IB · DP · Physics

3 hours · 15 questions

Structured Questions

5.1 Electric Fields

5.1.1 Charge & Current / 5.1.2 Drift Speed / 5.1.3 Potential Difference & DC / 5.1.4 Electric Fields / 5.1.5 Coulomb's Law

Easy (5 questions)	/61
Medium (5 questions)	/54
Hard (5 questions)	/41
Total Marks	**/156**

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Easy Questions

1 (a) Define the coulomb.

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(2 marks)

(b) A charge of 60×10^{-6} C flows through a given section of a conductor in 140×10^{-3} s. Calculate the electric current, stating the final answer in mA.

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(2 marks)

(c) Use words from the list below to complete the description of the movement of charge carriers in a conductor.

average current	**delocalised**	**electric force**
electric field	**randomly**	**drift**

The charge carriers in a metal conductor are _____ electrons.

Normally the electrons move _____ in all directions, but if a potential difference is applied between two points on the conductor, then an _____ is created.

This causes an _____ to act on on the charge carriers, causing them to _____ along the conductor in a resultant direction.

Therefore we can say that a steady _____ flows through the conductor.

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(4 marks)

(d) One equation for electric current states that

$$I = nAvq$$

Define the four terms used here to calculate current.

(3 marks)

2 (a) Define electrical current.

(2 marks)

(b) Define potential difference.

(i) State the definition in words.

[1]

(ii) State the equation, defining all terms.

[2]

(3 marks)

(c) A current of 3.0 A flows in a copper wire of cross-sectional area 1.5×10^{-6} m^2. Assume that the charge carriers are delocalised electrons with a charge of -1.6×10^{-19} C, moving with an average drift velocity of 1.0×10^{-4} ms^{-1}.

Calculate the charge density of the wire.

(3 marks)

(d) When working with the very small energies needed to move electrons, the unit electronvolt (eV) is often used rather than the joule (J).

Convert 4.6 MeV into joules.

(3 marks)

3 (a) For the point charges shown sketch a diagram showing the electric field lines.

(4 marks)

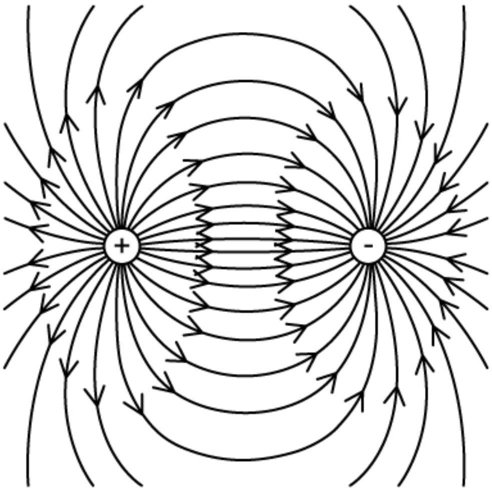
(b) Indicate, by drawing a circle around an area on your diagram from part (a) where the field lines are more dense and explain why they look like this.

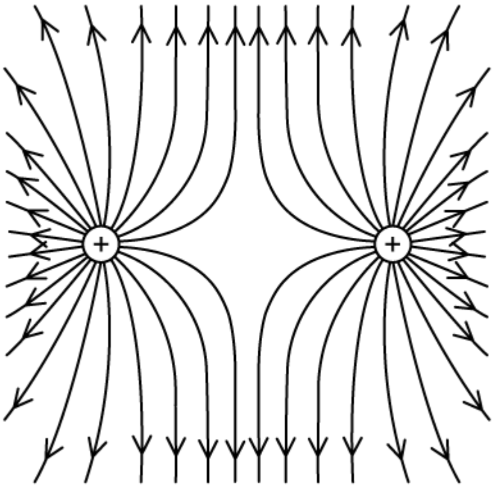
(2 marks)

(c) Sketch a diagram showing the electric field lines for the point charges shown.

