IB · HL · Physics

4 hours 23 questions

Structured Questions

Electric & Magnetic Fields

Electric Charge / Millikan's Oil Drop Experiment / Static Electricity / Coulomb's Law / Electric Field Strength / Electric Field Lines / Electric Potential (HL) / Electric Potential Energy (HL) / Electric Potential Energy Equation (HL) / Electric Potential Gradient (HL) / Electric Equipotential Surfaces (HL) / Magnetic Fields

Easy (7 questions)	/67
Medium (8 questions)	/88
Hard (8 questions)	/59
Total Marks	**/214**

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Easy Questions

1 (a) Sketch a diagram to show the electric field that acts between the two charges.

(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 to show the electric field that acts between the two charges.

(3 marks)

(d) Identify the differences between the central area of the diagrams you draw in (a) and (c).

(2 marks)

2 (a) 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.

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(4 marks)

(b) 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.

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(3 marks)

3 (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.

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(3 marks)

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

Calculate the field strength of the field.

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(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

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(3 marks)

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

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

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(4 marks)

4 (a) Define the term electrostatic field.

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(2 marks)

(b) The equation to describe field strength is:

$$field\ strength = \frac{X}{Y}$$

Define X and Y for an electric field.

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(2 marks)

(c) Based on your answer to part (b), define the terms in the following equation:

$$E = \frac{F}{Q}$$

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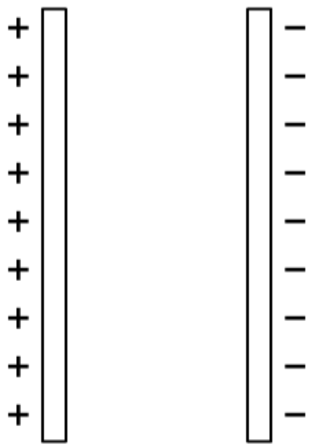
(1 mark)

5 (a) Draw the electric field lines around the positive and negative point charges below.

(3 marks)

(b) The diagram shows two parallel plates of opposite charge.



Draw the electric field lines between the two plates.

(3 marks)

(c) Electrostatic fields can be radial or uniform.

State the defining features of the equipotentials for:

(i) A radial field

[2]

(ii) A uniform field

[3]

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(5 marks)

(d) (i) On the diagram from part (a), draw the equipotential lines.

[2]

(ii) On the diagram from part (b), draw the equipotential lines.

[2]

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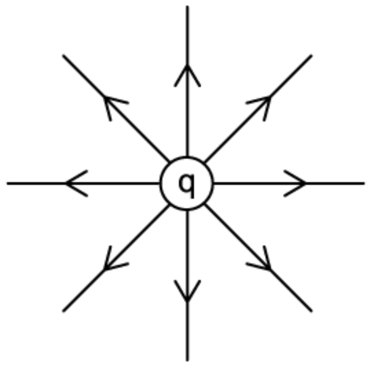
(4 marks)

6 (a) The diagram shows the electric field lines of a charged conducting sphere of radius *r* and charge *q*.



State and explain the charge on the conducting sphere.

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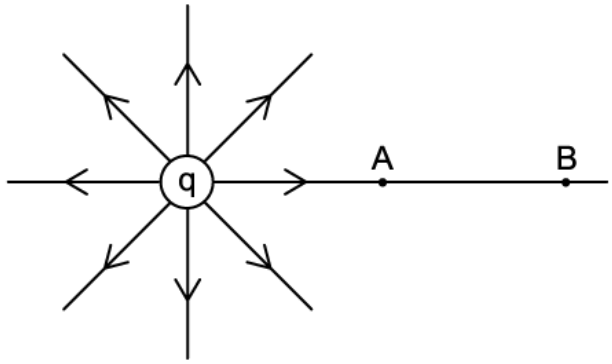
(2 marks)

(b) Two points A and B are located on the same field line.



Explain why electric potential decreases from A to B.

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(2 marks)

(c) A proton is placed at A and released from rest. The magnitude of the work done by the electric field in moving the proton from A to B is 2.5×10^{-16} J. Point A is at a distance of 0.1 m from the centre of the sphere and point B is at a distance of 0.5 m.

Calculate the electric potential between points A and B.

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(3 marks)

(d) The concept of potential is also used in the context of gravitational fields. Suggest why scientists describe different types of fields using the same terminology.

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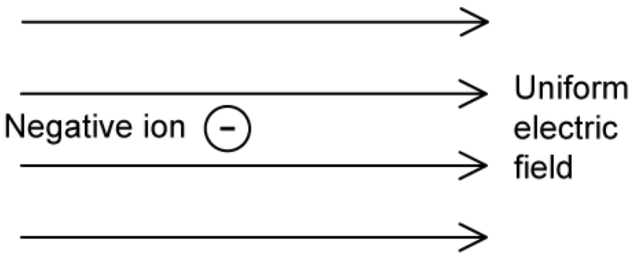
(1 mark)

7 (a) The diagram shows a negative ion which is free to move in a uniform electric field.



For the negative ion:

(i) State the direction of the electrostatic force acting on it.

[1]

(ii) Explain your answer with reference to the electric field lines in the diagram.

[2]

(3 marks)

(b) 4.0×10^{-16} J of work is done on the ion to accelerate it through the field a distance of 63 mm in a line parallel to the field lines.

