10.1 *[120 marks]*

A planet has radius *R*. At a distance *h* above the surface of the planet the gravitational field strength is *g* and the gravitational potential is *V*.

1a. State what is meant by gravitational field strength. *[1 mark]*

Markscheme

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

[1 mark]

1b. Show that $V = -g(R + h)$. *[2 marks]*

Markscheme

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

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* $R + h$

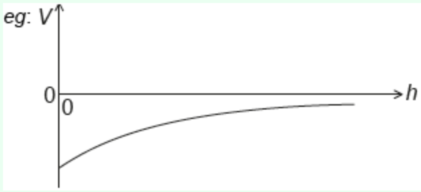
[2 marks]

1c. Draw a graph, on the axes, to show the variation of the gravitational potential *V* of the planet with height *h* above the surface of the planet. *[2 marks]*

Markscheme

correct shape and sign

non-zero negative vertical intercept



[2 marks]

1d. 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 mark]*

Markscheme

V = «–2.2 × (3.1 × 10^6 + 2.4 × 10^7) =» «–» 6.0 × 10^7 J kg^{-1}

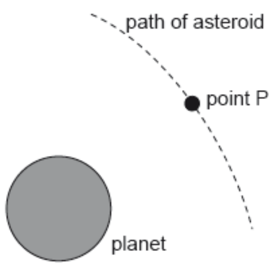
Unit is essential

Allow eg MJ kg^{-1} if power of 10 is correct

Allow other correct SI units eg m^2s^{-2}, N m kg^{-1}

[1 mark]

1e. The diagram shows the path of an asteroid as it moves past the planet. *[3 marks]*



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).

Markscheme

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

« $\frac{1}{2}mv^2 + mV = 0$ ⇒» $v = \sqrt{-2V}$

v = « $\sqrt{2 \times 6.0 \times 10^7}$ =» 1.1 × 10^4 «ms^{-1}»

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

Ignore negative sign errors in the workings

Allow ECF from 6(b)

[3 marks]

1f. 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 marks]*

Markscheme

ALTERNATIVE 1

force on asteroid is «$6.2 \times 10^{12} \times 2.2$ =» 1.4×10^{13} «N»

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

ALTERNATIVE 2

mass of planet = 2.4×10^{25} «kg» «from $V = -\frac{GM}{(R+h)}$»

force on planet «$\frac{GMm}{(R+h)^2}$» = 1.4×10^{13} «N»

MP2 must be explicit

[2 marks]

This question is in two parts. **Part 1** is about momentum. **Part 2** is about electric point charges.