(3 marks)

(d) Identify the differences between the central area of both the diagrams below.





(2 marks)

4 (a) The following descriptions apply to either direct current (dc), alternating current (ac) or both.

For each row in the table, identify which of the options (ac, dc or both) best fits the description.

Description	ac, dc, or both
energy is carried by electrons moving in wires	
supplied by cells or batteries	
typically used in high voltage devices	
typically used in low voltage devices	
charge carriers have a drift velocity	
current flows from positive to negative	
current changes direction with high frequency	
a potential difference across a conductor causes current to flow	

(4 marks)

(b) Distinguish between the following pairs of terms

(i) Conventional current and electron flow [2]

(ii) Delocalised electrons and charge carriers [2]

(4 marks)

(c) Complete the sentence stating Coulomb's Law by using words from the text box.

directly	**electrostatic force**	**inversely**
sum	**product**	**separation**

The attractive or repulsive ______ ______ between two point charges is ______ proportional to the ______ of the charges and ______ proportional to the square of their ______ .

(3 marks)

(d) Coulomb's Law is represented by the equation

$$F = k\frac{q_1 q_2}{r^2}$$

Define each of the terms used in this equation and state the units.

(4 marks)

5 (a) When calculating the electrostatic force between two charged bodies, a constant *k* called Coulomb's constant is taken into account.

State the relationship, name and the factor that affects the magnitude of k.

(3 marks)

(b) An electron experiences a force of 0.3 N in an electric field.

Calculate the field strength of the field.

(3 marks)

(c) In a vacuum, an alpha particle approaches an aluminium nucleus.

State:

- The charge on the nucleus
- The charge on the alpha particle
- The nature of the force between them

(3 marks)

(d) Calculate the magnitude of the electrostatic force acting on each of the charges from part (c).

- $q_1 = 3.2 \times 10^{-19}$ C
- $q_2 = 2.08 \times 10^{-18}$ C
- $r = 2.0 \times 10^{-3}$ m
- $k = 8.99 \times 10^{9}$ N m^2 C^{-2}

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(4 marks)

Medium Questions

1 (a) Electric fields exist in the space around charged particles. The strength of an electric field depends on the position occupied within that space.

Define what is meant by the strength of an electric field.

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(2 marks)

(b) An electron e^- and a positron e^+ occupy two positions in space.

Sketch on the image the resultant electric field in the region between the electron and the positron.

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....

(2 marks)

(c) The distance between the electron and the positron is 150 cm.

(i) Calculate the magnitude of the electrostatic force between the electron and the positron.

[2]

(ii) State the direction of the electrostatic force on the electron.

[1]

....

....

(3 marks)

(d) A positive test charge is placed exactly midway between the electron and the positron.

Outline the subsequent motion of the positive test charge.

(2 marks)

2 (a) An integrated circuit uses thin strips of gold and silicon as connectors and resistors respectively.

A strip of gold, of cross-sectional area 2.0×10^{-6} m^2 has a charge carrier density of 7.0×10^{28} m^{-3} and a current of 8.5 mA.

Calculate the charge carrier drift speed for gold.

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(2 marks)

(b) An approximate value for the charge carrier drift speed for a sample of silicon of the same dimensions, carrying the same current, would be 0.20 m s^{-1}.

Compare this value with the one you obtained in part (a) for gold and explain the reason for the difference between the two drift speeds.

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(2 marks)

(c) In another integrated circuit a current of 2.0 A flows through a resistor for 90 minutes.

Determine the number of electrons that pass a point in the resistor this time.

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(3 marks)

(d) The current in part (c) flows across a potential difference of 12 V.

Using your answer to part (c), calculate the total energy transferred in the integrated circuit.

