners report

- a. Candidates were asked to show that the shuttle could not escape the Earth's field. There are many ways of approaching this, but in general answers were good, with only the weakest candidates failing to know where to start.
- b.i. The determination of total energy of a mass in Earth orbit is a standard classroom derivation. Most were able to reproduce it, but not everyone explained how the formula for orbital KE was derived.
- b.ii. Determining the radius of the orbit proved difficult for most candidates with many obtaining negative values or orbits with a radius less than the radius of the Earth. This was due to carelessness with the symbols used for the two different radii.
- c. Few candidates equated a decrease in total energy with an increasingly negative value. The consequent fact that the radius of the orbit decreases and velocity increases was counter-intuitive for most candidates. Most incorrectly opted for a decrease in KE due to resistive forces.
-

a. Outline what is meant by escape speed. [1]

b. A probe is launched vertically upwards from the surface of a planet with a speed [3]

$$v = \frac{3}{4}v_{\text{esc}}$$

where v_{esc} is the escape speed from the planet. The planet has no atmosphere.

Determine, in terms of the radius of the planet R , the maximum height from the surface of the planet reached by the probe.

c. The total energy of a probe in orbit around a planet of mass M is $E = -\frac{GMm}{2r}$ where m is the mass of the probe and r is the orbit radius. A [3]
probe in low orbit experiences a small frictional force. Suggest the effect of this force on the speed of the probe.

Markscheme

a. speed to reach infinity/zero gravitational field

OR

speed to escape gravitational pull/effect of planet's gravity

Do not allow reference to leaving/escaping an orbit.

Do not allow "escaping the atmosphere".

b. «kinetic energy at take off» = $\frac{9}{16} \times \frac{GMm}{R}$

kinetic energy at take off + «gravitational» potential energy = «gravitational» potential energy at maximum height

OR

$$\frac{9}{16} \times \frac{GMm}{R} - \frac{GMm}{R} = -\frac{GMm}{R}$$

solves for r and subtracts R from answer = $\frac{9R}{7}$

Award **[0]** for work that assumes constant g .

c. energy reduces/lost

radius decreases

speed increases

Do not allow "kinetic energy reduces" for MP1

Examiners report

a. [N/A]

b. [N/A]

c. [N/A]

This question is about escape speed and gravitational effects.

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

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

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

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

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

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

Markscheme

a. (minimum) speed of object to escape gravitational field of a planet/travel to infinity;

at surface of planet;

without (further) energy input;

b. (i) $-\frac{6.67 \times 10^{-11} \times 3.5 \times 10^{21}}{8.0 \times 10^5}$;

$-2.9 \times 10^5 \text{ J kg}^{-1}$; (allow Nm kg^{-1})

Award **[1 max]** if negative sign omitted.

(ii) $\frac{1}{2}mv^2 = mV$;

speed = $\sqrt{2 \times 2.9 \times 10^5}$; (allow ECF from (b)(i))

$7.6 \times 10^2 \text{ m s}^{-1}$;

Ignore sign.

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

c. time to hit surface = $\sqrt{\frac{2.0 \times 1.5}{0.37}}$ (= 2.85s);

distance to impact = 2.85×1.8 ;

5.1m;

Examiners report

a. [N/A]

b. [N/A]

c. [N/A]

a. Explain what is meant by the gravitational potential at the surface of a planet. [2]

b. An unpowered projectile is fired vertically upwards into deep space from the surface of planet Venus. Assume that the gravitational effects of the Sun and the other planets are negligible. [5]

The following data are available.

Mass of Venus	= 4.87×10^{24} kg
Radius of Venus	= 6.05×10^6 m
Mass of projectile	= 3.50×10^3 kg
Initial speed of projectile	= $1.10 \times$ escape speed

(i) Determine the initial kinetic energy of the projectile.

(ii) Describe the subsequent motion of the projectile until it is effectively beyond the gravitational field of Venus.

Markscheme

a. the «gravitational» work done «by an external agent» per/on unit mass/kg

Allow definition in terms of reverse process of moving mass to infinity eg “work done on external agent by...”.

Allow “energy” as equivalent to “work done”

in moving a «small» mass from infinity to the «surface of» planet / to a point

N.B.: on SL paper Q5(a)(i) and (ii) is about “gravitational field”.

b. i

escape speed

Care with ECF from MP1.

$$v = \ll \sqrt{\left(\frac{2GM}{R}\right)} \Rightarrow \gg$$

$$\sqrt{\left(\frac{2 \times 6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{6.05 \times 10^6}\right)} \text{ or } 1.04 \times 10^4 \ll m \text{ s}^{-1} \gg$$

$$\text{or } \ll 1.1 \times 1.04 \times 10^4 \text{ m s}^{-1} \gg = 1.14 \times 10^4 \ll m \text{ s}^{-1} \gg$$

$$\text{KE} = \ll 0.5 \times 3500 \times (1.1 \times 1.04 \times 10^4 \text{ m s}^{-1})^2 \gg = 2.27 \times 10^{11} \ll \text{J} \gg$$

Award [1 max] for omission of 1.1 – leads to $1.88 \times 10^{11} \text{ m s}^{-1}$.

Award [2] for a bald correct answer.

ii
Velocity/speed decreases / projectile slows down «at decreasing rate»

«magnitude of» deceleration decreases «at decreasing rate»

Mention of deceleration scores MP1 automatically.

velocity becomes constant/non-zero

OR

deceleration tends to zero

Accept “negative acceleration” for “deceleration”.