Calculate the magnitude of the electrostatic force acting on the negative ion.

(5 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]

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(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.

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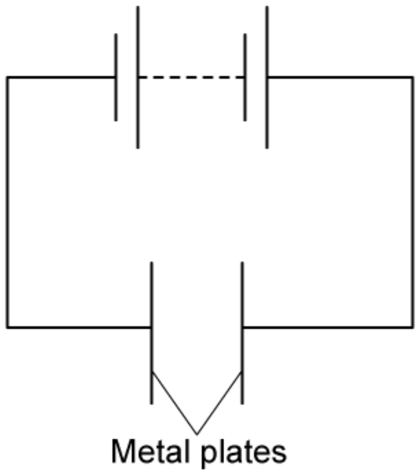
(2 marks)

2 (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.

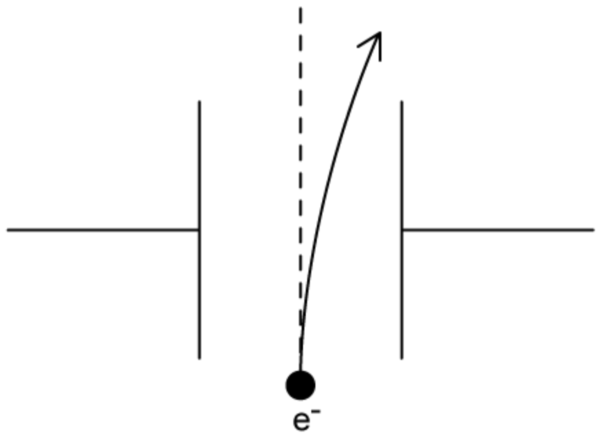
[1]

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

[1]

(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.

(3 marks)

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

(3 marks)

3 (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}.

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(4 marks)

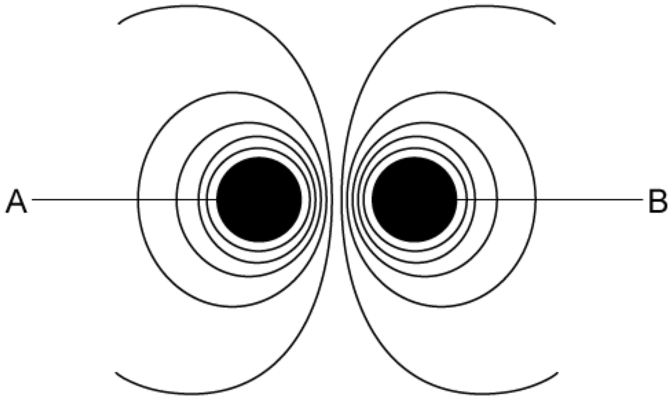
(d) Ionisation is the process of removing an outer shell electron from an atom, so it is transferred from its orbit to a point where the potential is zero.

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)

4 (a) Two charged objects, A and B, are brought close together. The equipotential lines around each object is shown.



(i) Label a position at which the electric field strength is the strongest with the letter S.

[1]

(ii) Label a position at which the electric field strength is weakest with the letter W.

[1]

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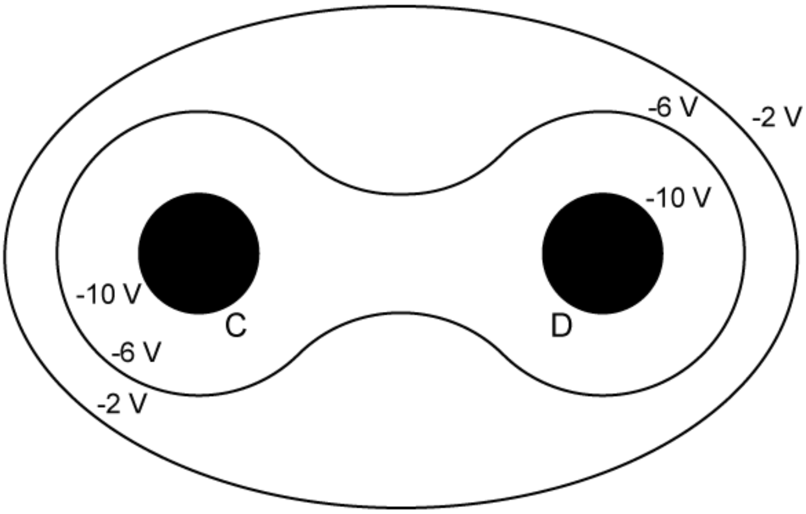
(2 marks)

(b) A different pair of equally charged objects, C and D, are brought close together. Equipotential lines at –10 V, –6 V and –2 V around C and D are shown.



Draw electric field lines between C and D.