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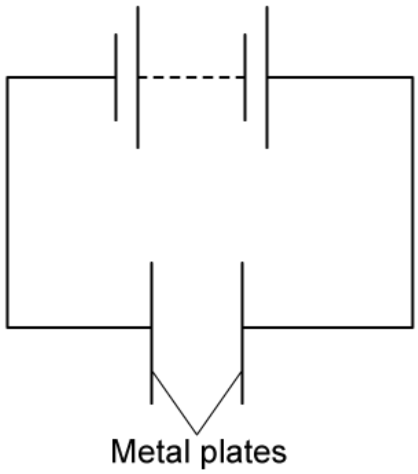
(2 marks)

3 (a) A parallel-plate capacitor is an electrical component that stores electric charge.

It is set up by connecting two metal plates to a power supply.



Label:

(i) the positively charged metal plate with the letter **A**

[1]

(ii) the negatively charged metal plate with the letter **B**

[1]

(iii) the electric field lines between the plates.

[2]

(4 marks)

(b) State, for each of the scenarios below, whether the electric field strength between the metal plates increases, decreases, or stays constant:

(i) a positive test charge moving from one plate to the other.

[1]

(ii) a positive test charge moving between the plates along a line parallel to each other.

[1]

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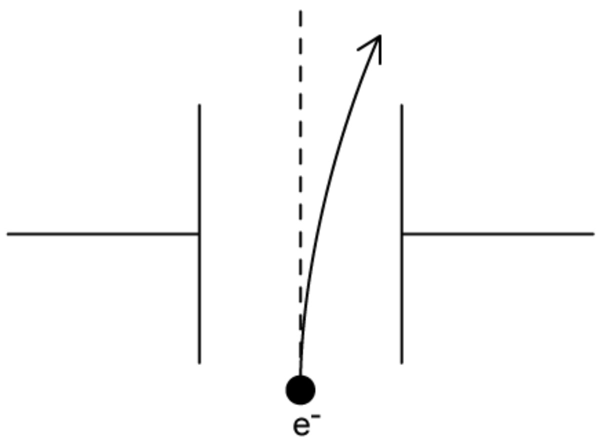
(2 marks)

(c) A free electron finds itself incident in the space between the metal plates and is deflected as it moves between them.



The magnitude of the electric field strength is 200 N C^{-1}. Calculate the magnitude of the electron's acceleration in the space between the plates.

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(3 marks)

(d) Explain the shape of the path shown in part (c).

(3 marks)

4 (a) State Coulomb's law in words.

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(2 marks)

(b) In simple models of the hydrogen atom, an electron is in a circular orbit around the proton.

The magnitude of the force between the proton and the electron is 5.8×10^{-9} N.

Calculate:

(i) the orbital radius of the electron.

[2]

(ii) the magnitude of the electric field strength due to the proton at any point in the electron's orbit.

[2]

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(4 marks)

(c) The gravitational field strength *g* due to the proton at any point in the electron's orbit is given by the equation:

$$g = G\frac{m_p}{r^2}$$

where m_p is the proton mass, *r* is the orbital radius and *G* is the gravitational constant.

Show that the ratio of the gravitational field strength to the electric field strength due to the proton at any point in the electron's orbit is of the order 10^{-28}.

(4 marks)

(d) Ionisation is the process of removing an outer shell electron from an atom, so it is transferred from its orbit to a point where the potential is zero.

The potential difference between the electron's orbit in a hydrogen atom and this point is about 3.4 V.

Calculate the gain in potential energy of an orbiting electron in a hydrogen atom if it is ionised.

(2 marks)

5 (a) When a copper wire is exposed to an electric field, a current is detected in it.

Explain, with reference to charge carriers, why there is a current detected in the wire.

(2 marks)

(b) Calculate the drift speed of the charge carriers in the copper wire if a potential difference of 4.0 V is applied to it.

The following data are available for the wire:

density of free electrons = 8.5×10^{28} m^{-3}

resistance = 25 Ω

diameter = 0.8 mm

(4 marks)

(c) A defect is discovered in the wire. This causes the cross-sectional area to increase by 42% at a point **X** along its length.

Calculate the new drift speed of charge carriers in the copper wire at point **X** if the same potential difference is applied as that in part (b).

