

SL Paper 2

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

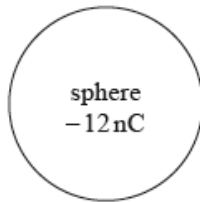
Part 1 Energy resources

A photovoltaic panel is made up of a collection (array) of photovoltaic cells. The panel has a total area of 1.3 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 W m^{-2} . The panel produces a power output of 210 W when the solar radiation is at its maximum intensity.

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 W m^{-2} .

Part 2 Electric fields

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



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.

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

- a. 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]
- b. With reference to the energy transformations and the operation of the devices, distinguish between a photovoltaic cell and a solar heating panel. [2]
- c.i. Determine the efficiency of the photovoltaic panel. [2]
- c.ii. State **two** reasons why the intensity of solar radiation at the location of the panel is not constant. [2]

2.

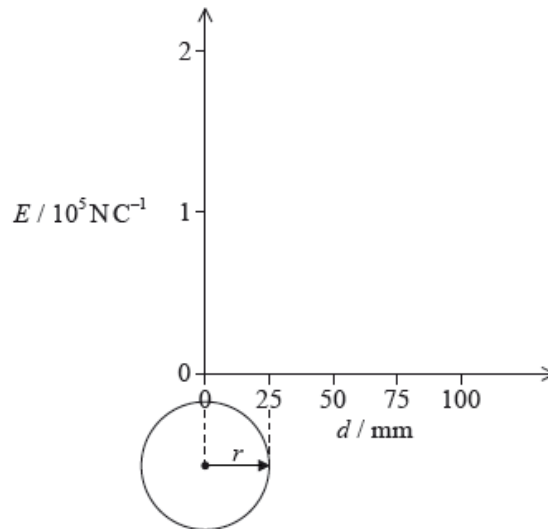
d.i. Calculate the minimum area of solar heating panel required to provide this power. [2]

d.ii. 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]

f. Using the diagram, draw the electric field pattern due to the charged sphere. [2]

g.i. Show that the magnitude of the electric field strength at the surface of the sphere is about $2 \times 10^5 \text{ N C}^{-1}$. [2]

g.ii. 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]



h.i. Calculate the initial acceleration of the electron. [2]

h.ii. Discuss the subsequent motion of the electron. [2]

Markscheme

a. *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.

b. 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)

c.i. (power available at roof) = 1.3×750 (= 975 W);

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

c.ii.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;

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

8 m^2 ;

d.ii.calculates area of photovoltaic panels needed as about 26 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.

f. 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.

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

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

g.ii.line drawn showing zero field strength inside sphere;

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

h.i.force = $1.7 \times 10^5 \times 1.6 \times 10^{-19}$; (allow use of $2 \times 10^5 \text{ NC}^{-1}$)

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

h.ii.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;

Examiners report

a. [N/A]

b. [N/A]

c.i. [N/A]

c.ii. [N/A]

d.i. [N/A]

d.ii. [N/A]

f. It was disappointing to see some candidates sketching very imprecise lines. Most fields were radial, but often with incorrect direction.

g.i. Another “show that” question which often elicited a jumble of numbers. Line of reasoning needs to be clear. Although there were many arithmetic/POT mistakes the field strength was often given correctly.