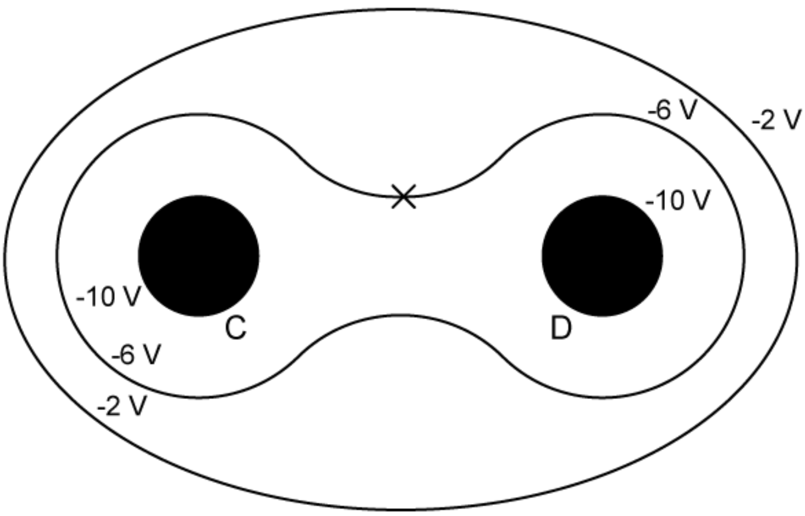
(3 marks)

(c) Identify the electric charge on objects A and B and explain your answer.

(3 marks)

(d) Objects C and D are now given a charge of –3.5 nC and –4.0 nC respectively.

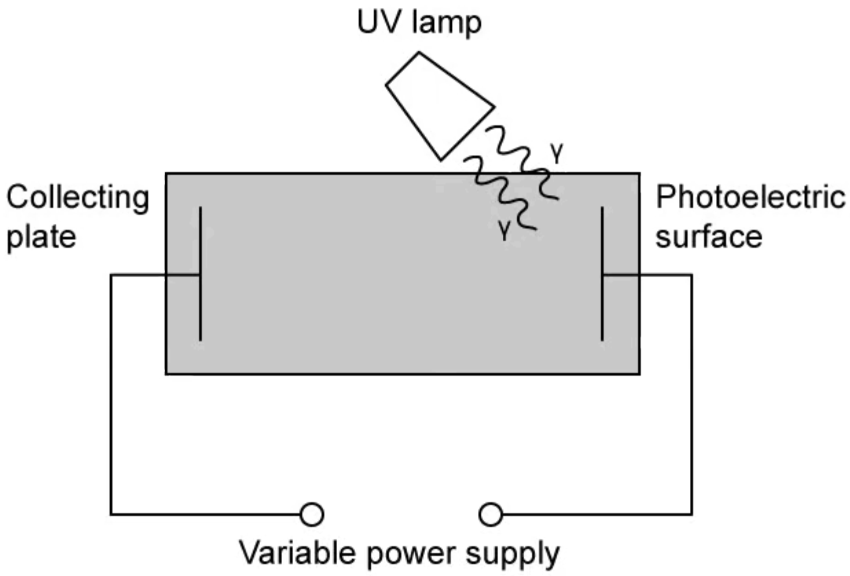
X is a position at –6 V which is equidistant from both C and D.



Determine the potential due to object C at the position labelled X.

(4 marks)

5 (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 metallic, photoelectric surface as shown.



The photoelectric surface is grounded, and the variable power supply is adjusted so that the electric potential of the collecting surface is 1.5 V.

Describe the properties of the electric field between the photoelectric surface and the collecting plate.

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(2 marks)

(b) On the diagram, draw and label equipotential lines at 0.5 V and at 1.0 V.

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(2 marks)

(c) Electrons are released from the photoelectric surface and move toward the collecting plate.

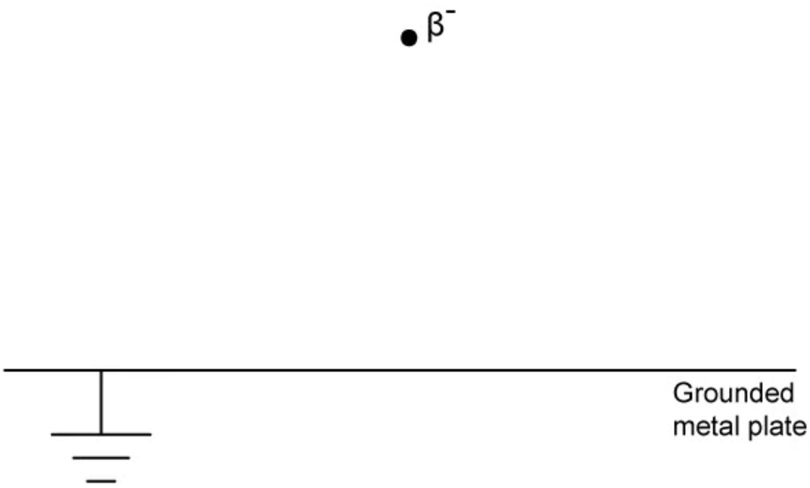
Determine the work done by the electric field on the electrons as they arrive at the midpoint between the photoelectric surface and the collecting plate.

(2 marks)

(d) Describe the motion of the electrons between the photoelectric plate and the collector plate. Your answer should consider the field at the edges of the plates.

(4 marks)

6 (a) A β^- particle is placed above a grounded metal plate.



Sketch the electric field lines between the β^- particle and the metal plate.

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(3 marks)

(b) The β^- particle is replaced with an α particle at the same position above the grounded metal surface.

Outline the similarities and differences between the electric field now created to that in part (a).

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(3 marks)

(c) The grounded metal surface is removed in order to analyse the combined electric field created between the α particle and the β^- particle.

Sketch the electric field produced between an α particle and a β⁻ particle.