Explain how you arrived at your answer.

(3 marks)

(d) When the applied potential difference is removed, the current in the copper wire falls to zero. However, individual charge carriers move within the wire at thermal speeds which are often orders of magnitude above drift speeds.

(i) Suggest a reason why charge carriers can attain such large speeds with no potential difference applied.

[1]

(ii) Explain why the current remains zero.

[2]

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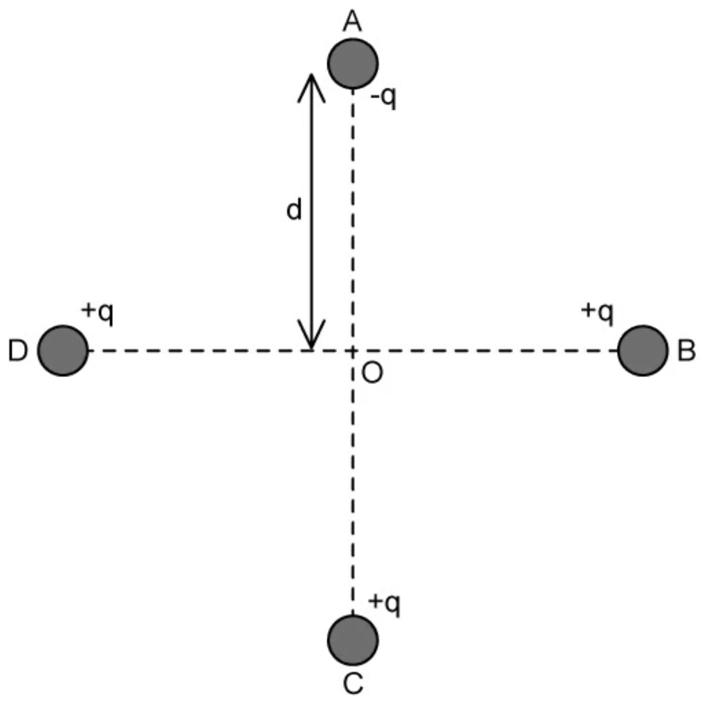
(3 marks)

Hard Questions

1 (a) Four point charges A, B, C and D are each placed at a distance *d* from O as shown. Charges B, C and D each have a charge of $+q$ and A has a charge $-q$.



(i) Derive an expression for the magnitude of the resultant electric field strength at O. [1]

(ii) Determine the direction of the resultant electric field at O. [1]

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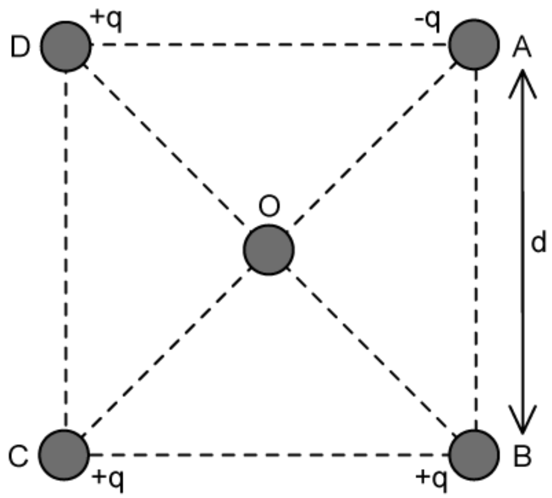
(2 marks)

(b) The arrangement of the charges is changed to the grid shown. Each charge is now the corner of a square of side *d*.



Calculate the magnitude of the resultant electric field strength at point O.