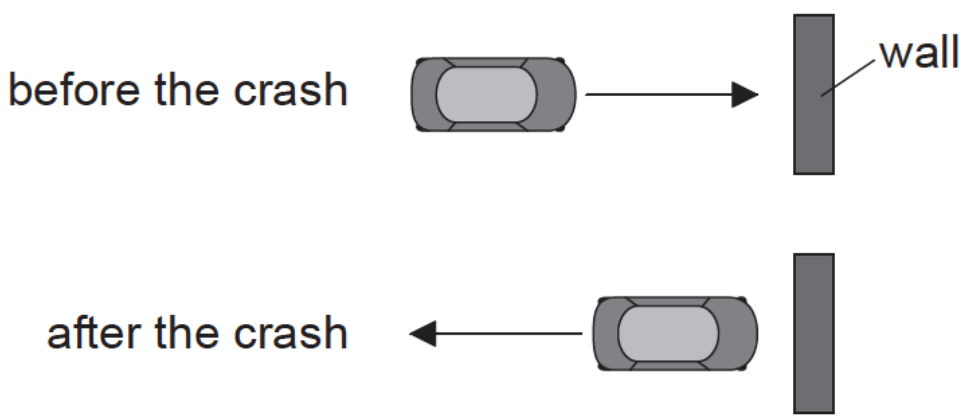
Part 1 Momentum

2a. State the law of conservation of linear momentum. *[2 marks]*

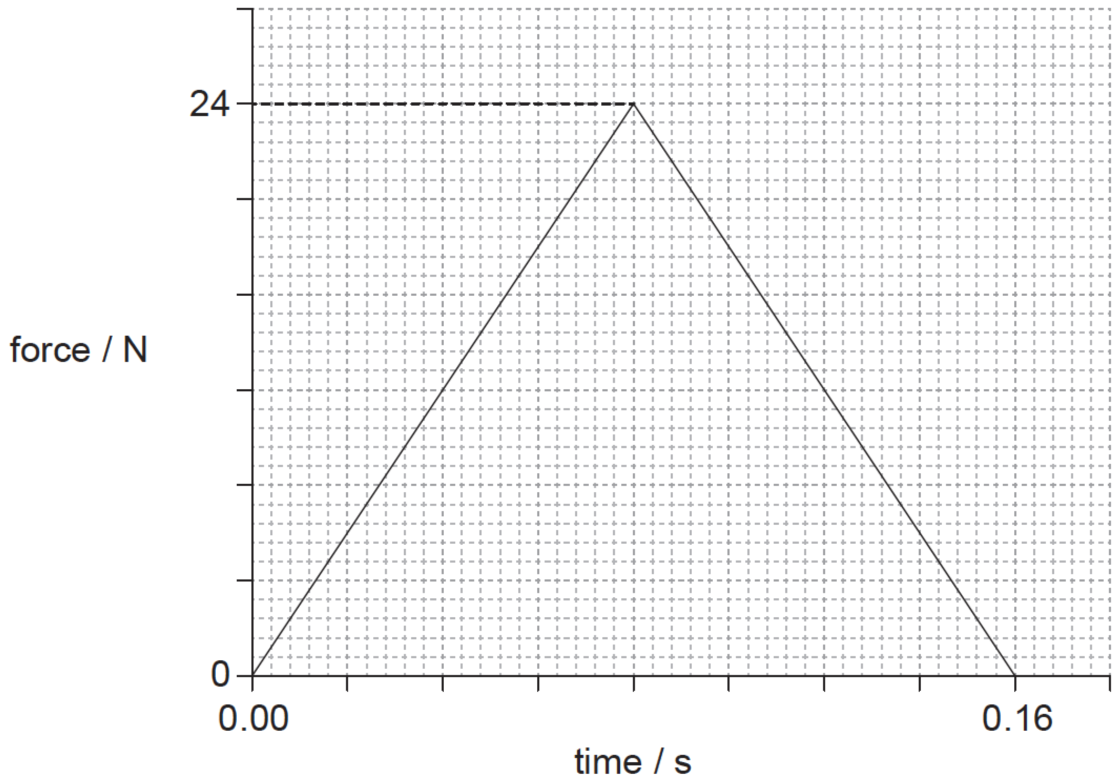
Markscheme

total momentum does not change/is constant; } *(do not allow "momentum is conserved")*
provided external force is zero / no external forces / isolated system;

2b. A toy car crashes into a wall and rebounds at right angles to the wall, as shown in the plan view. *[9 marks]*



The graph shows the variation with time of the force acting on the car due to the wall during the collision.

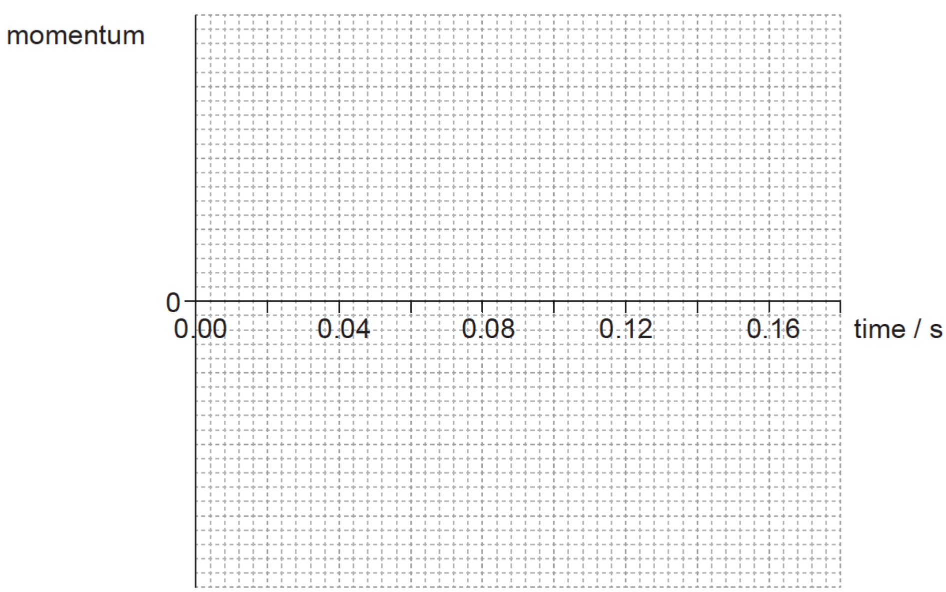


The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

(i) Determine the initial momentum of the car.

(ii) Estimate the average acceleration of the car before it rebounds.

(iii) On the axes, draw a graph to show how the momentum of the car varies during the impact. You are not required to give values on the y-axis.



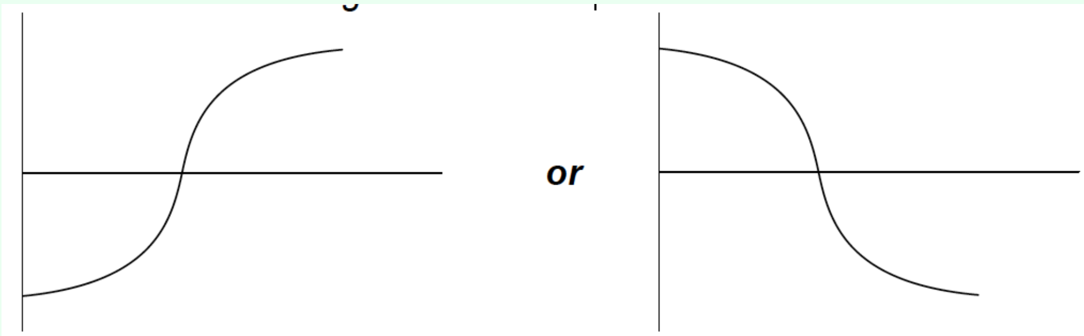
Markscheme

(i) clear attempt to calculate area under graph;
initial momentum is half change in momentum;
$\left(\frac{1}{2} \times \frac{1}{2} \times 24 \times 0.16\right) = 0.96\,(\text{kgms}^{-1})$
*Award **[2 max]** for calculation of total change (1.92kg ms^{-1})*

(ii) initial speed $= \left(\frac{0.96}{0.8} =\right) 1.2\text{ms}^{-1}$;
$a = \frac{1.2-(-1.2)}{0.16}$ ***or*** $a = \frac{-1.2-1.2}{0.16}$;
–15(ms^{-2}); *(must see negative sign or a comment that this is a deceleration)*

or
average force =12 N;
uses F=0.8×a ;
–15(ms^{-2}); *(must see negative sign or a comment that this is a deceleration)*
*Award **[3]** for a bald correct answer.*
Other solution methods involving different kinematic equations are possible.