Must see “velocity” not “speed” for MP3.

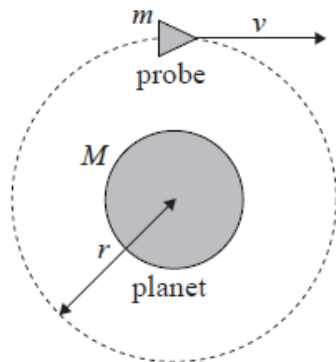
Examiners report

a. [N/A]

b. [N/A]

This question is about a probe in orbit.

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



(diagram not to scale)

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

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

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

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

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

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

Markscheme

a. because the force is always at right angles to the velocity / motion/orbit is an equipotential surface;

Do not accept answers based on the displacement being zero for a full revolution.

b. (i) equating gravitational force $\frac{GMm}{r^2}$;

to centripetal force $\frac{mv^2}{r}$ to get result;

(ii) kinetic energy is $\frac{GMm}{2r}$;

addition to potential energy $-\frac{GMm}{r}$ to get result;

c. the total energy (at the new orbit) will be greater than before/is less negative;

hence probe engines must be fired to produce force in the direction of motion / positive work must be done (on the probe);

Award **[1]** for mention of only potential energy increasing.

Examiners report

a. [N/A]

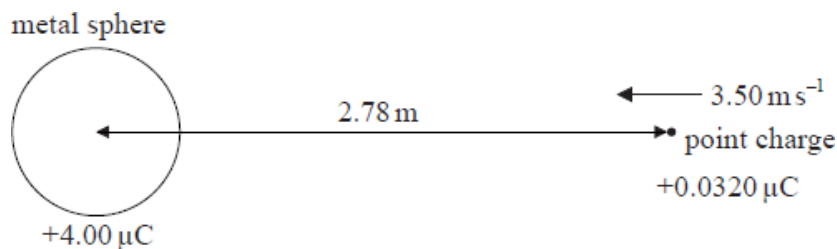
b. [N/A]

c. [N/A]

This question is about electric potential.

a. Define *electric potential* at a point in an electric field. [3]

b. A positive point charge is moving towards a small, charged metal sphere along a radial path. [6]



At the position shown in the diagram, the point charge has a speed of 3.50 m s^{-1} and is at a distance of 2.78 m from the centre of the metal sphere. The charge on the sphere is $+4.00 \mu\text{C}$.

(i) State the direction of the velocity of the point charge with respect to an equipotential surface due to the metal sphere.

(ii) Show that the electric potential V due to the charged sphere at a distance of 2.78 m from its centre is $1.29 \times 10^4 \text{ V}$.

(iii) The electric potential at the surface of the sphere is $7.20 \times 10^4 \text{ V}$. The point charge has a charge of $+0.0320 \mu\text{C}$ and its mass is $1.20 \times 10^{-4} \text{ kg}$. Determine if the point charge will collide with the metal sphere.

Markscheme

a. the work done per unit charge;

when a small/test/point positive charge; (*charge sign is essential*)

is moved from infinity to the point;

b. (i) perpendicular / at right angles / at 90° / normal;

$$(ii) V = \frac{8.99 \times 10^9 \times 4.00 \times 10^{-6}}{2.78} \text{ or } 1.2935 \times 10^4 \text{V}; \text{ (use of } \frac{1}{4\pi\epsilon_0} \text{ gives } 1.29378 \times 10^4)$$

$$(\approx 1.29 \times 10^4 \text{V})$$

$$(iii) \text{ difference in potential} = (7.20 \times 10^4 - 1.29 \times 10^4) = 5.91 \times 10^4;$$

required loss in

$$\text{kinetic energy/minimum kinetic energy to reach sphere} = (0.032 \times 10^{-6} \times 5.91 \times 10^4) = 1.89 \times 10^{-3} \text{J};$$

$$\text{available kinetic energy} = (\frac{1}{2} \times 1.20 \times 10^{-4} \times 3.50^2) = 7.35 \times 10^{-4} \text{J}; \text{ not enough (initial) kinetic energy to reach sphere;}$$

Response needs some statement of conclusion, e.g. so it does not reach sphere.

Allow answer in terms of minimum speed to reach sphere 5.61ms^{-1} .

Examiners report

a. There were three marks for this question and most scored 1 or 2. The full definition of electric potential at a point was simply not well enough remembered. Many forgot that it is (i) the work done per unit charge on a (ii) positive (test) charge (iii) as the charge is moved from infinity to the point in question.

b. (i) Most failed to read the question and did not realize that the question required the direction with respect to an equipotential surface. Most gave the direction relative to the diagram.