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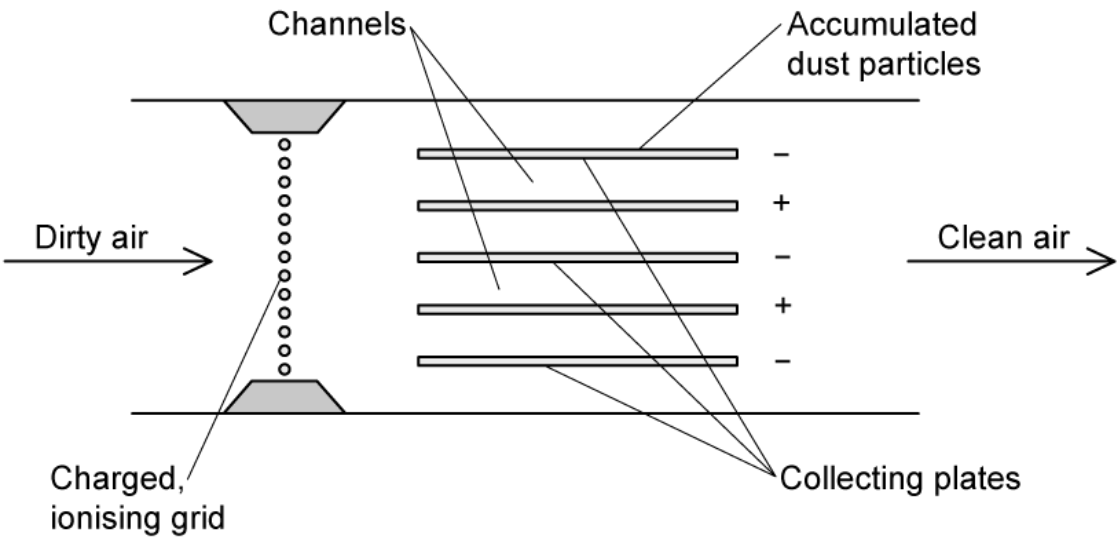
(2 marks)

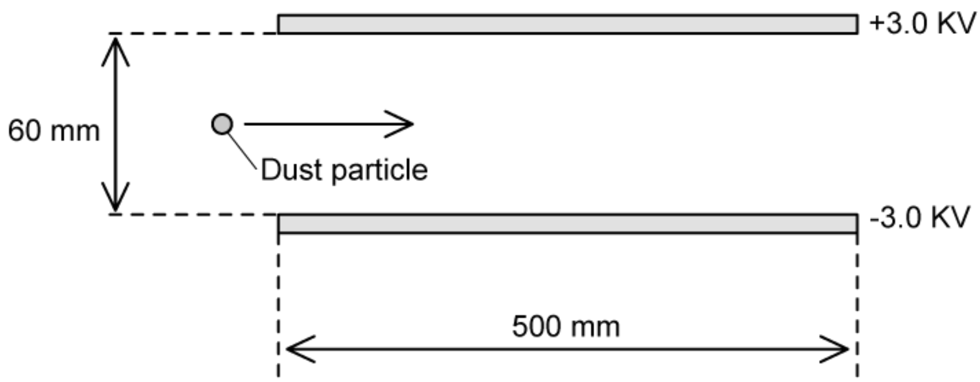
2 (a) The diagram shows an air filter which uses charged collecting plates to remove dust from the air of a workshop.

The air intake passes through a charged, ionising grid which attracts dust particles, cleaning the air which is then returned back into the workshop.



A dust particle of mass 6.7×10^{-15} kg enters the region between the collecting plates travelling horizontally with an initial velocity of 11 m s^{-1}. The particle carries a charge of 2.6×10^{-18} C.

Assume that the dust particles move horizontally between the plates.



Determine the electrostatic force acting on the particle.

(3 marks)

(b) Some particles are not caught by the air filter, but pass straight through. Others are caught by the filter. The particles are identical in mass and charge, and they all travel parallel to the plane of the plates. The plates are initially completely clean. Assume the particles are evenly vertically distributed.

Deduce the percentage of dust particles which will be 'trapped' by the negatively charged plate. Ignore the effect of gravity.