(3 marks)

(d) Discuss whether there is a point of zero electric field for the diagram in part (c).

(2 marks)

7 (a) Define *electric potential* at a point in an electric field.

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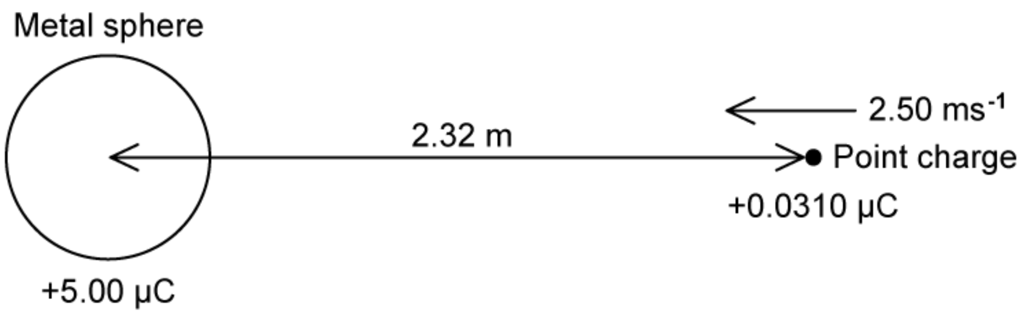
(2 marks)

(b) A point charge of mass 1.30×10^{-4} kg is moving radially towards a small, charged metal sphere as shown.



The electric potential at the surface of the sphere is 9.00×10^{4} V. Determine if the point charge will collide with the metal sphere.

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(5 marks)

(c) Determine the speed at which the point charge is certain to collide with the metal sphere.

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(2 marks)

(d) Protons are positively charged and are often described as "colliding" in particle accelerator experiments, as well as in the core of stars.

Discuss the implications of two protons colliding in terms of the forces between them. Describe the conditions necessary for such a collision to take place.

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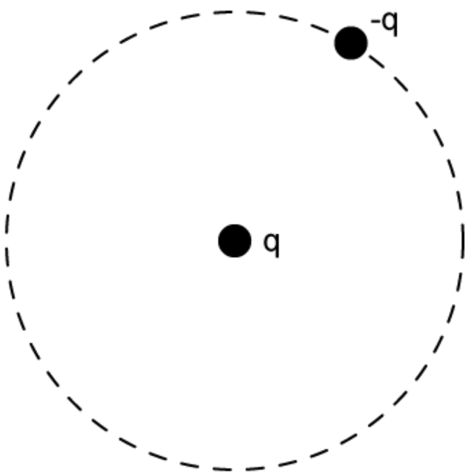
(4 marks)

8 (a) A charge –*q* with mass *m* orbits a stationary charge *q* with a constant orbital radius *r*.



Draw the electrostatic force on –*q* due to the electric field created by *q*.

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(2 marks)

(b) Show that the orbital speed of *v* is given by:

$$v = \sqrt{\frac{1}{4\pi\varepsilon_0 mr}}\, q$$

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(2 marks)

(c) Show that the total energy *E* of the orbiting charge is given by:

$$E = -\frac{1}{8\pi\varepsilon_0}\frac{q^2}{r}$$

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(3 marks)

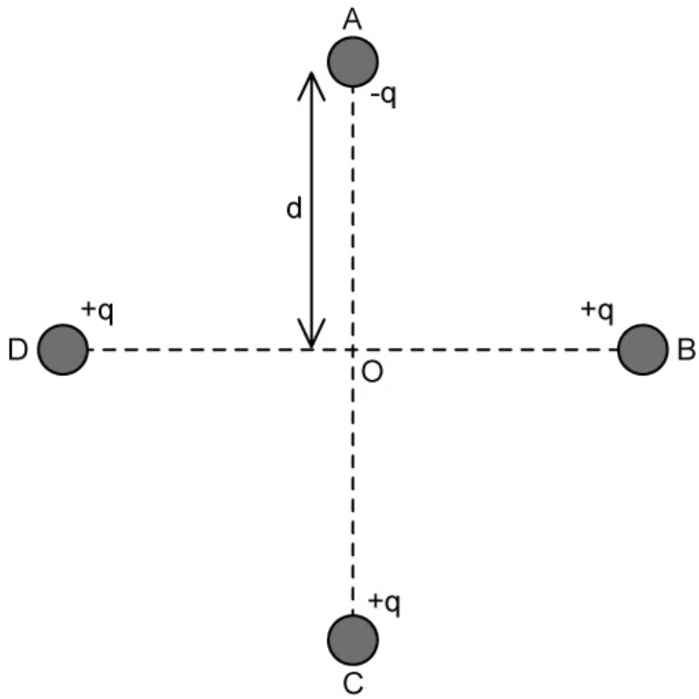
(d) Hence, determine an equation for how much energy must be supplied to $-q$ if it is to orbit the stationary charge q at twice the radius in part (c), $2r$.

(2 marks)

Hard Questions

1 (a) Four point charges A, B, C and D are each placed at a distance *d* from O as shown below.

A has a charge –*q* and B, C and D each have a charge +*q*.



Write an expression for the magnitude of the resultant electric field strength at O in terms of *q* and *d*.