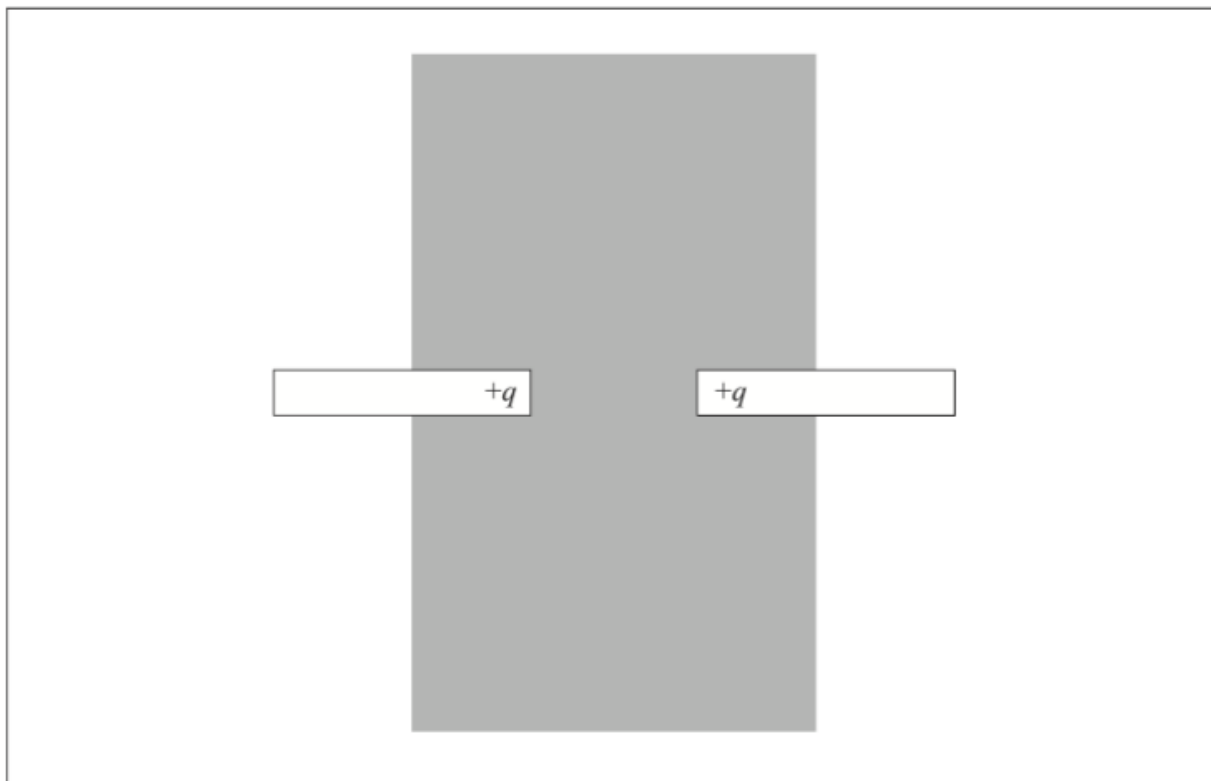
(ii) This was well done by a great many, however examiners did expect to see a full substitution, it was not acceptable to leave the permittivity of free space as a symbol in this “show that” question.

(iii) Even where candidates could negotiate a path through this testing question, solutions were seldom clear.

This question is in **two** parts. **Part 1** is about electric charge and resistance. **Part 2** is about orbital motion.

Part 1 Electric charge and resistance

Two plastic rods each have a positive charge $+q$ situated at one end. The rods are arranged as shown.

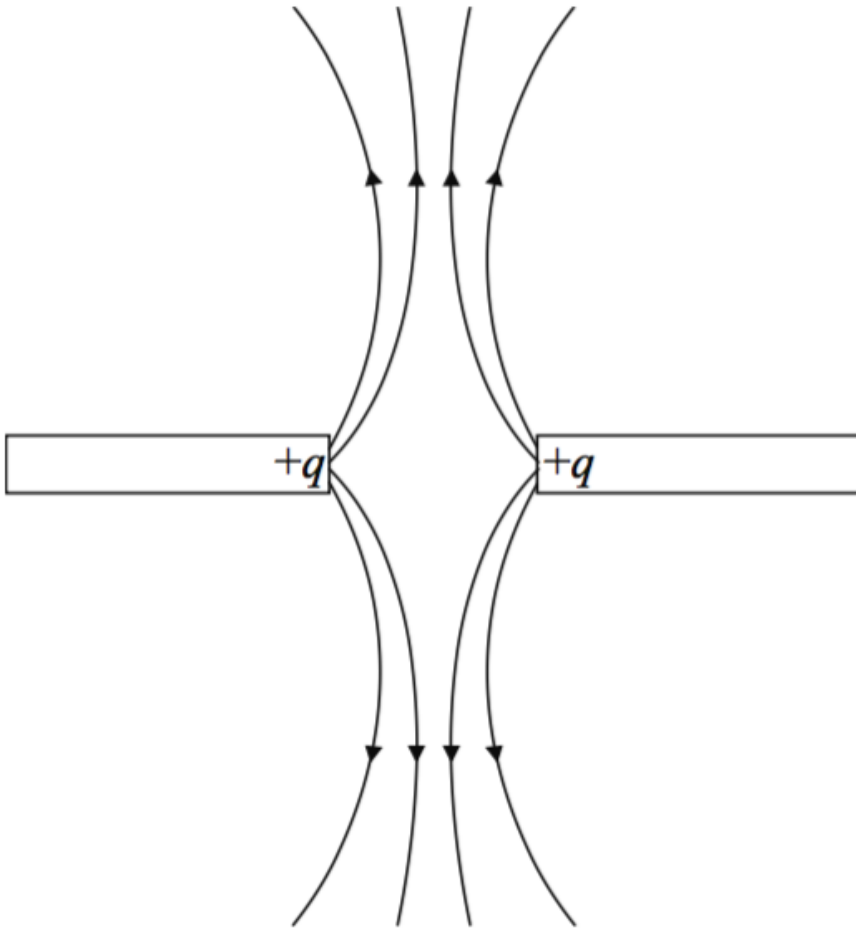


Assume that the charge at the end of each rod behaves as a point charge. Draw, in the shaded area on the diagram

- (i) the electric field pattern due to the two charges.
- (ii) a line to represent an equipotential surface. Label the line with the letter V.