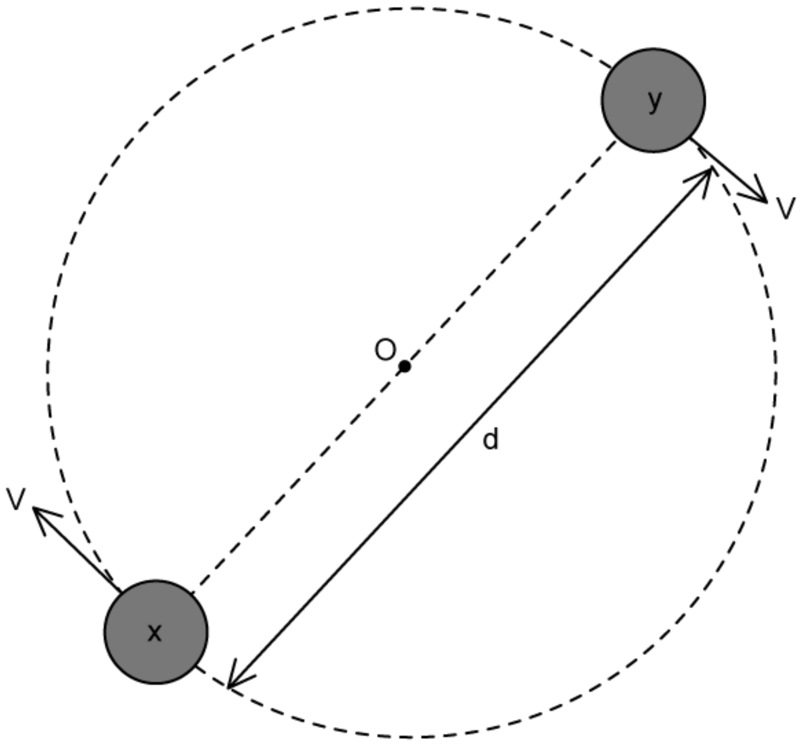
(4 marks)

(c) As the air filter operates, there is a build up of particles on the negative plates. The gap between the plates therefore becomes narrower, by up to 10% of its initial height.

Discuss whether this narrowing makes the filter more or less effective at removing dust particles.

(3 marks)

3 (a) Two charged objects X and Y are made to circle a point O. X and Y are at a distance, d = 1.8×10^{-8} m and they have equal masses, where $m = 1.7 \times 10^{-9}$ kg. The objects carry an equal but opposite charge, where the magnitude $q = 3.2 \times 10^{-19}$ C.



For this motion calculate

(i) The acceleration of X and Y.

[3]

(ii) Hence, the time to make one complete orbit.

[2]

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(5 marks)

(b) The particles **X** and **Y** in part (a) are replaced with a gold nucleus $^{197}_{79}Au$, and an alpha particle.

Calculate the field strength at the surface of(i)A gold nucleus with radius 7.0 fm.

[1]

(ii) An alpha particle with radius 1.7 fm.

[1]

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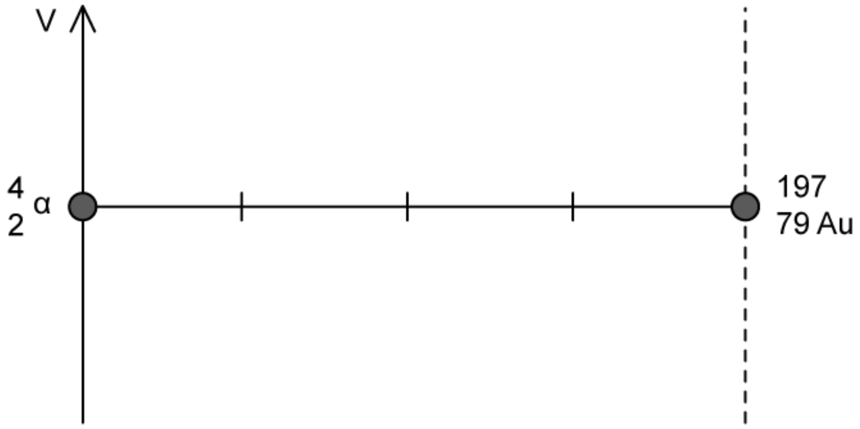
(2 marks)

(c) The alpha particle and gold nucleus are at rest at a distance where the electric fields only just interact with each other.