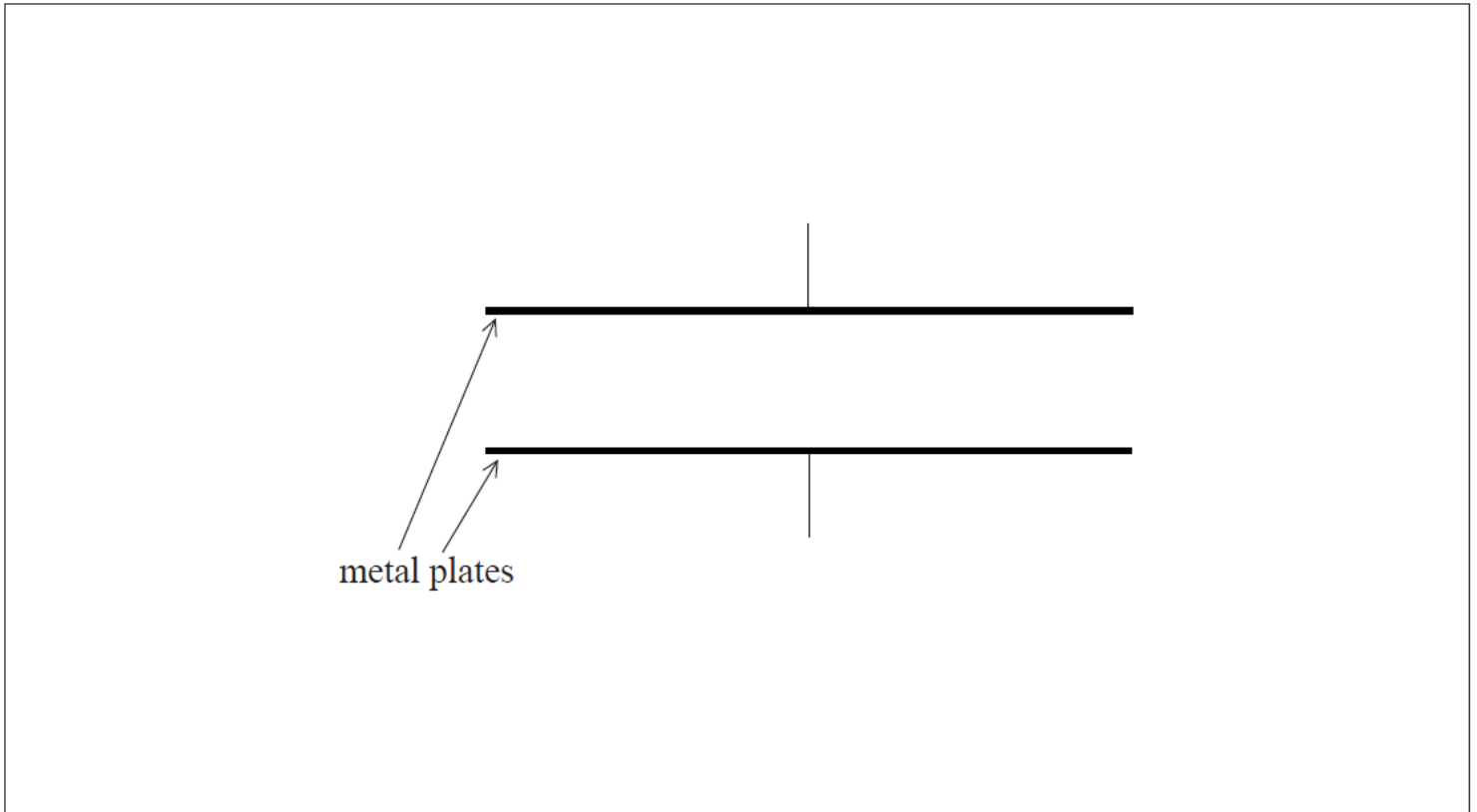
g.ii. It was extremely rare to find a zero line for the field inside of the sphere. The inverse square drop-off was often very approximate and did not always start from the surface of the sphere. The line should not touch the x -axis, but often did.

h.i. This was done correctly by a minority of candidates with many arithmetic and POT errors.

h.ii. Some candidates clearly do not fully understand the difference between velocity and acceleration. It was rare to find that direction of motion was given with precision. Some candidates said that the electron would stop as the field strength approached zero.

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

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

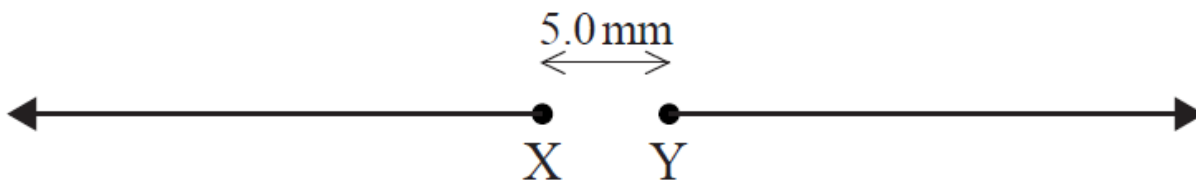


(i) Label, on the diagram, the polarity of the metal plates which would cause an electron positioned between the plates to accelerate upwards.

(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 $2.5 \times 10^3 \text{ NC}^{-1}$.

c. 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]