(iii) goes through t=0.08s **and** from negative momentum to positive / positive momentum to negative;
constant sign of gradient throughout;
curve as shown;
Award marks for diagram as shown.



2c. Two identical toy cars, A and B are dropped from the same height onto a solid floor without rebounding. Car A is unprotected whilst car B is in a box with protective packaging around the toy. Explain why car B is less likely to be damaged when dropped. *[4 marks]*

Markscheme

impulse is the same/similar in both cases / momentum change is same;
impulse is force × time / force is rate of change of momentum;
time to come to rest is longer for car B;
force experienced by car B is less (so less likely to be damaged);

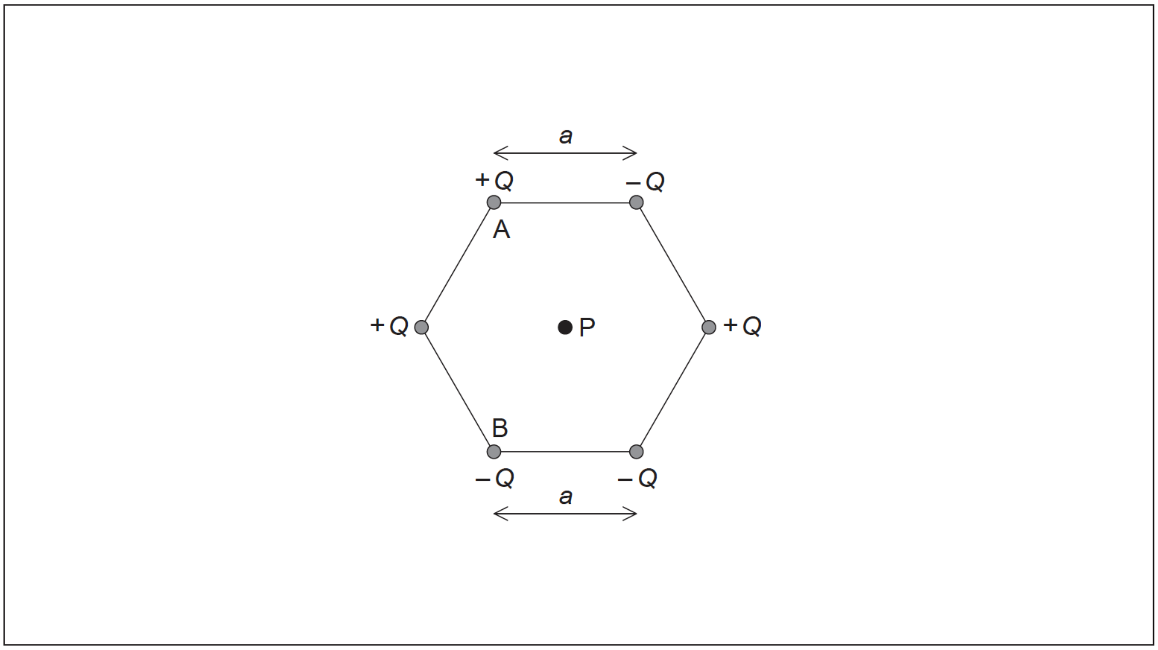
Part 2 Electric point charges

2d. Define *electric field strength* at a point in an electric field. *[2 marks]*

Markscheme

electric force per unit charge;
acting on a small/point positive (test) charge;

2e. Six point charges of equal magnitude *Q* are held at the corners of a hexagon with the signs of the charges as shown. Each side of the hexagon has a length *a*. *[8 marks]*



P is at the centre of the hexagon.

(i) Show, using Coulomb's law, that the magnitude of the electric field strength at point P due to **one** of the point charges is

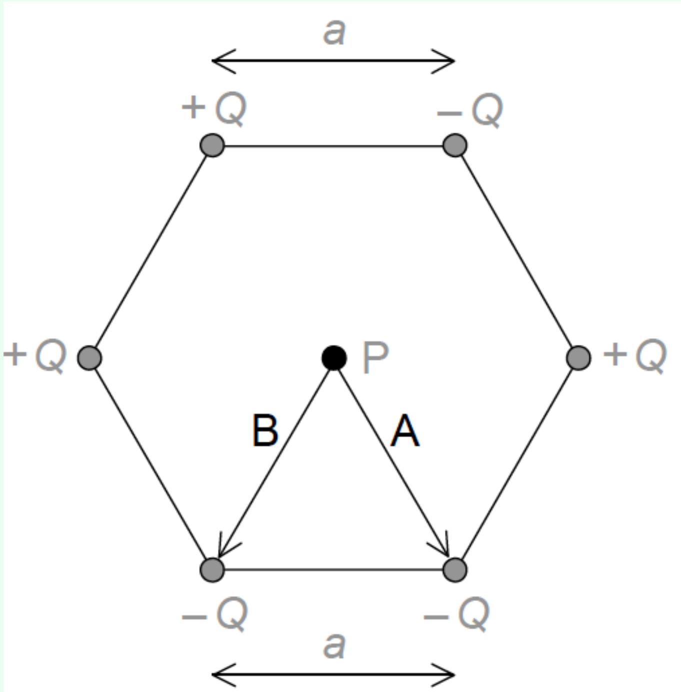
$$\frac{kQ}{a^2}$$

(ii) On the diagram, draw arrows to represent the direction of the field at P due to point charge A (label this direction A) and point charge B (label this direction B).