Markscheme

(i)



at least four field lines (minimum two per rod) to show overall shape of pattern; direction of lines all away from poles;

Ignore all working outside region.

Any field lines crossing loses first mark even if accidental.

(ii) any line labelled V perpendicular to the field lines it traverses; *(judge by eye)*

Ignore unlabelled lines as they could be field lines.

Examiners report

The shapes of possible equipotential surfaces were very poorly constructed. Candidates in their diagrams showed a poor understanding of the relationship.

Part 2 Gravitational potential

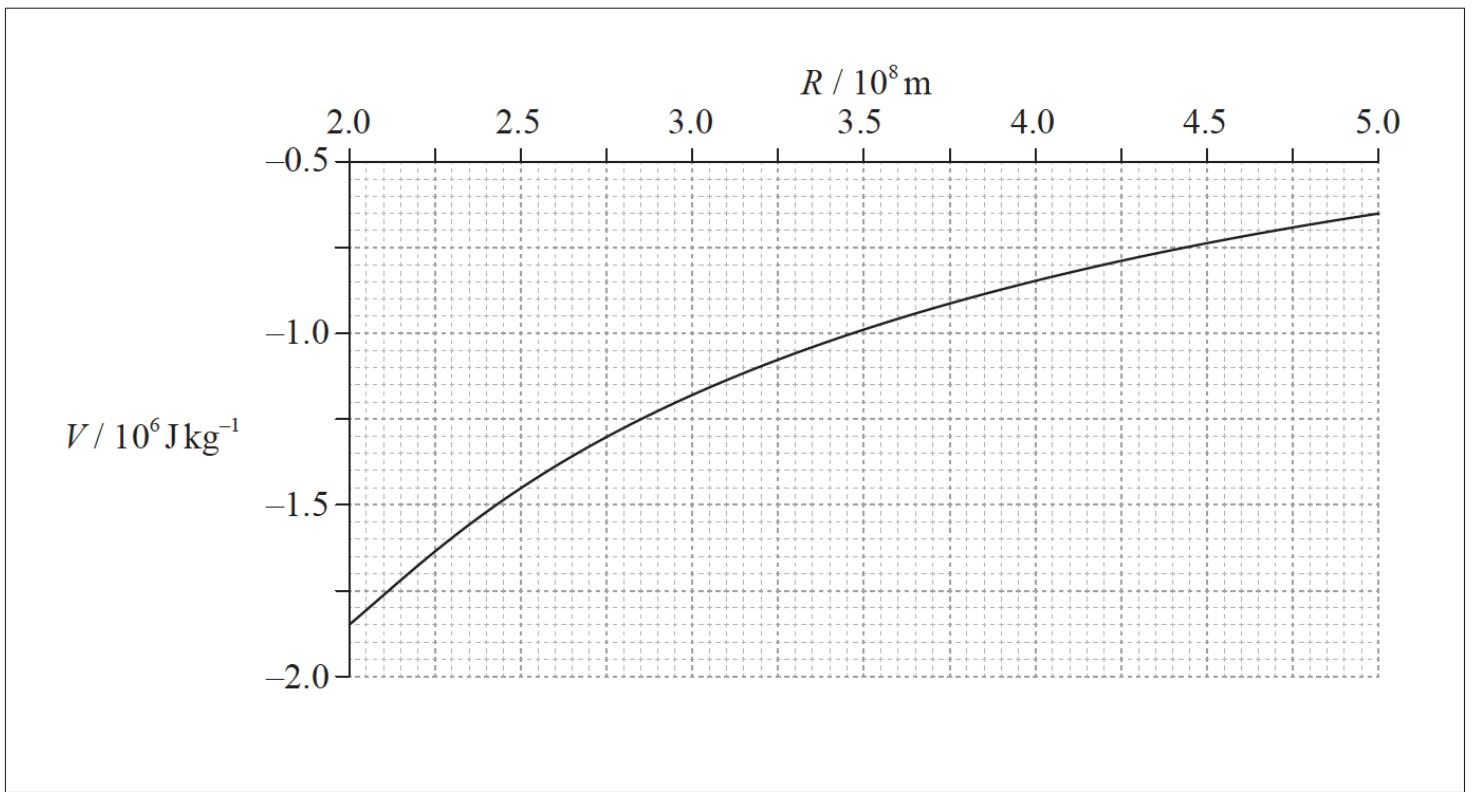
e. Define *gravitational potential* at a point in a gravitational field.

[3]

f. The graph shows how the gravitational potential V of Earth varies with distance R from the centre of Earth in the range $R=2.0 \times 10^8$ m to

[6]

$R=5.0 \times 10^8$ m.



The Moon is at a distance of $4.0 \times 10^8 \text{ m}$ from the centre of Earth. At some time in the past it was at a distance of $2.7 \times 10^8 \text{ m}$ from the centre of Earth.

Use the graph opposite to determine

(i) the present day magnitude of the acceleration of the Moon.

(ii) by how much the potential energy of the Moon has changed as a result of moving from $R = 2.7 \times 10^8 \text{ m}$ to $R = 4.0 \times 10^8 \text{ m}$. The mass of the Moon is $7.4 \times 10^{22} \text{ kg}$.

g. State why the change of potential energy in (f)(ii) is an increase.