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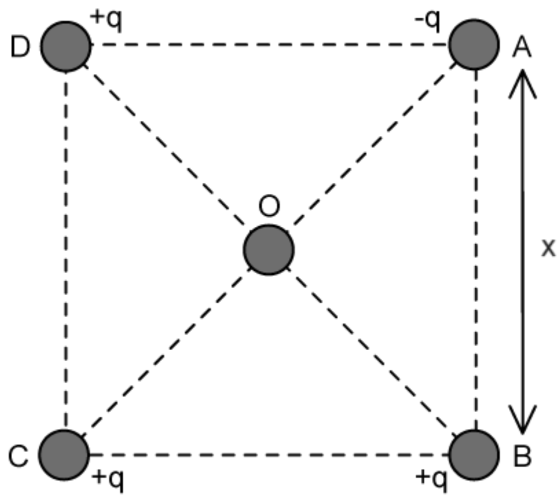
(2 marks)

(b) The arrangement of the charges is changed to the grid shown below. Each charge is now the corner of a square of side *x*, where *x* = 2*d*.

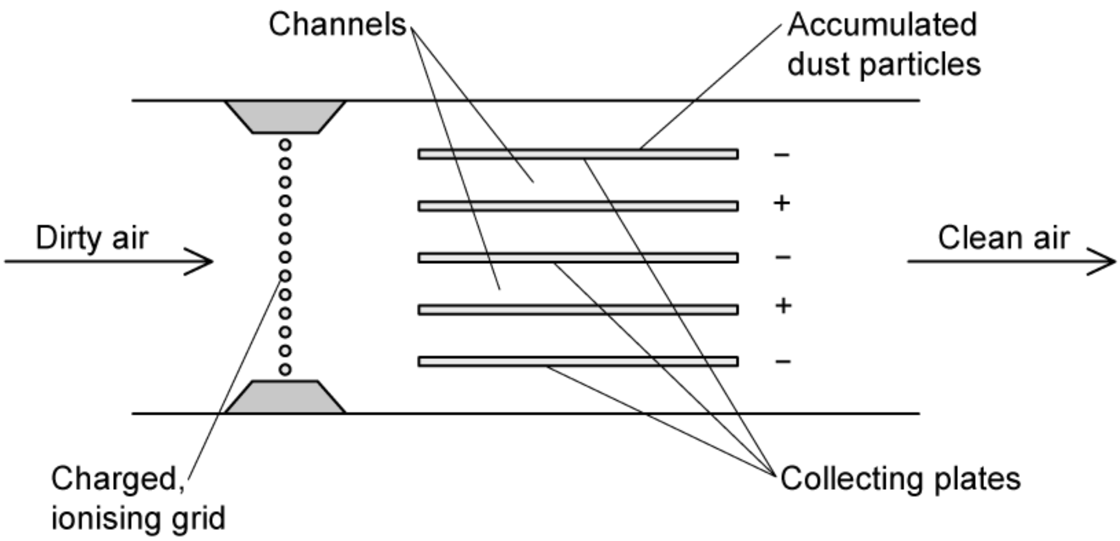


Write an expression for the magnitude of the resultant electric field strength at point O in terms of *q* and *d*.

(3 marks)

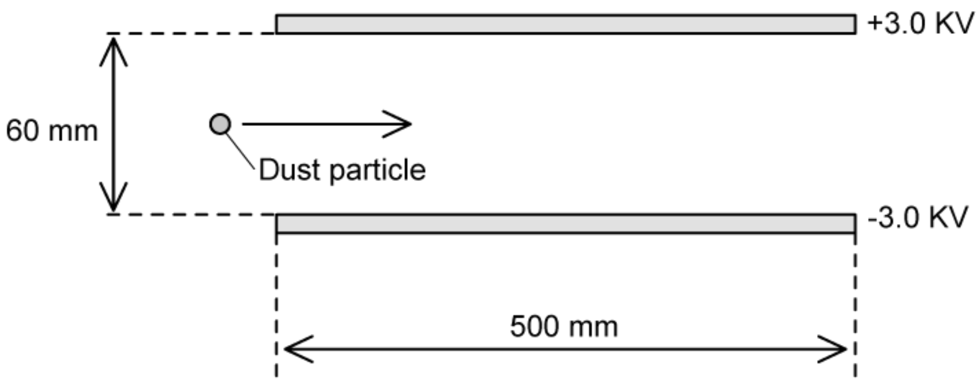
2 (a) The diagram shows an air filter which uses charged collecting plates to remove dust from the air of a workshop.

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 electric 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)