(iii) The magnitude of *Q* is 3.2 μC and length *a* is 0.15 m. Determine the magnitude and the direction of the electric field strength at point P due to all six charges.

Markscheme

(i) states Coulomb's law as $\frac{kQq}{r^2}$ ***or*** $\frac{F}{q} = \frac{kQ}{r^2}$
states explicitly q=1;
states r=a;

(ii) 

arrow labelled A pointing to lower right charge;
arrow labelled B point to lower left charge;
Arrows can be anywhere on diagram.

(iii) overall force is due to +Q top left and -Q bottom right / top right and bottom left and centre charges all cancel; } *(can be seen on diagram)*
force is therefore $\frac{2kQ}{a^2}$;

2.6×106 (N C^{-1}) ;
towards bottom right charge; *(allow clear arrow on diagram showing direction)*

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about electric fields.

Part 1 Energy resources

3a. The Sun is a renewable energy source whereas a fossil fuel is a non-renewable energy source. Outline the difference between renewable and non-renewable energy sources. *[2 marks]*

Markscheme

renewable sources:

rate of use/depletion of energy source;

is less than rate of production/regeneration of source;

Accept equivalent statement for non-renewable sources.

or

mention of rate of production / usage;

comparison of sources in terms of being used up/depleted/lasting a long time *etc*;

*Award **[1]** if answer makes clear the difference but does not address the rate of production.*

3b. With reference to the energy transformations and the operation of the devices, distinguish between a photovoltaic cell and a solar heating panel. *[2 marks]*

Markscheme

solar heating panel converts solar/radiation/photon/light energy into thermal/heat energy and photovoltaic cell converts solar/radiation/photon/light energy into electrical energy; } *(both needed)*

in solar heating hot liquid is stored/circulated and photovoltaic cell generates emf/pd; } *(both needed)*

A photovoltaic panel is made up of a collection (array) of photovoltaic cells. The panel has a total area of $1.3\ \mathrm{m}^2$ and is mounted on the roof of a house. The maximum intensity of solar radiation at the location of the panel is $750\ \mathrm{W\,m^{-2}}$. The panel produces a power output of 210 W when the solar radiation is at its maximum intensity.

3c. Determine the efficiency of the photovoltaic panel. *[2 marks]*

Markscheme

(power available at roof) $= 1.3 \times 750\ (= 975\ \mathrm{W})$;

efficiency $= \left(\frac{210}{975} =\right)\ 0.22$ ***or*** 22%;

3d. State **two** reasons why the intensity of solar radiation at the location of the panel is not constant. *[2 marks]*

1.

2.

Markscheme

depends on time of day;

depends of time of year;

depends on weather (*eg* cloud cover) at location;

power output of Sun varies;

Earth-Sun distance varies;

The owner of the house chooses between photovoltaic panels and solar heating panels to provide 4.2 kW of power to heat water. The solar heating panels have an efficiency of 70%. The maximum intensity of solar radiation at the location remains at $750\ \mathrm{W\,m^{-2}}$.

3e. Calculate the minimum area of solar heating panel required to provide this power. *[2 marks]*

Markscheme

area of panel $= \frac{4200}{0.7 \times 750}$;

$8\ \mathrm{m}^2$;

3f. Comment on whether it is better to use a solar heating panel rather than an array of photovoltaic panels for the house. Do not consider the installation cost of the panels in your answer. *[2 marks]*

Markscheme

calculates area of photovoltaic panels needed as about $26\ \mathrm{m}^2$ / makes a quantitative comparison;

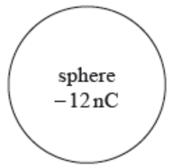
solar heating takes up less area/more efficient/faster;

further energy conversion needed, from electrical to thermal, with photovoltaic panels, involving further losses / *OWTTE*;

Allow ECF from (d)(i) with appropriate reverse argument.

Part 2 Electric fields

An isolated metal sphere is placed in a vacuum. The sphere has a negative charge of magnitude 12 nC.



3g. Using the diagram, draw the electric field pattern due to the charged sphere. *[2 marks]*

Markscheme

radial field with arrows and direction correct towards the sphere; *(both needed)*

no field inside sphere;

At least four lines of force to be shown on diagram.

Outside the sphere, the electric field strength is equivalent to that of a point negative charge of magnitude 12 nC placed at the centre of the sphere. The radius r of the sphere is 25 mm.