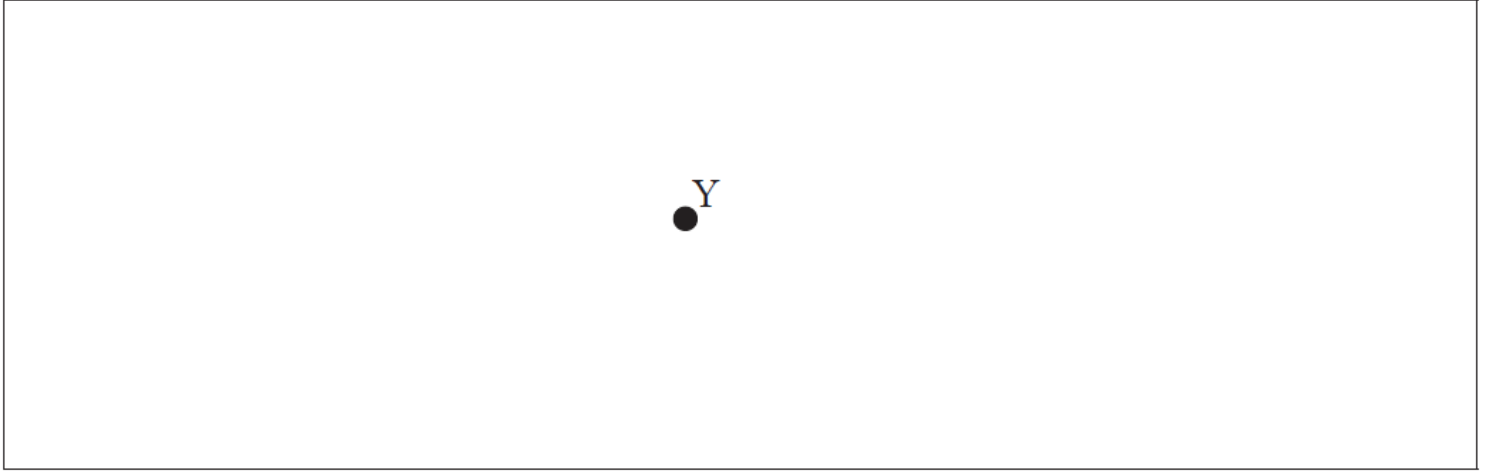


(i) Show that the initial electric force acting on each electron due to the other electron is approximately $9 \times 10^{-24} \text{ N}$.

(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.

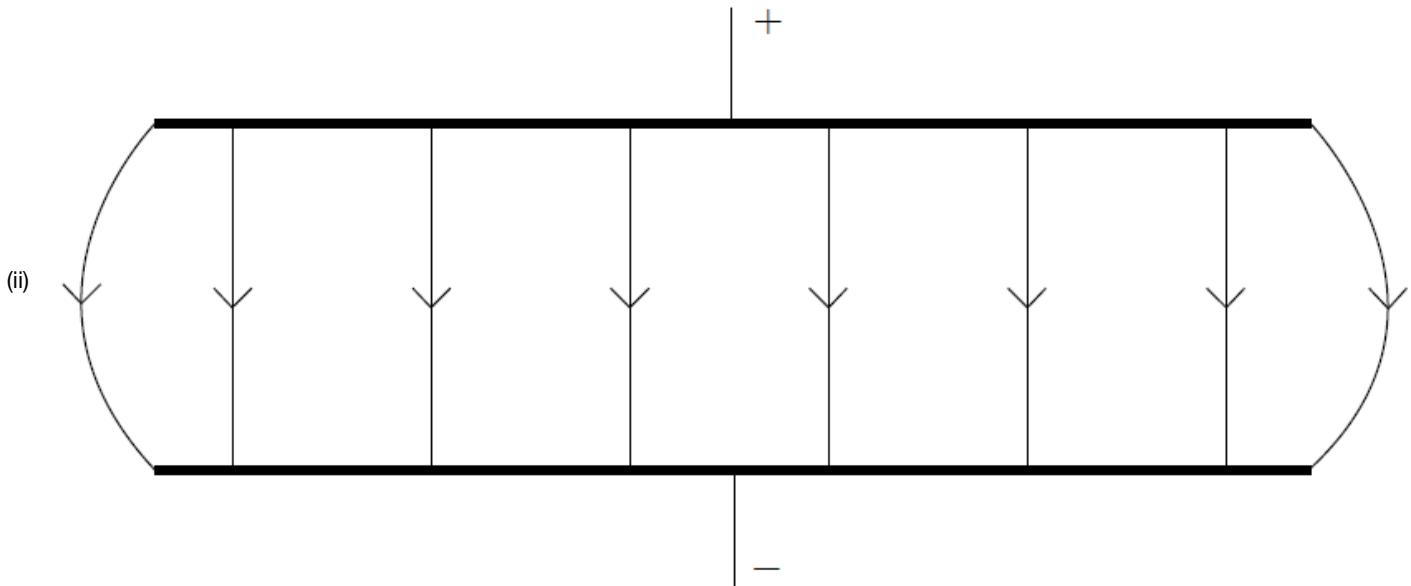


Markscheme

a. force per unit charge;

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

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



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

downward arrows (minimum of one and none upward);

(iii) $F = 2.5 \times 10^3 \times 1.6 \times 10^{-19}$
 4.0×10^{-16} (N);

Award [2] for a bald correct answer.

c. (i) use of $F = \frac{(1.60 \times 10^{-19})^2}{4\pi\epsilon_0(5.0 \times 10^{-3})^2}$ **or** $F = \frac{(1.60 \times 10^{-19})^2}{(5.0 \times 10^{-3})^2} \times 8.99 \times 10^9$;

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;