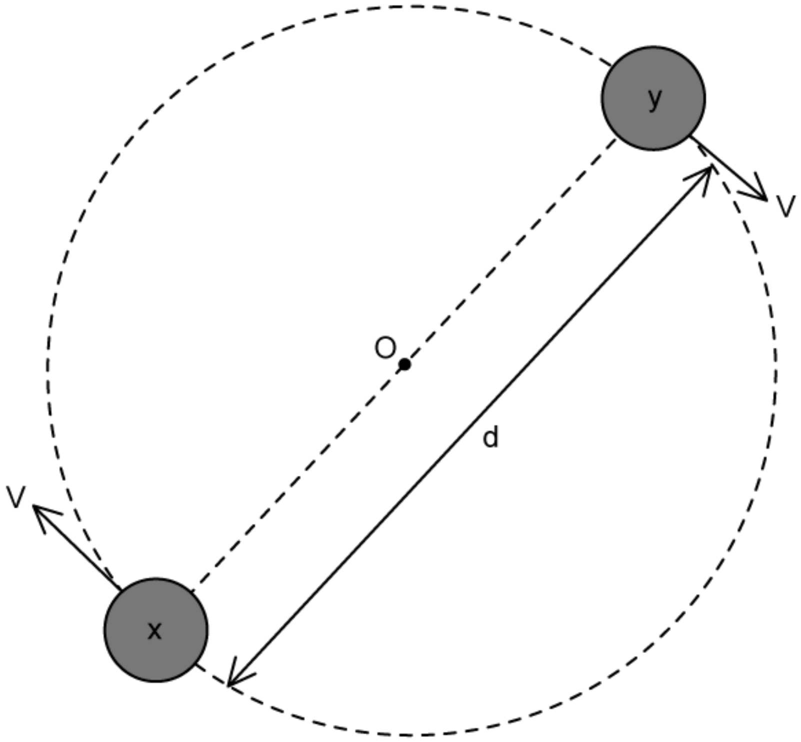
(c) As the air filter operates, there is a build up of particles on the negative plates. The gap between the plates therefore becomes narrower, by up to 10% of its initial height.

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 a radius of 7.0 fm.

[1]

(ii) An alpha particle with a radius of 1.7 fm.

[1]

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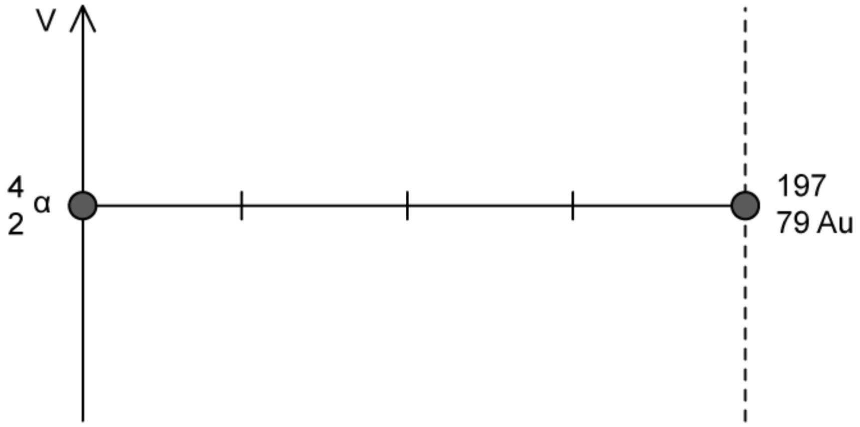
(2 marks)

(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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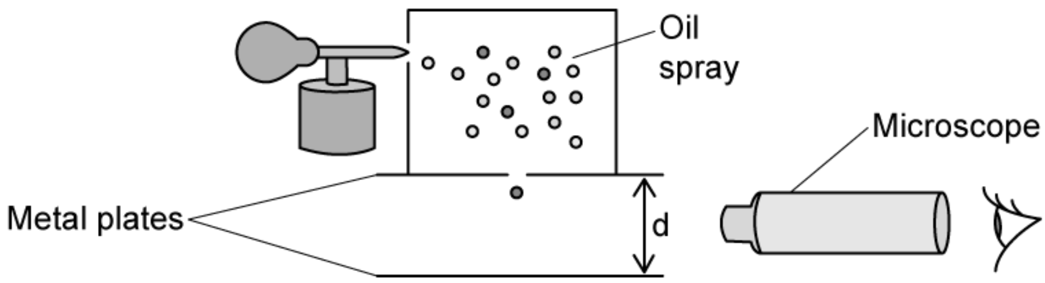
(3 marks)

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

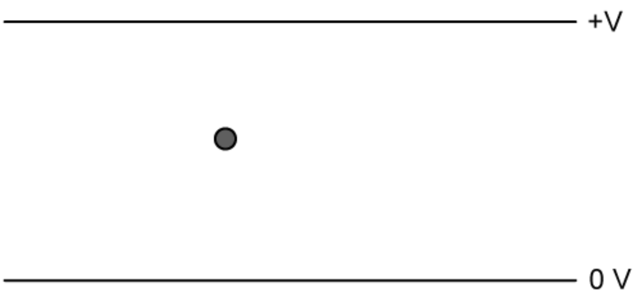


Negatively charged oil drops are sprayed into a region above two parallel metal plates which are separated by a distance, *d*. The oil drops enter the region between the plates.

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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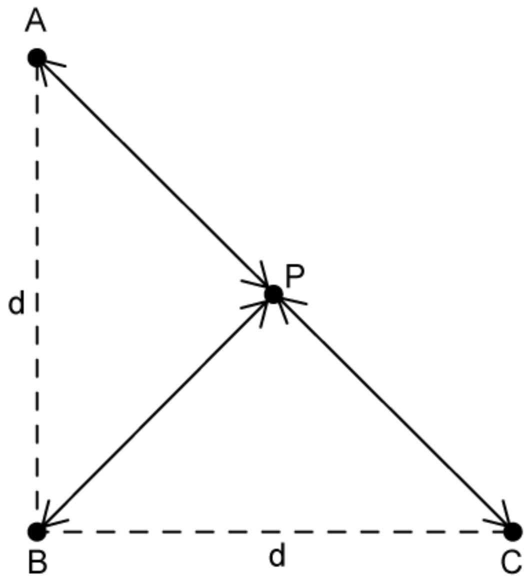
(2 marks)

5 (a) Three charges are fixed at the corners of a right-angled triangle.