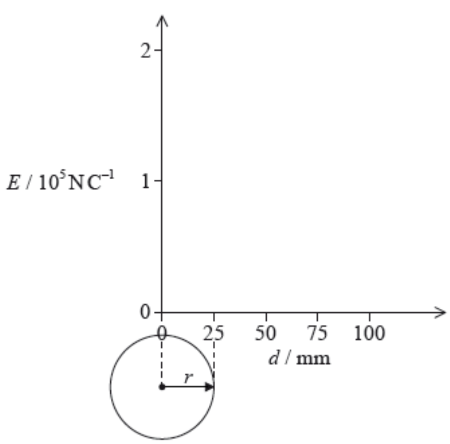
3h. Show that the magnitude of the electric field strength at the surface of the sphere is about $2 \times 10^5\ \mathrm{N\,C^{-1}}$. *[2 marks]*

Markscheme

use of $E = \frac{kQ}{r^2}$;

$1.73 \times 10^5\ \mathrm{N\,C^{-1}}$; *(must see answer to 2+ significant figures)*

3i. On the axes, draw a graph to show the variation of the electric field strength E with distance d from the centre of the sphere. *[2 marks]*



Markscheme

line drawn showing zero field strength inside sphere;

decreasing in inverse square-like way from a value of $2 \times 10^{5}\,\mathrm{N\,C^{-1}}$ ***or*** $1.7 \times 10^{5}\,\mathrm{N\,C^{-1}}$ at the surface, $d = 25\ \mathrm{mm}$;

An electron is initially at rest on the surface of the sphere.

3j. Calculate the initial acceleration of the electron. *[2 marks]*

Markscheme

force $= 1.7 \times 10^{5} \times 1.6 \times 10^{-19}$; *(allow use of* $2 \times 10^{5}\,\mathrm{NC^{-1}}$*)*

acceleration $= \left(\frac{2.7 \times 10^{-14}}{9.1 \times 10^{-31}} =\right)\ 3.0 \times 10^{16}\,\mathrm{m\,s^{-2}}$;

3k. Discuss the subsequent motion of the electron. *[2 marks]*

Markscheme

radially away from sphere / away from centre of sphere;

velocity increasing but at a decreasing rate / accelerating with decreasing acceleration;

because (electric) field (strength) is decreasing;

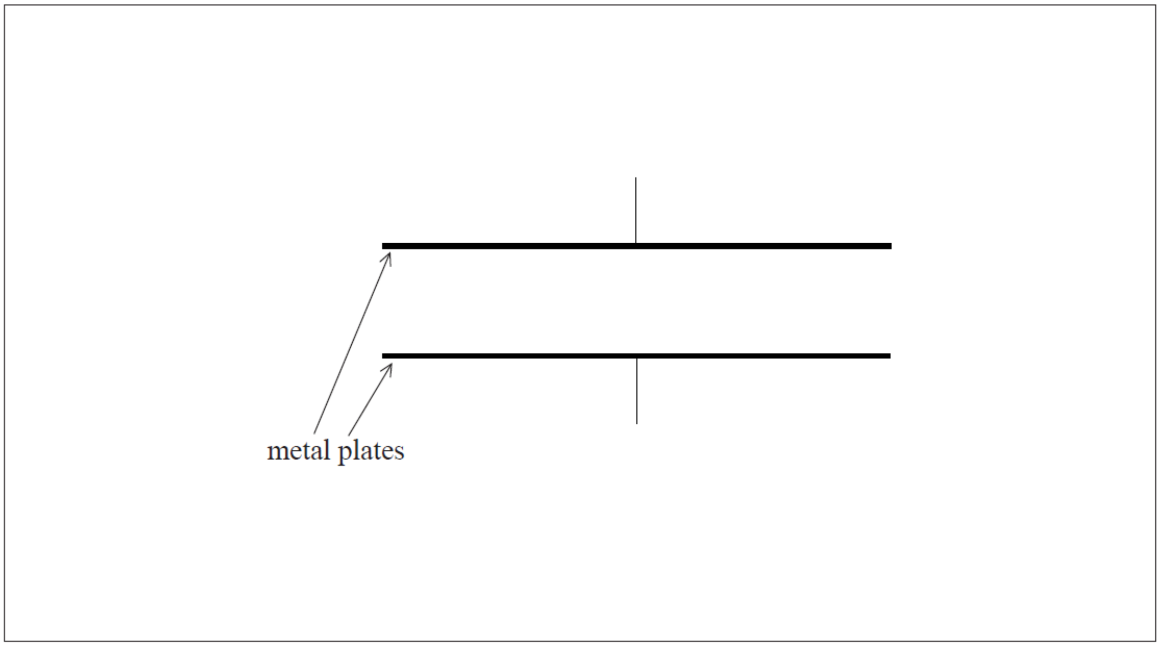
4a. Define *electric field strength*. *[2 marks]*

Markscheme

force per unit charge;

on a positive test charge / on a positive small charge;

4b. The diagram shows a pair of horizontal metal plates. Electrons can be deflected vertically using an electric field between the plates. *[5 marks]*



(i) Label, on the diagram, the polarity of the metal plates which would cause an electron positioned between the plates to accelerate upwards.

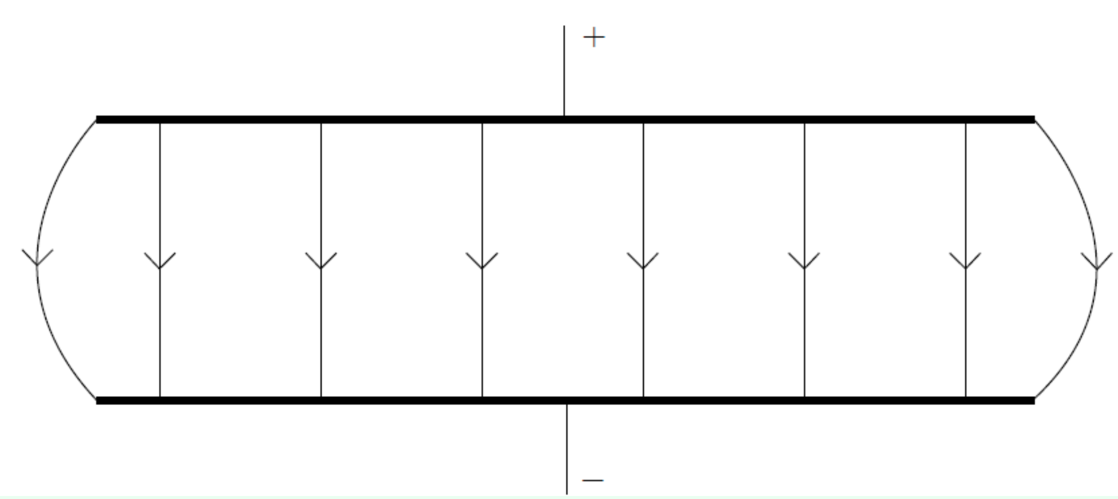
(ii) Draw the shape and direction of the electric field between the plates on the diagram.