Examiners report

- a. (i) As this is worth two marks, candidates should see the signal that force per unit charge is unlikely to gain full marks; and so it proved. Although a mark was available for saying this there needed to be a reference to the charge being a positive test charge.
- b. (i) G2 comments that the term 'polarity' was confusing to candidates proved to be unfounded and nearly all candidates marked in a positive and negative terminal – although the actual polarity was often incorrect.
- (ii) With error carried forwards, the direction of the field was often correct but the drawing often was below an acceptable standard with line of force not bridging the plates, being very unevenly spaced and having no edge effect.
- (iii) This calculation was almost invariably very well done.
- c. (i) In another 'show that' question it was expected that candidates would use Coulombs law and the data value for the electronic charge to give a value of more than one digit; often this was not the case but otherwise this was generally well done
- (ii) Most candidates used their value for the force (or 9×10^{-24} N) and the mass of the electron on the data sheet to calculate a correct value for the acceleration.
- (iii) This was an unusual opportunity for candidates to use Newton's laws and many did say that the acceleration would decrease with distance. Too often they incorrectly believed that this meant that the electron would slow down – it continues to accelerate but at an ever decreasing rate.
- (iv) Clearly, this part represented a simplification of a complex situation but as set up was not beyond the skills of most of the candidates. The electron represents an instant in which a conventional current would leave the page and the field at this instant would be that of concentric circles with an anti-clockwise (counter-clockwise) direction. Many candidates did draw this but diagrams were too frequently hurriedly drawn and of a poor standard.

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

Part 1 Lightning discharge

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

$$E = \frac{\sigma}{\epsilon_0}$$

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 $1.2 \times 10^7 \text{ m}^2$.

Part 2 Fuel for heating

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

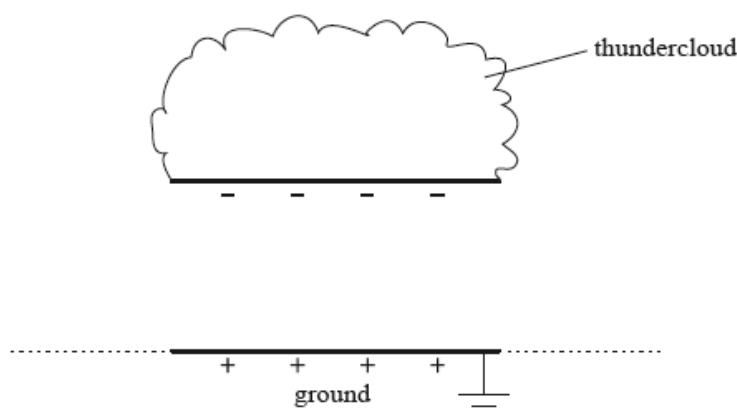
| | |
|---------------------------------------------------|---------------------------------------|
| Density of liquid fuel | $= 8.0 \times 10^2 \text{ kg m}^{-3}$ |
| Energy produced by 1 m^3 of liquid fuel | $= 2.7 \times 10^{10} \text{ J}$ |
| Rate at which fuel is consumed | $= 0.13 \text{ g s}^{-1}$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

Part 2.a. Define *electric field strength*.

[2]

Part 2.b. A thundercloud can be modelled as a negatively charged plate that is parallel to the ground.

[3]



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.

Part 2.c. Determine the magnitude of the electric field between the base of the thundercloud and the ground.

[12]

(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 $2.5 \times 10^8 \text{ V}$. Determine the energy released in the discharge.

Part 2.a. Define the *energy density* of a fuel.

[1]

Part 2.b. 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]

(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.

Part 2.c. State, in terms of molecular structure and their motion, **two** differences between a liquid and a gas.

[2]

1.

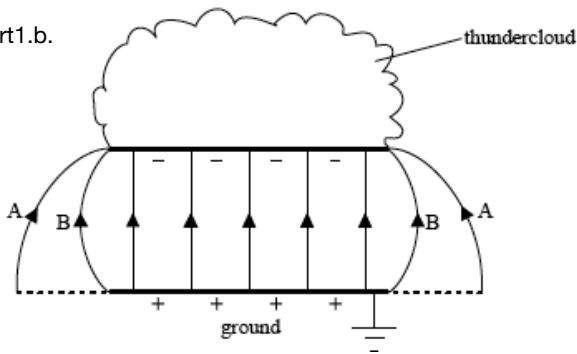
2.

Markscheme

Part 1.a. force acting per unit charge;

on positive test / point charge;

Part 1.b.



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;

Part 1.c. $\sigma = \left(\frac{35}{1.2 \times 10^7} = \right) 2.917 \times 10^{-6} \text{ (C m}^{-2}\text{);}$

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

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

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

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

$$= 20 \text{ m s};$$

(iv) use of energy = p.d. \times charge;

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

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

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

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

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

Allow ecf from (c)(ii).

Part 2.a. energy (released) per unit mass;

Accept per unit volume or per kg or per m³.

Do not accept per unit density.

Part 2.b. volume of fuel used per second = $\frac{\text{rate}}{\text{density}}$ ($= 1.63 \times 10^{-7} \text{ (m}^3\text{);}$)

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

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

Award [3] for bald correct answer.

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

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

Part 2
Part 2.c. 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.

Examiners report

Part 1
Part 1.a. Many omitted the reference to a test charge that is positive.

Part 1.b. Common errors were to draw the field lines in the wrong direction, to omit edge effects, and to fail to draw field lines that touch the plates.

Part 1.c. This part was well done.

(ii) Most candidates could only identify one assumption made in the calculation.