The length of both the horizontal and vertical sides is *d*.

Show that the electric potential at point P, halfway between the −2Q and −6Q charge is given by $-\dfrac{2Q}{\sqrt{2}\,\pi\varepsilon_0 d}$.

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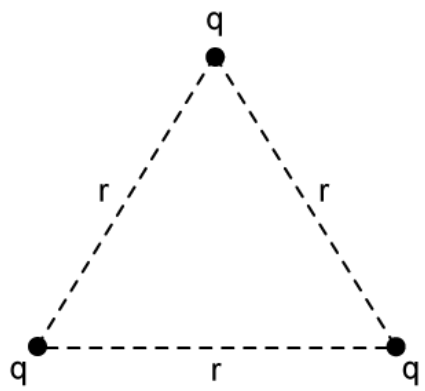
(2 marks)

(b) Before the discovery of quarks, scientists speculated that the subatomic particles might be made up of smaller particles.
If an electron was made up of three smaller, identical particles with charge *q*, which are brought in from an infinite distance to the vertices of an equilateral triangle, it would have this arrangement.



The radius of an electron is 2.82 fm.

Show that the work done in forming an electron consisting of 3 identical particles in this arrangement is given by:

$$\frac{e^2}{12\pi\varepsilon_0 r}$$

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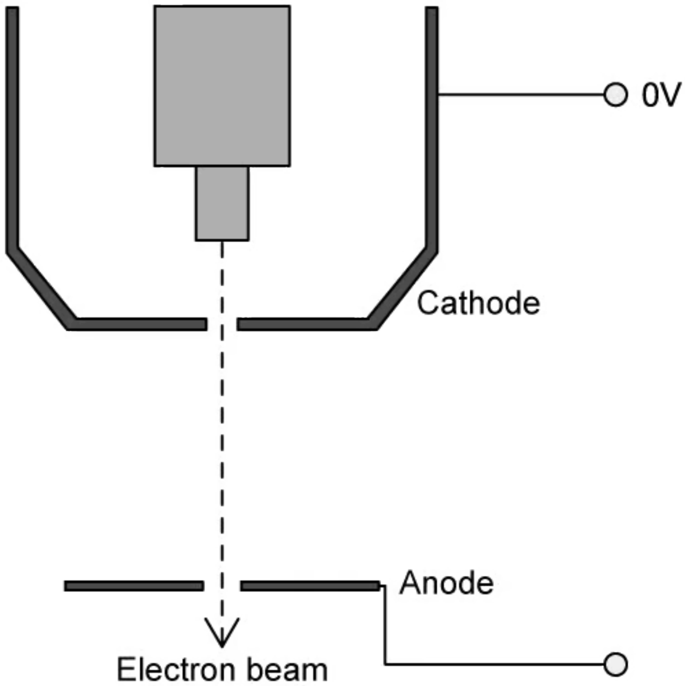
(5 marks)

(c) In an electron gun, electrons are released from a cathode and accelerated towards an anode. The electrons leave the electron gun at 10% of the speed of light.



Calculate the potential difference between the cathode and the anode.

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(2 marks)

6 (a) A science fiction film director is planning for a battle scene between two spacecrafts. The first spacecraft uses an electron gun to fire a beam of electrons at the second spacecraft from close range. The electron beam is created by accelerating electrons from rest between electrodes with a potential difference of 120 V.

To shield against the attack, the second aircraft creates a uniform electric field around itself.

Calculate the strength of the electric shield if the electrons fired from the electron beam are stopped after 85 m.

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(1 mark)

(b) After the failure of the first spacecraft to break through the electric shield of the second spacecraft a new weapon is to be designed. Instead of firing electrons, research is carried out to see if firing negatively charged ions with a charge of $-2e$ and a mass of 2.26×10^{-26} kg would be more effective.

Calculate the magnitude of the minimum velocity at which these ions would need to be fired if they are to strike the second spacecraft from a distance of 1 km.

Assume that the second spacecraft uses the same electric field as in part (a) to shield itself and that the electric field is uniform.

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(3 marks)

(c) Another option to attack the second spacecraft is to create a superweapon which can be fired from their home planet.

As this weapon will be fired a long distance from the second spacecraft, the spaceship and shield can be modelled as a charged particle with a charge of −130 C. The electrons fired by the superweapon have a kinetic energy of 12 MeV.