For the axes shown sketch the graph of electric potential *V* against distance along the straight line between the charges.



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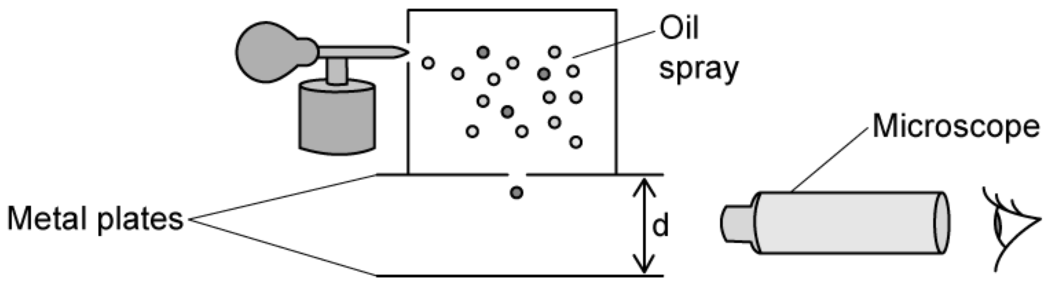
(3 marks)

4 (a) An experiment to determine the charge on an electron is shown.

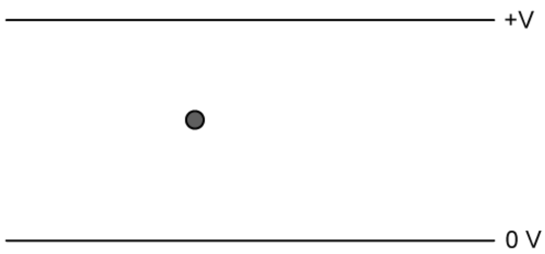


Negatively charged oil drops are sprayed into a region above two parallel metal plates which are separated by a distance, *d*. The oil drops enter the region between the plates.

A potential difference *V* is applied which causes an electric field to be set up between the plates.

(i) Using the sketch below, which shows one oil drop falling between the plates, show the electric field between the plates.

[1]



(ii) Hence or otherwise explain why the oil drop stops falling when *V* is increased.

[2]

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(3 marks)

(b) The oil drop has mass = *m* and charge = *q*. The distance between the plates = 2.5 cm.

The oil drop stops falling when potential difference, V = 5000 V

Determine the charge to mass ratio of the oil drop.

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(2 marks)

(c) Two oil drops are suspended between the plates at the same time. The oil drops can be considered as identical point charges with mass 1×10^{-13} kg which are spaced 2.2 mm apart.

Calculate the electrostatic force between the drops.

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(2 marks)

(d) For the oil drops in part (c)

Describe and explain the expected observations as the potential difference increases above 5000 V, using a mathematical expression to justify your answer.

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(2 marks)

5 (a) A uniform copper wire contains 5.0×10^{23} electrons and has a current of 2.0 A flowing through it.

Calculate the time it will take all the electrons present in the wire at one instant to come out of the end.

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....

(2 marks)

(b) The wire in part (a) is 5.0 m in length and has a diameter of 1.22 mm.

Calculate the electron density in the copper wire.

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(2 marks)

(c) Using the calculated values from parts (a) and (b)

(i) Determine how long it would take an electron travelling in a wire of this material to get from London to New York, a distance of approximately 5 500 km. State your answer in a reasonable unit for the amount of time.

[1]

(ii) Hence explain how it is possible to send information by electrical signals across these distances.

[1]

(iii) The electrons are travelling with either constant velocity or constant acceleration. Select the most likely option and explain your answer.

[2]

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(4 marks)