(iii) The estimation of discharge time was well done.

(iv) There was a general failure to recognise that the average pd during the discharge is half the maximum (starting) value and this lost a mark.

Part 2
Part 2.a. A handful of candidates defined energy density as energy converted per unit density, but most gave energy released per unit mass with a minority quoting energy released per unit volume.

Part 2.b. Again, this was done well by the majority with the usual smattering of significant figure penalties and mistakes in handling powers of ten.

(ii) Arguments were weak and poorly supported by calculation.

Part 2.c. Candidates found great difficulty in stating the differences between liquids and gases. They often focused on either molecular structure or motion, but not both as required in the question.

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 [7]

$2.0 \times 10^{-10} \text{ m}$.

(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 $2.0 \times 10^{-10} \text{ m}$ from the proton.

(iii) The magnitude of the gravitational field due to the proton at a distance of $2.0 \times 10^{-10} \text{ m}$ from the proton is H .

Show that the ratio $\frac{H}{E}$ is of the order $10^{-28} \text{ C kg}^{-1}$.

(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 5.0Ω . [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 5.0Ω 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) $F = \left(k \frac{q_1 q_2}{r^2} = \right) \frac{9 \times 10^9 \times [1.6 \times 10^{-19}]^2}{4 \times 10^{-20}}$;
 $= 5.8 \times 10^{-9} \text{ (N)}$;

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

(ii) $\left(\frac{(b)(i)}{1.6 \times 10^{-19}} \right)$ or $3.6 \times 10^{10} \text{ (NC}^{-1})$ 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) $H = \left(G \frac{m}{r^2} = \right) \frac{6.67 \times 10^{-11} \times 1.673 \times 10^{-27}}{4 \times 10^{-20}} = 2.8 \times 10^{-18} \text{ (Nkg}^{-1})$;

$\frac{H}{E} = \frac{2.8 \times 10^{-18}}{3.6 \times 10^{10}}$ or $7.8 \times 10^{-29} \text{ (Ckg}^{-1})$;

$(\approx 10^{28} \text{ Ckg}^{-1})$

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 = $\frac{5.1 \times 10^{-19}}{1.6 \times 10^{-19}}$ or 3.19(V);

(≈ 3.2 V)

(iii) pd across 5.0Ω resistor = $\left(\frac{4.0 \times 10^{-19}}{1.6 \times 10^{-19}} = \right) 2.5 \text{ (V)}$;

pd across $r = (3.2 - 2.5) = 0.70 \text{ (V)}$;

and

either

current in circuit = $\left(\frac{2.5}{5.0} = \right) 0.5 \text{ (A)}$;

resistance of $r = \left(\frac{0.70}{0.50} = \right) 1.4 \text{ (}\Omega\text{)}$;

or

resistance of $r = \frac{0.70}{2.5} \times 5.0$;

$= 1.4 \text{ (}\Omega\text{)}$;

or

$$3.2=0.5(R+r);$$

resistance of $r=1.4(\Omega)$;

Award **[4]** for alternative working leading to correct answer.

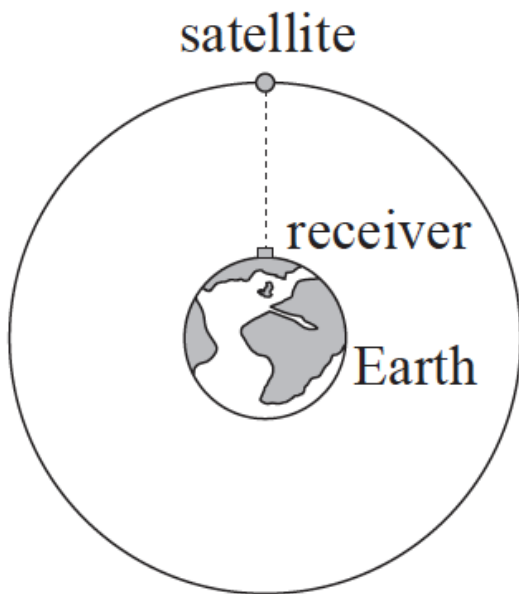
Award **[4]** for a bald correct answer.

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.
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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]



(not to scale)

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) $3 \times 10^8 \times 67 \times 10^{-3}$;
 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** $\frac{6.7 \times 10^{-11} \times 6.0 \times 10^{24}}{[2.6 \times 10^7]^2}$;

0.57 N kg^{-1} ; (allow ms^{-2})

(iii) $v = \sqrt{0.57 \times (2.0 \times 10^7 + 6.4 \times 10^6)}$ by equating $\frac{v^2}{r}$ and g ;
 3900 ms^{-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]
-