(iii) Calculate the force on an electron between the plates when the electric field strength has a value of 2.5×10^3 NC^{-1}.

Markscheme

(i) top plate positive and bottom negative (or +/- and ground);

(ii)



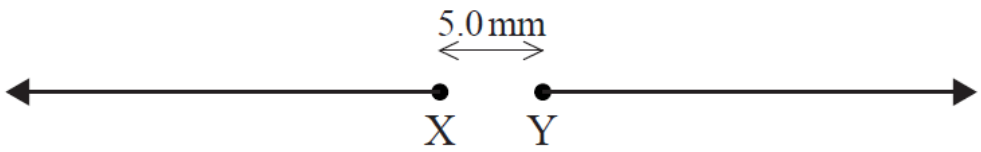
uniform (by eye) line spacing and edge effect, field lines touching both plates;

downward arrows (minimum of one and none upward);

(iii) $F=2.5\times10^3\times1.6\times10^{-19}$
4.0×10^{-16} (N);

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

4c. The diagram shows two isolated electrons, X and Y, initially at rest in a vacuum. The initial separation of the electrons is 5.0 mm. The electrons subsequently move apart in the directions shown. *[8 marks]*

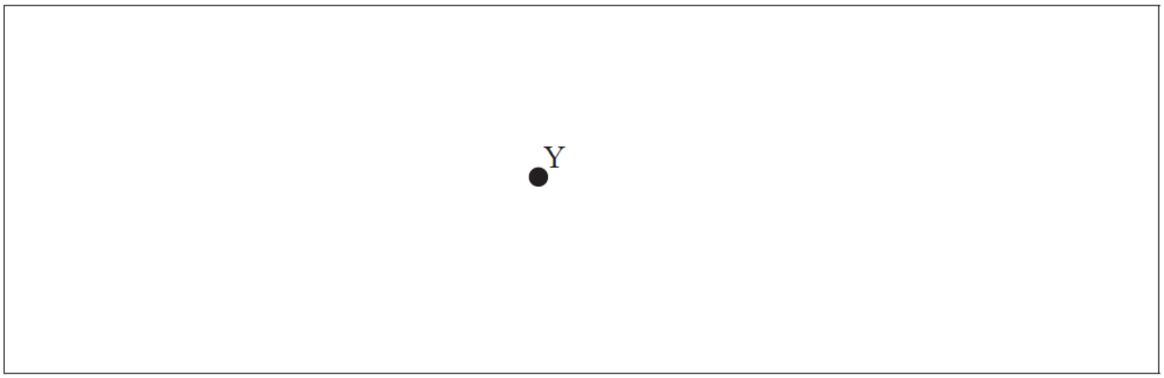


(i) Show that the initial electric force acting on each electron due to the other electron is approximately 9×10^{-24}N.

(ii) Calculate the initial acceleration of one electron due to the force in (c)(i).

(iii) Discuss the motion of one electron after it begins to move.

(iv) The diagram shows Y as seen from X, at one instant. Y is moving into the plane of the paper. For this instant, draw on the diagram the shape and direction of the magnetic field produced by Y.



Markscheme

(i) use of $F = \frac{(1.60\times10^{-19})^2}{4\pi\varepsilon_0(5.0\times10^{-3})^2}$ ***or*** $F = \frac{(1.60\times10^{-19})^2}{(5.0\times10^{-3})^2} \times 8.99 \times 10^9$;

9.2×10^{-24}(N);

(ii) 1.0×10^{7} (ms^{-2}) (9.9×10^{6} (ms^{-2}) if 9×10^{-24} (N) used);

(iii) electron will continue to accelerate;
speed increases with acceleration;
acceleration reduces with separation;
when outside the field no further acceleration/constant speed;
any reference to accelerated charge radiating and losing (kinetic) energy;

(iv) minimum of two concentric circles centred on Y;
anti-clockwise;

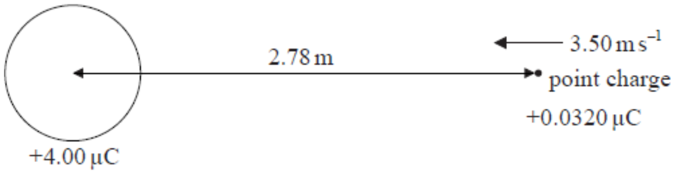
This question is about electric potential.

5a. Define *electric potential* at a point in an electric field. *[3 marks]*

Markscheme

the work done per unit charge;
when a small/test/point positive charge; *(charge sign is essential)*
is moved from infinity to the point;

5b. A positive point charge is moving towards a small, charged metal sphere along a radial path. *[6 marks]*



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 μC.