[1]

Markscheme

e. work done per unit mass;

in bringing (test) mass from infinity to point;

reference to small/point (test) mass;

f. (i) tangent construction attempted at $R = 4.0 \times 10^8 \text{ m}$;

triangle/pair of coordinates used in calculation;

attempt to calculate gradient;

$2.5 \times 10^{-3} \text{ ms}^{-2}$; (accept answers in the range of 2.2 to 2.7)

Award **[1 max]** for $\frac{V}{R}$ to give $(-)2.1 \times 10^{-3}$.

(ii) change in $V = 0.45 \times 10^6 - 0.50 \times 10^6 \text{ J kg}^{-1}$;

change in PE = $(0.5 \times 10^6 \times 7.4 \times 10^{22}) - (3.3 - 3.7 \times 10^{28} \text{ J})$;

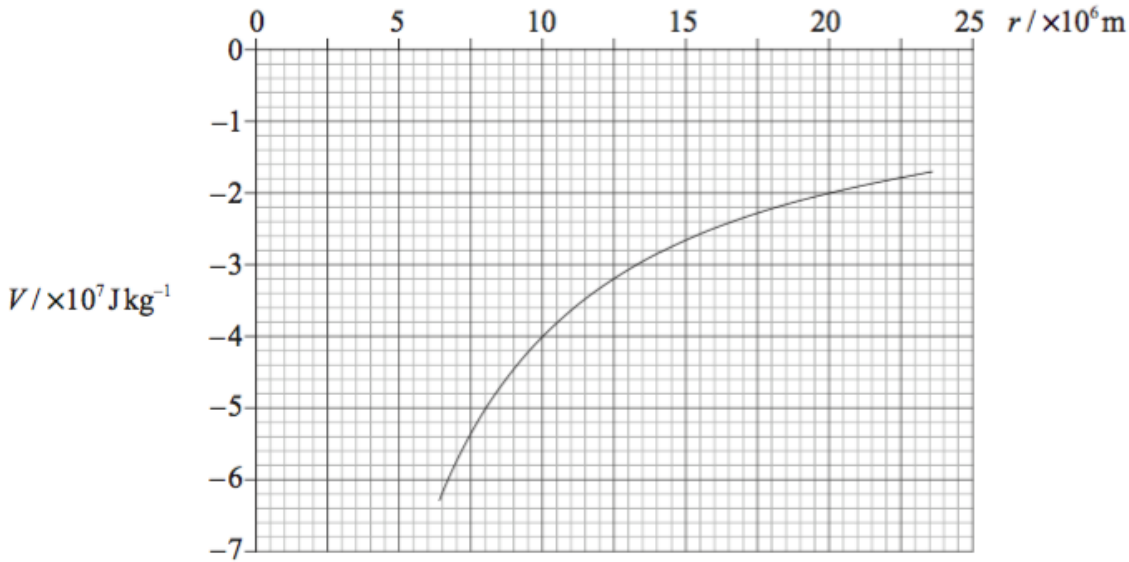
g. work is done against the gravitational field of Earth / Moon is now closer to infinity/further from Earth / $\frac{-GMm}{R}$ means that as R increases potential increases/becomes less negative;

Examiners report

- e. [N/A]
- f. [N/A]
- g. [N/A]

Part 2 Orbital motion

- a. A satellite, of mass m , is in orbit about Earth at a distance r from the centre of Earth. Deduce that the kinetic energy E_K of the satellite is equal to [3]
half the magnitude of the potential energy E_P of the satellite.
- b. The graph shows the variation with distance r of the Earth's gravitational potential V . Values of V for $r < R$, where R is the radius of Earth, are not [6]
shown.



The satellite in (a) has a mass of 8.2×10^2 kg and it is in orbit at a distance of 1.0×10^7 m from the centre of Earth. Using data from the graph and your answer to (a), calculate for the satellite

- (i) its total energy.
- (ii) its orbital speed.
- (iii) the energy it must gain to move to an orbit a distance 2.0×10^7 m from the centre of the Earth.

Markscheme

- a. $\frac{mv^2}{r} = \frac{GMm}{r^2}$;
 $E_K = \frac{1}{2}mv^2 = \frac{GMm}{2r}$;
 $E_P = -\frac{GMm}{r}$ (hence magnitude of $E_K = \frac{1}{2}$ magnitude of E_P);

b. (i) total energy = $(KE + PE) = -\frac{V_m}{2}$;
 $= \left(-\frac{4.0 \times 10^7 \times 8.2 \times 10^2}{2} \right) = -1.6 \times 10^{10} \text{ J};$

(ii) $v = \sqrt{V}$; (or use of $E_k = \frac{1}{2}mv^2$)

$= 6.3 \times 10^3 \text{ ms}^{-1}$;

(iii) total energy in new orbit = $\left(-\frac{2.0 \times 10^7 \times 8.2 \times 10^2}{2} \right) = -0.82 \times 10^{10} \text{ (J)}$;

energy required = $(1.6 \times 10^{10} - 0.82 \times 10^{10}) = 7.8 \times 10^9 \text{ J}$;

or

total energy is proportional to E_p ;

so energy required = $-(b)(i) \div 2 = 8 \text{ or } 8.2 \times 10^9 \text{ J}$; (allow ECF from (b)(i))

Examiners report

- a. The deduction that the kinetic energy of a satellite is equal to half the magnitude of its potential energy was poorly shown by about half the candidates. The proof can begin with the equating of centripetal and gravitational forces for the satellite with a subsequent substitution into the kinetic energy equation, but many failed to remember this. Some got most of the way but failed to show the examiner the final step with the factor 1/2.
- b. (i) (ii) and (iii) This sequence of calculations of the total energy, the orbital speed and the energy change for the satellite was poor. This is standard work and candidates made little of it. The understanding of energy topics in gravitational fields was poorly demonstrated by the candidates throughout this question.