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

Part 1 Momentum

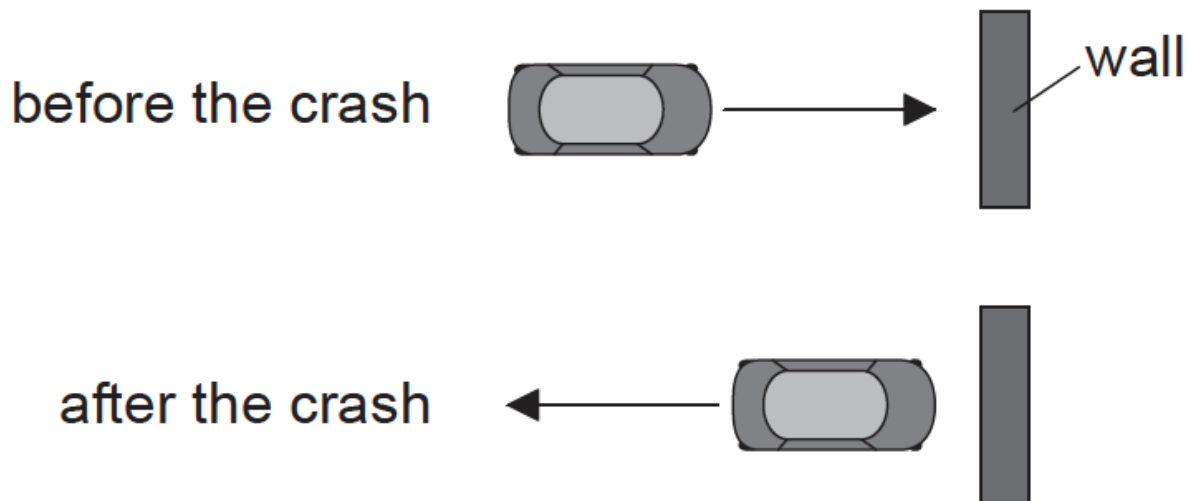
Part 2 Electric point charges

a. State the law of conservation of linear momentum.

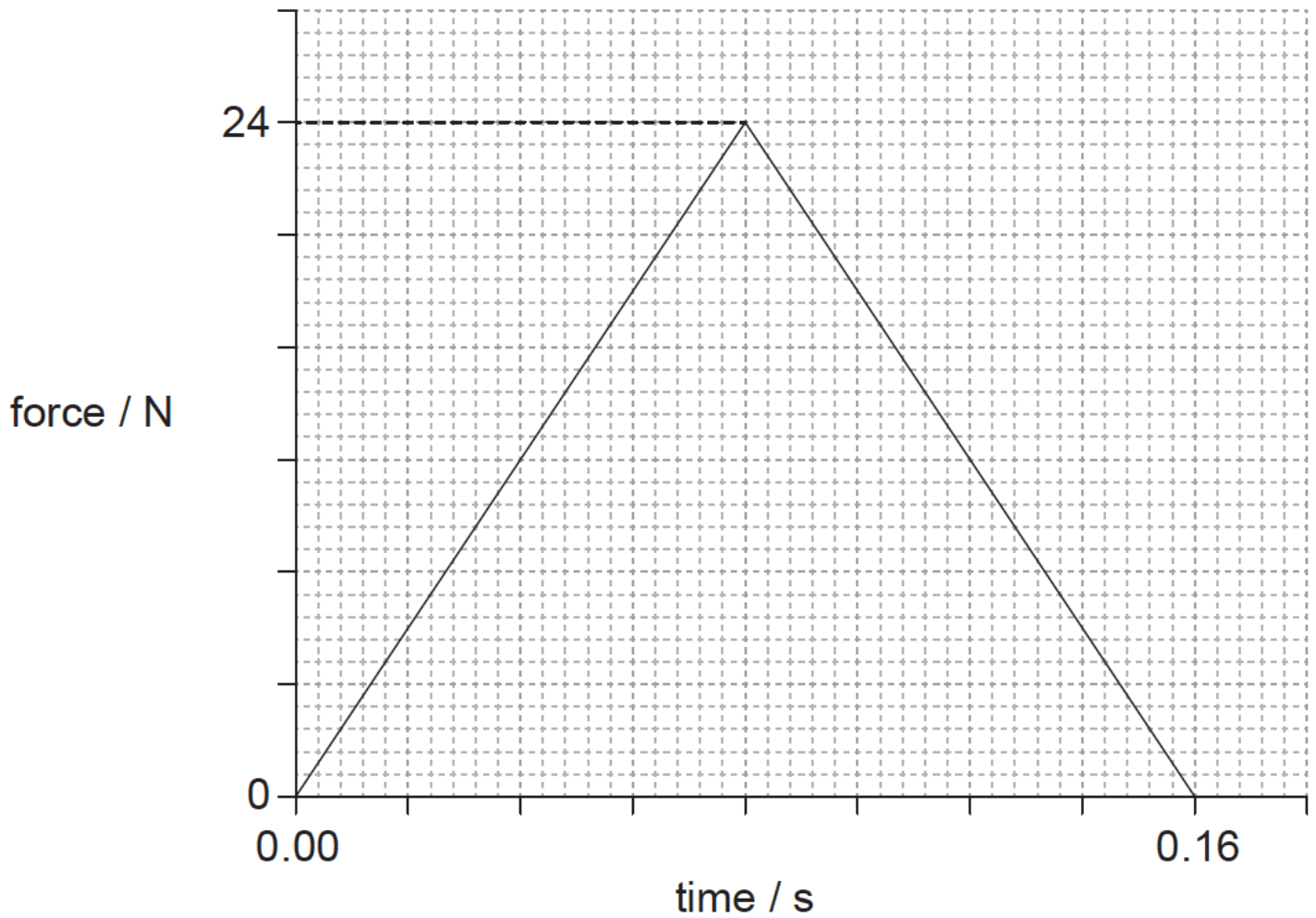
[2]