(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 1.29×10^{4} V.

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

Markscheme

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

(ii) $V = \frac{8.99\times10^{9}\times4.00\times10^{-6}}{2.78}$ ***or*** $1.2935 \times 10^{4}\mathrm{V}$; (*use of* $\frac{1}{4\pi\varepsilon_0}$ *gives 1.29378×10*^{4})
(≈1.29×10^{4}V)

(iii) difference in potential = (7.20×10^{4}-1.29×10^{4}=)5.91×10^{4};
required loss in kinetic energy/minimum kinetic energy to reach sphere = ($0.032\times10^{-6}\times5.91\times10^{4}$=)$1.89\times10^{-3}$J ;
available kinetic energy=(½×$1.20\times10^{-4}\times3.50^{2}$=)$7.35\times10^{-4}$J; 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}.

This question is in **two** parts. **Part 1** is about a lightning discharge. **Part 2** is about fuel for heating.

Part 1 Lightning discharge

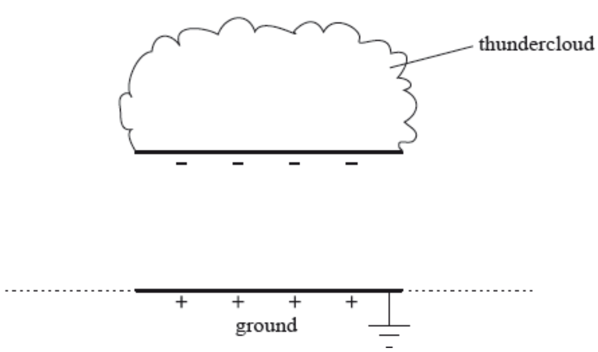
6a. Define *electric field strength*. *[2 marks]*

Markscheme

force acting per unit charge;

on positive test / point charge;

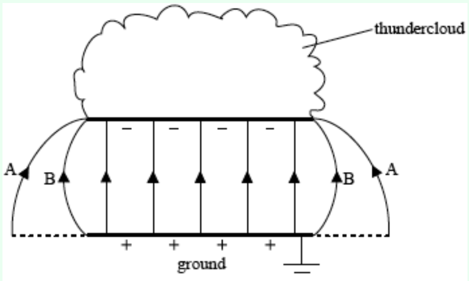
6b. A thundercloud can be modelled as a negatively charged plate that is parallel to the ground. *[3 marks]*



The magnitude of the charge on the plate increases due to processes in the atmosphere. Eventually a current discharges from the thundercloud to the ground.

On the diagram, draw the electric field pattern between the thundercloud base and the ground.

Markscheme



lines connecting plate and ground equally spaced in the central region of thundercloud and touching both plates; *(judge by eye)*

edge effects shown; *(accept either edge effect A or B shown on diagram)*

field direction correct;

The magnitude of the electric field strength E between two infinite charged parallel plates is given by the expression

$$E = \frac{\sigma}{\varepsilon_0}$$

where σ is the charge per unit area on one of the plates.

A thundercloud carries a charge of magnitude 35 C spread over its base. The area of the base is $1.2 \times 10^7\ \mathrm{m}^2$.

6c. (i) Determine the magnitude of the electric field between the base of the thundercloud and the ground. *[12 marks]*

(ii) State **two** assumptions made in (c)(i).

1.

2.

(iii) When the thundercloud discharges, the average discharge current is 1.8 kA. Estimate the discharge time.

(iv) The potential difference between the thundercloud and the ground before discharge is $2.5 \times 10^8\ \mathrm{V}$. Determine the energy released in the discharge.

Markscheme

(i) $\sigma = \left(\frac{35}{1.2 \times 10^7} =\right)\ 2.917 \times 10^{-6}\ (\mathrm{C\,m^{-2}})$;

$E = \frac{2.917 \times 10^{-6}}{8.85 \times 10^{-12}}$;

$= 3.3 \times 10^5\ \mathrm{N\,C^{-1}}$ ***or*** $\mathrm{V\,m^{-1}}$;

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

(ii) edge of thundercloud parallel to ground;

thundercloud and ground effectively of infinite length;

permittivity of air same as vacuum;

(iii) $t = \frac{Q}{I}$;

$t = \frac{35}{1800}$;

$= 20\ \mathrm{ms}$;

(iv) use of energy $= \mathrm{p.d.} \times \mathrm{charge}$;

$\mathrm{average\ p.d.} = 1.25 \times 10^8\ (\mathrm{V})$;

$\mathrm{energy\ released} = 1.25 \times 10^8 \times 35$;

$= 4.4 \times 10^9\ \mathrm{J}$;

*Award **[3 max]** for 8.8 GJ if average p.d. point omitted.*

Accept solution which uses average current $\left(from \frac{charge}{time}\right)$.

Allow ecf from (c)(ii).

Part 2 Fuel for heating

6d. Define the *energy density* of a fuel. *[1 mark]*

Markscheme

energy (released) per unit mass;

Accept per unit volume or per kg or per m^3.

Do not accept per unit density.

A room heater burns liquid fuel and the following data are available.