This question is in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about orbital motion.

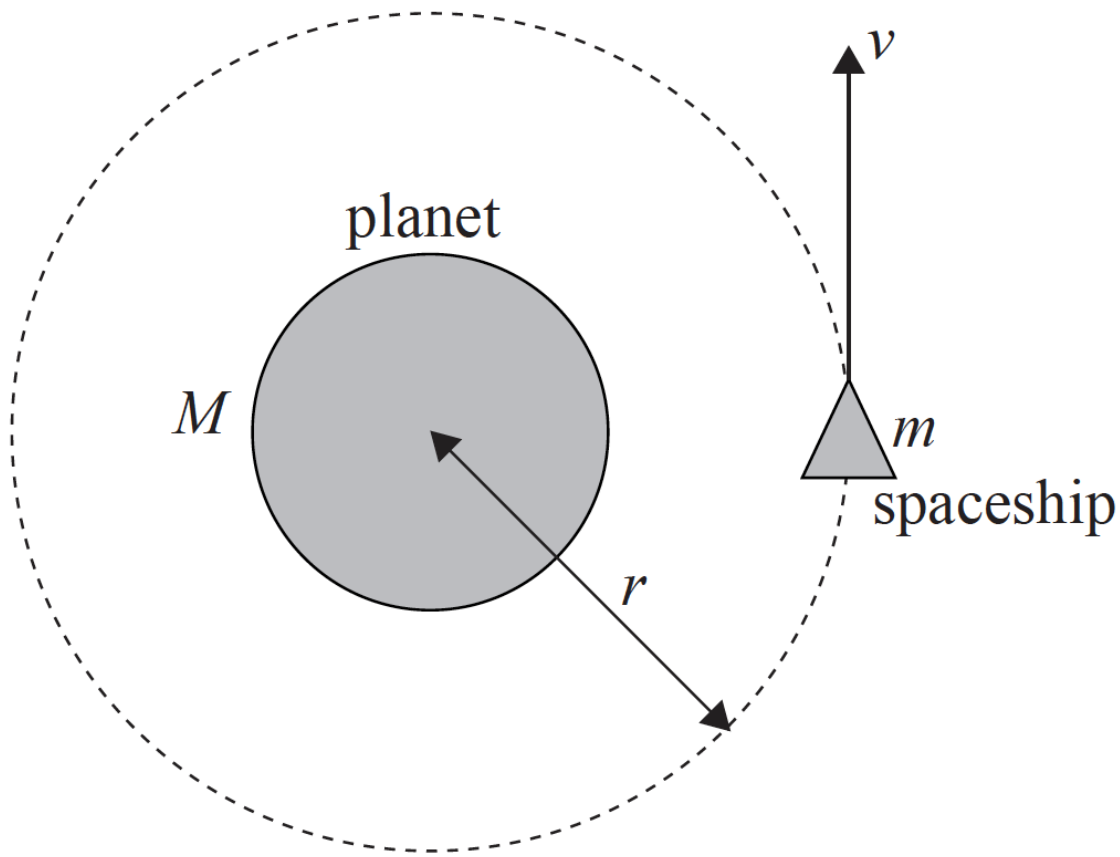
Part 1 Solar radiation and the greenhouse effect

The following data are available.

Quantity	Symbol	Value
Radius of Sun	R	$7.0 \times 10^8 \text{ m}$
Surface temperature of Sun	T	$5.8 \times 10^3 \text{ K}$
Distance from Sun to Earth	d	$1.5 \times 10^{11} \text{ m}$
Stefan-Boltzmann constant	σ	$5.7 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

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. State the Stefan-Boltzmann law for a black body. [2]
- b. Deduce that the solar power incident per unit area at distance d from the Sun is given by [2]

$$\frac{\sigma R^2 T^4}{d^2}.$$
- c. Calculate, using the data given, the solar power incident per unit area at distance d from the Sun. [2]
- d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). [2]
- e. The average power absorbed per unit area at the Earth's surface is 240Wm^{-2} . By treating the Earth's surface as a black body, show that the average surface temperature of the Earth is approximately 250K. [2]
- f. Explain why the actual surface temperature of the Earth is greater than the value in (e). [3]
- h. (i) Identify the force that causes the centripetal acceleration of the spaceship. [4]
 - (ii) Explain why astronauts inside the spaceship would feel "weightless", even though there is a force acting on them.
- i. Deduce that the speed of the spaceship is $v = \sqrt{\frac{GM}{r}}$. [2]
- j. The table gives equations for the forms of energy of the orbiting spaceship. [4]

Form of Energy	Equation
Kinetic	$E_K = \frac{GMm}{2r}$
Gravitational potential	$E_P = -\frac{GMm}{r}$
Total (kinetic + potential)	$E = -\frac{GMm}{2r}$

The spaceship passes through a cloud of gas, so that a small frictional force acts on the spaceship.

- State and explain the effect that this force has on the total energy of the spaceship.
- Outline the effect that this force has on the speed of the spaceship.