b. A toy car crashes into a wall and rebounds at right angles to the wall, as shown in the plan view.

[9]



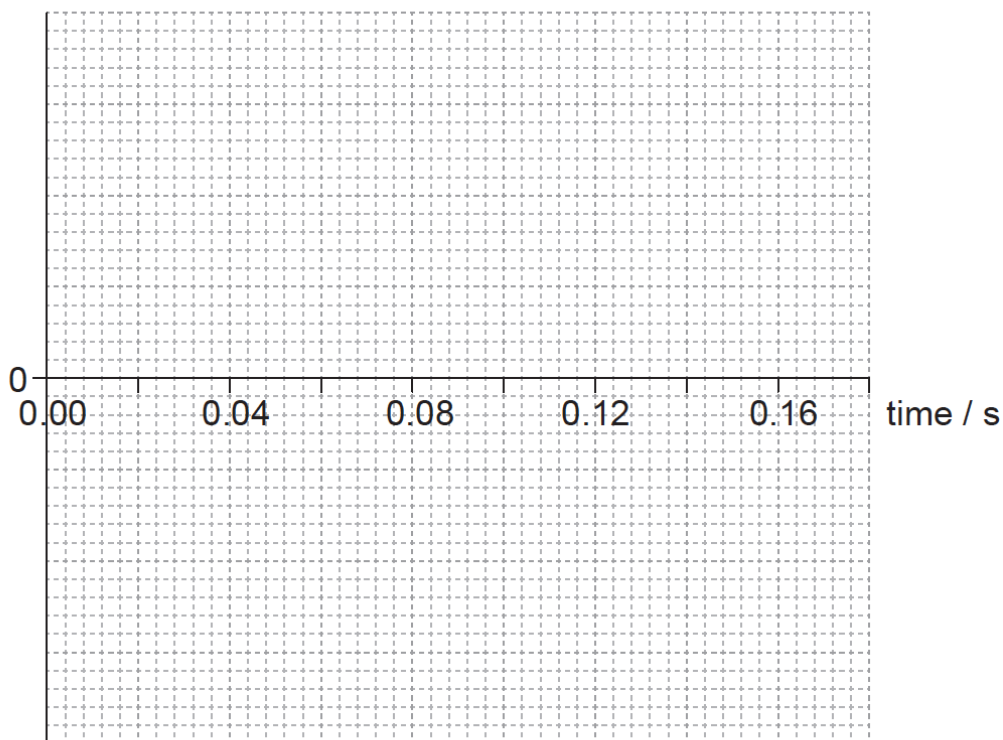
The graph shows the variation with time of the force acting on the car due to the wall during the collision.



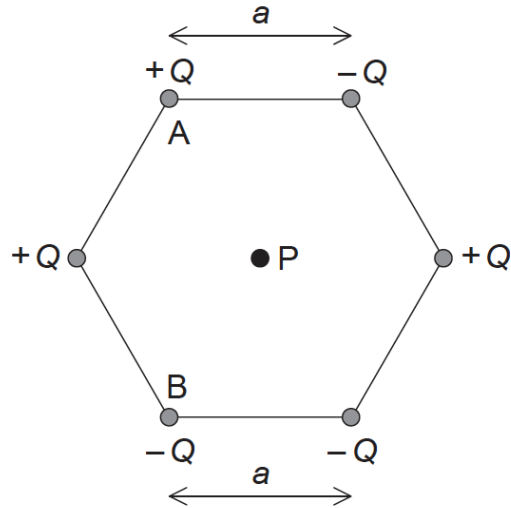
The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

- (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.

momentum



- c. 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]
- d. Define *electric field strength* at a point in an electric field. [2]
- e. 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]



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 $3.2 \mu\text{C}$ 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

a. total momentum does not change/is constant; } (do not allow "momentum is conserved")

provided external force is zero / no external forces / isolated system;

b. (i) clear attempt to calculate area under graph;

initial momentum is half change in momentum;

$$\left(\frac{1}{2} \times \frac{1}{2} \times 24 \times 0.16\right) = 0.96 \text{ (kgms}^{-1}\text{)}$$