Density of liquid fuel	$= 8.0 \times 10^2\ \mathrm{kg\,m^{-3}}$
Energy produced by $1\ \mathrm{m^3}$ of liquid fuel	$= 2.7 \times 10^{10}\ \mathrm{J}$
Rate at which fuel is consumed	$= 0.13\ \mathrm{g\,s^{-1}}$
Latent heat of vaporization of the fuel	$= 290\ \mathrm{kJ\,kg^{-1}}$

6e. (i) Use the data to calculate the power output of the room heater, ignoring the power required to convert the liquid fuel into a gas. *[5 marks]*

(ii) Show why, in your calculation in (b)(i), the power required to convert the liquid fuel into a gas at its boiling point can be ignored.

Markscheme

(i) volume of fuel used per second $= \frac{\text{rate}}{\text{density}}\ \left(= 1.63 \times 10^{-7}\ (\mathrm{m^3})\right)$;

energy $= 2.7 \times 10^{10} \times 1.63 \times 10^{-7}$;

$= (4.3875 =)\ 4.4\ \mathrm{kW}$;

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

(ii) power required $= (2.9 \times 10^5 \times 0.13 \times 10^{-3} =)\ 38\ \mathrm{W}$;

small fraction/less than 1% of overall power output / *OWTTE*;

6f. State, in terms of molecular structure and their motion, **two** differences between a liquid and a gas. *[2 marks]*

1.

2.

Markscheme

sensible comment comparing molecular structure;

e.g. liquid molecular structure (more) ordered than that of a gas.

in gas molecules far apart/about 10 molecular spacings apart / in liquid molecules close/touching.

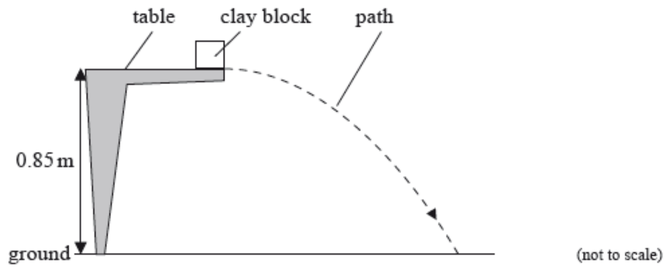
sensible comment comparing motion of molecules;

e.g. in liquid: molecules interchange places with neighbouring molecules / no long distance motion.
in gases: no long-range order / long distance motion.

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 ms^{-1} horizontally. The table surface is 0.85 m above the ground.



7a. (i) Ignoring air resistance, calculate the horizontal distance travelled by the clay block before it strikes the ground. *[7 marks]*

(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.

Markscheme

(i) use of kinematic equation to yield time;

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

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

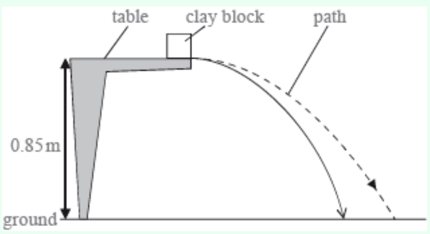
$= 1.8 \text{ m};$

Accept g = 10 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;



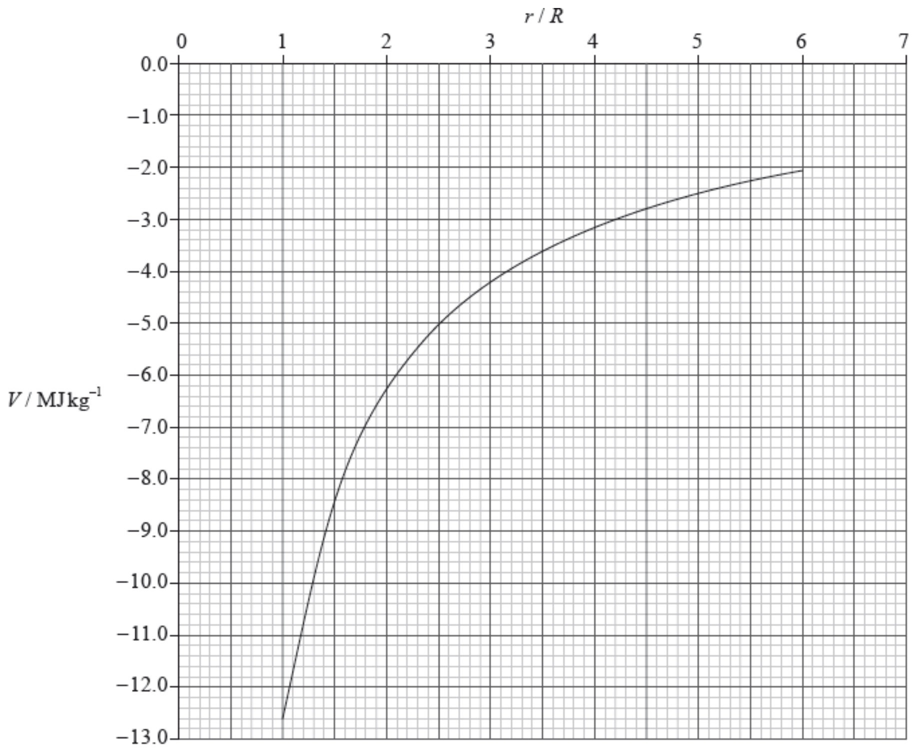
Part 2 Gravitational field of Mars

7b. Define *gravitational potential energy* of a mass at a point. *[1 mark]*

Markscheme

work done in moving mass from infinity to a point;

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



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

7c. (i) calculate the change in gravitational potential energy of the rocket at a distance 4 *R* from the centre of Mars. *[5 marks]*

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

Markscheme

(i) 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 $[12.6 \times 10^6 - 3.2 \times 10^6]$;

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

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

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

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

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