Markscheme

- a. power/energy per second emitted is proportional to surface area;
and proportional to fourth power of absolute temperature / temperature in K;
Accept equation with symbols defined.

- b. solar power given by $4\pi R^2 \sigma T^4$;
spreads out over sphere of surface area $4\pi d^2$;
Hence equation given.

- c. $\left(\frac{\sigma R^2 T^4}{d^2}\right) = \frac{5.7 \times 10^{-8} \times [7.0 \times 10^8]^2 \times [5.8 \times 10^3]^4}{[1.5 \times 10^{11}]^2}$;
 $= 1.4 \times 10^3 \text{ (Wm}^{-2}\text{)}$;
Award [2] for a bald correct answer.

- d. some energy reflected;
some energy absorbed/scattered by atmosphere;
depends on latitude;
depends on time of day;
depends on time of year;
depends on weather (eg cloud cover) at location;
power output of Sun varies;
Earth-Sun distance varies;

e. power radiated=power absorbed;

$$T = \sqrt[4]{\frac{240}{5.7 \times 10^{-8}}} (= 250\text{K});$$

Accept answers given as 260 (K).

f. radiation from Sun is re-emitted from Earth at longer wavelengths;

greenhouse gases in the atmosphere absorb some of this energy;

and radiate some of it back to the surface of the Earth;

h. (i) gravitational force / gravitational attraction / weight; (*do not accept gravity*)

(ii) astronauts and spaceship have the same acceleration;

acceleration is towards (centre of) planet;

so no reaction force between astronauts and spaceship;

or

astronauts and spaceships are both falling towards the (centre of the) planet;

at the same rate;

so no reaction force between astronauts and spaceship;

i. gravitational force equated with centripetal force / $\frac{GmM}{r^2} = \frac{mv^2}{r}$;

$$\Rightarrow v^2 = \frac{GM}{r} \Rightarrow \left(v = \sqrt{\frac{GM}{r}} \right);$$

j. (i) thermal energy is lost;

total energy decreases;

(ii) since E decreases, r also decreases;

as r decreases v increases / E_k increases so v increases;

Examiners report

a. The Stefan-Boltzmann law was poorly understood with few candidates stating that the absolute temperature is raised to the fourth power.

b. This question was poorly done with few candidates substituting the surface area of the sun or the surface area of a sphere at the Earth's radius of orbit.

c. Despite not being able to state or manipulate the Stefan-Boltzmann law most candidates could substitute values into the expression and calculate a result.

d. This question was well answered at higher level.

e. To show the given value there is the requirement for an explanation of why the incident power absorbed by the Earth's surface is equal to the power radiated by the Earth, few candidates were successful in this aspect. Although most could substitute into the Stefan-Boltzmann equation they needed to either show that the fourth root was used or to find the temperature to more significant figures than the value given.

f. A surprising number of candidates could not explain the greenhouse effect. A common misunderstanding was that the Earth reflected radiation into the atmosphere and that the atmosphere reflected the radiation back to the Earth.

h. (i) Most were able to state gravitational force, however a significant number stated gravity and consequently did not get the mark.

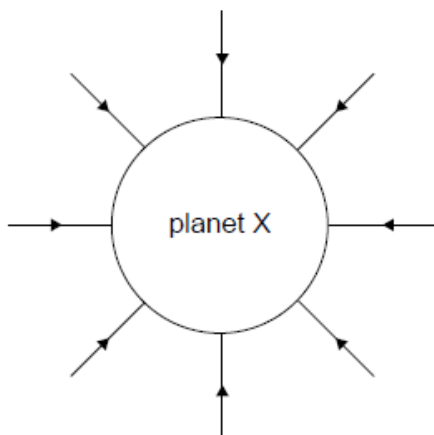
(ii) Many answers only discussed the astronauts and not the spaceship, missing points such as 'falling at the same rate' or 'with the same acceleration'.

i. This was well answered with candidates able to adequately show in their explanation where the expression comes from.

j. ji) Most appreciated that the effect of the force would be to decrease the total energy.