Award **[2 max]** for calculation of total change (1.92kg ms^{-1})

$$\text{(ii) initial speed} = \left(\frac{0.96}{0.8}\right) = 1.2\text{ms}^{-1};$$

$$a = \frac{1.2 - (-1.2)}{0.16} \text{ or } a = \frac{-1.2 - 1.2}{0.16};$$

$-15(\text{ms}^{-2})$; (must see negative sign or a comment that this is a deceleration)

or

average force = 12 N;

uses $F = 0.8 \times a$;

$-15(\text{ms}^{-2})$; (must see negative sign or a comment that this is a deceleration)

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

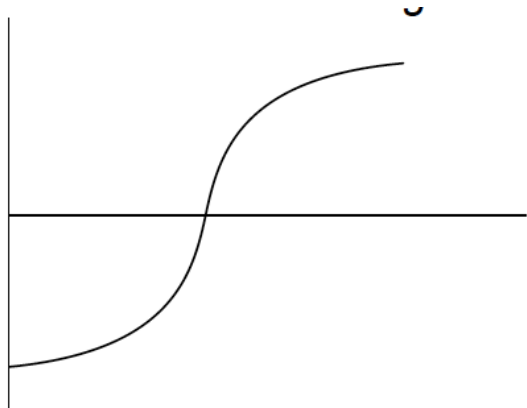
Other solution methods involving different kinematic equations are possible.

(iii) goes through $t=0.08\text{s}$ **and** from negative momentum to positive / positive momentum to negative;

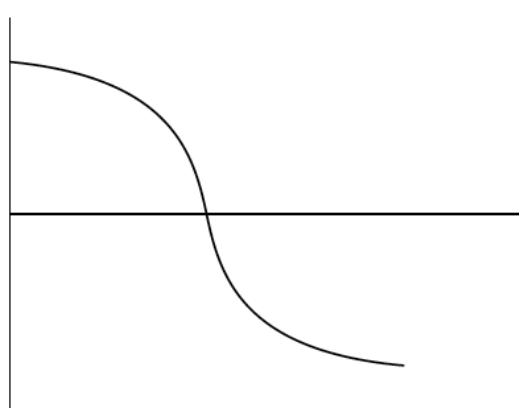
constant sign of gradient throughout;

curve as shown;

Award marks for diagram as shown.



or



c. impulse is the same/similar in both cases / momentum change is same;

impulse is force \times 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);

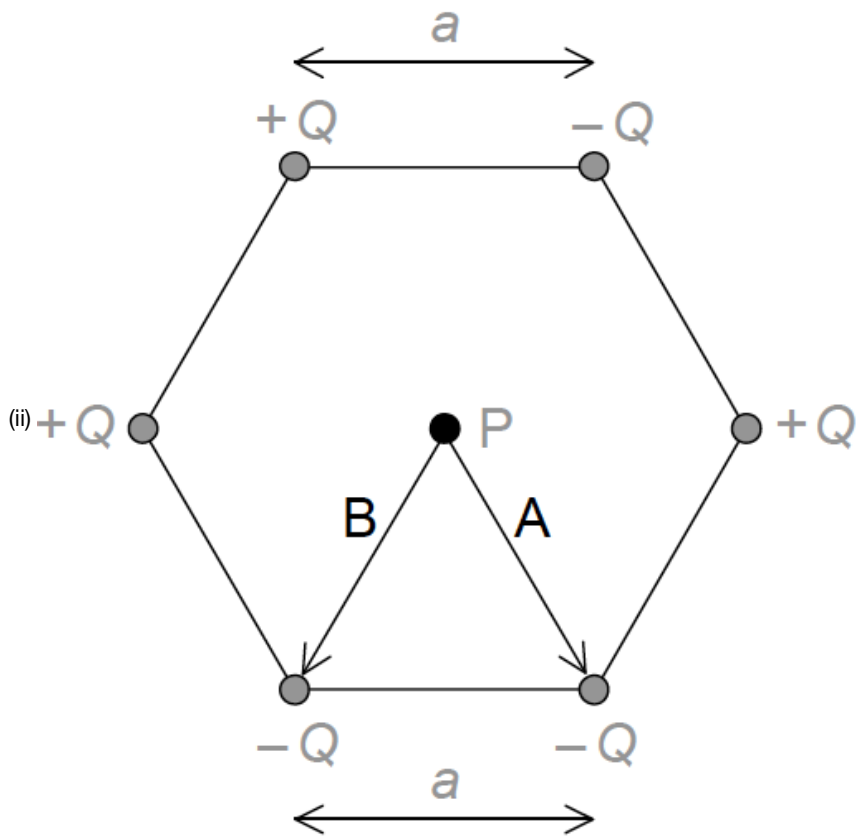
d. electric force per unit charge;

acting on a small/point positive (test) charge;

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

states explicitly $q=1$;

states $r=a$;



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

2.6×10^6 (N C⁻¹);

towards bottom right charge; (allow clear arrow on diagram showing direction)

Examiners report

- [N/A]
- [N/A]
- [N/A]
- [N/A]
- [N/A]