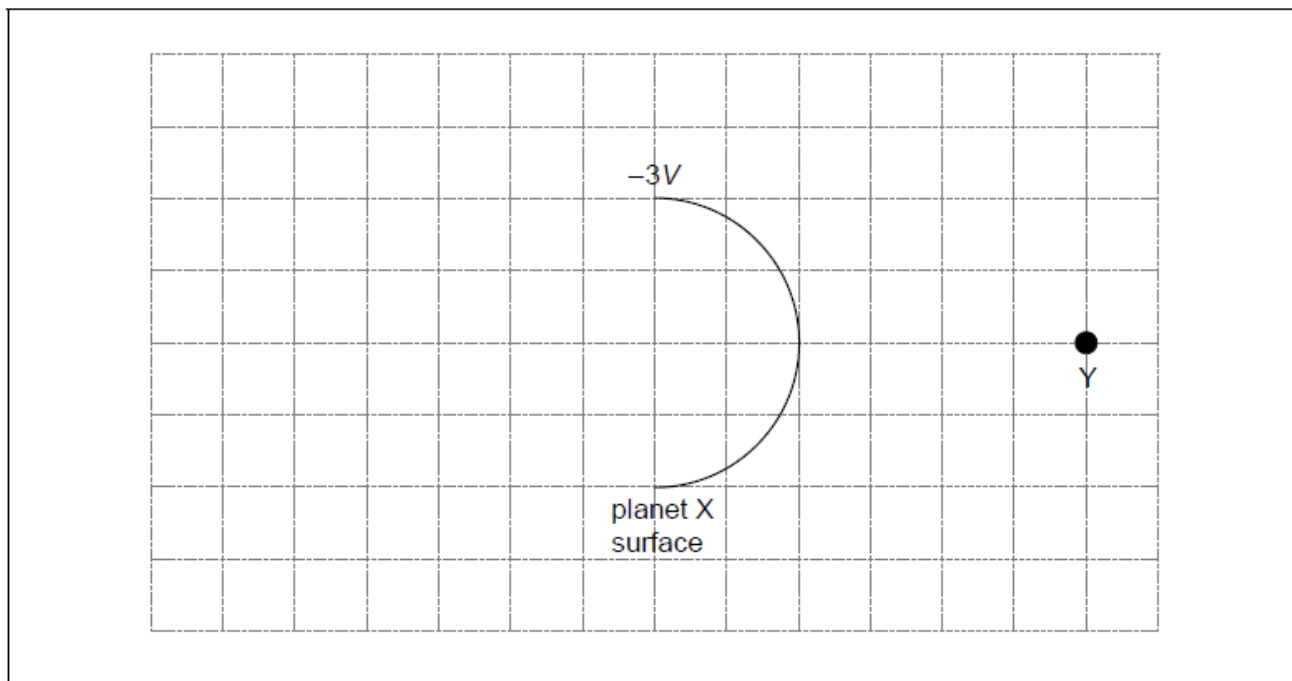
jii) Very few appreciated that they should use the equations above to answer this part of the question. As a consequence, the most common answer discussed a decrease in kinetic energy and a decrease in speed.

The diagram shows the gravitational field lines of planet X.



a. Outline how this diagram shows that the gravitational field strength of planet X decreases with distance from the surface. [1]

b. The diagram shows part of the surface of planet X. The gravitational potential at the surface of planet X is $-3V$ and the gravitational potential at point Y is $-V$. [2]



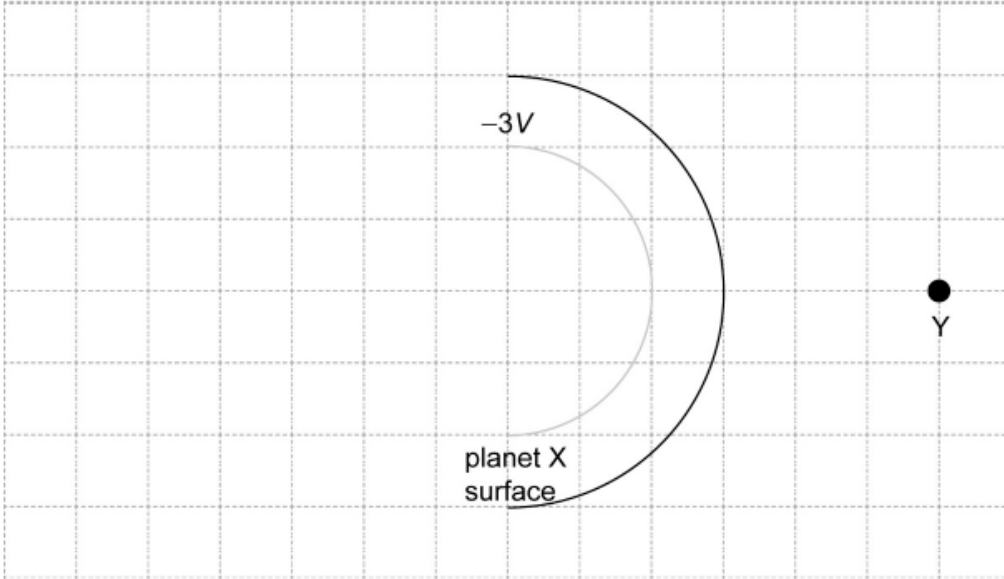
Sketch on the grid the equipotential surface corresponding to a gravitational potential of $-2V$.

c. A meteorite, very far from planet X begins to fall to the surface with a negligibly small initial speed. The mass of planet X is 3.1×10^{21} kg and its radius is 1.2×10^6 m. The planet has no atmosphere. Calculate the speed at which the meteorite will hit the surface. [3]

- d. At the instant of impact the meteorite which is made of ice has a temperature of $0\text{ }^{\circ}\text{C}$. Assume that all the kinetic energy at impact gets transferred into internal energy in the meteorite. Calculate the percentage of the meteorite's mass that melts. The specific latent heat of fusion of ice is $3.3 \times 10^5\text{ J kg}^{-1}$. [2]

Markscheme

- a. the field lines/arrows are further apart at greater distances from the surface
- b. circle centred on Planet X
three units from Planet X centre



c. loss in gravitational potential = $\frac{6.67 \times 10^{-11} \times 3.1 \times 10^{21}}{1.2 \times 10^6}$

«= $1.72 \times 10^5\text{ J Kg}^{-1}$ »

equate to $\frac{1}{2}v^2$

$v = 590\text{ m s}^{-1}$ »

Allow ECF from MP1.

- d. available energy to melt one kg $1.72 \times 10^5\text{ J}$ »

fraction that melts is $\frac{1.72 \times 10^5}{3.3 \times 10^5} = 0.52$ **OR** 52%

Allow ECF from MP1.

Allow 53% from use of 590 ms^{-1} .

Examiners report

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