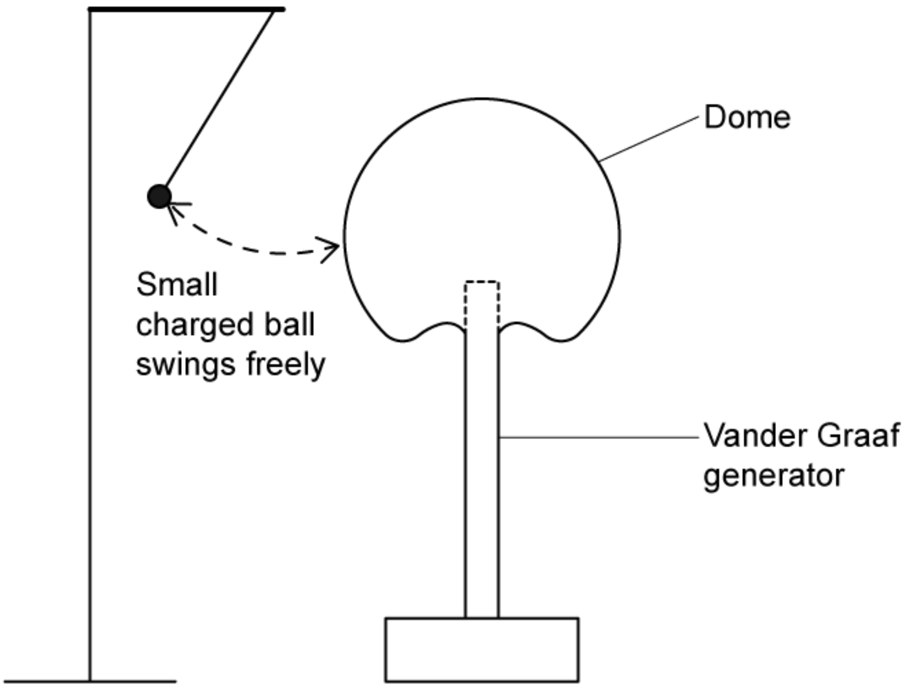
Calculate how close the electrons will come to the second spacecraft before the shield stops them.

(2 marks)

7 This question is about forces on objects held in fields. The first part is about electrically charged objects and the second part concerns bodies moving in gravitational fields.

The dome of a Van der Graaf generator can be treated as a conducting metal sphere with radius 20 cm. The dome is charged so that it has uniform surface charge + 13.1 μC. A stand is set up nearby, so that a pith ball with radius 1 cm, mass 11 g and charge + 1.8 μC can swing freely near to the dome.

The line of motion of the ball can be treated as normal to the surface of the dome.



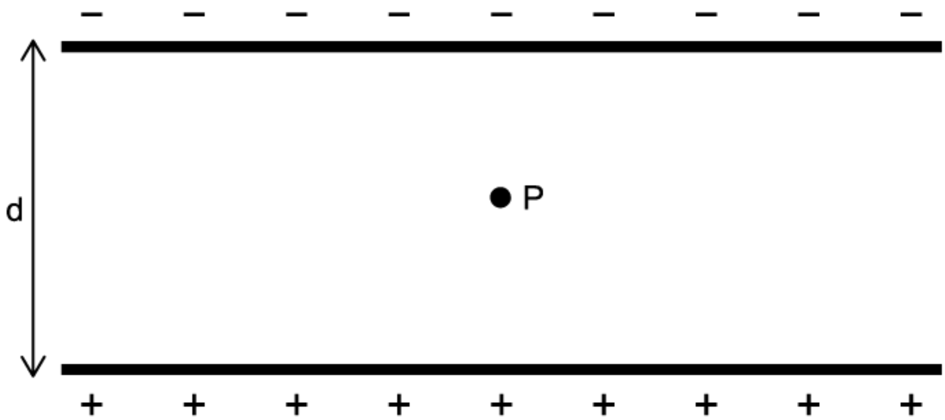
The pith ball is held at a point 40 cm from the surface of the dome and pushed, so that it moves towards the dome with initial speed of 2.2 m s^{-1}. It stops moving and hangs suspended at a certain distance from the surface of the dome.

Calculate the distance between the surfaces of the dome and the pith ball when the ball stops moving.

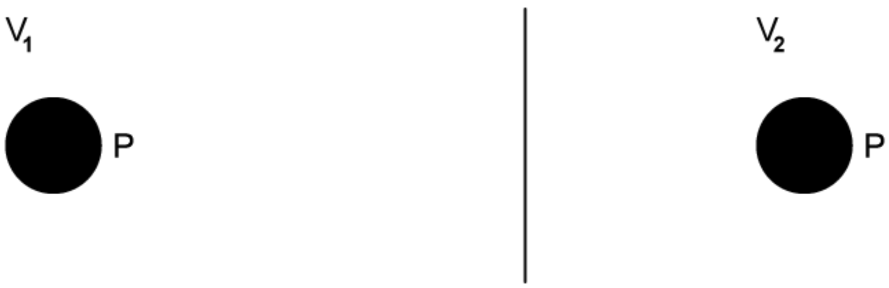
(4 marks)

8 (a) Two charged, horizontal, parallel metal plates are a distance *d* apart.

A small oil drop P is positioned between the plates such that when the potential difference between the plates is V_1, the drop is stationary. The potential difference is changed to V_2 and the drop moves upwards with a constant velocity *v*.



Complete the diagrams with the names, directions and relative magnitudes of the forces acting on the oil drop for the situations when pd = V_1 and pd = V_2.



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(4 marks)

(b) When a small, smooth sphere moves through a fluid such as air with low velocity *v* it experiences a resistive force. The force can be expressed in terms of a constant *k* so that:

$$resistive\ force = kv$$

The magnitude of the charge on the oil drop is q, and the distance between the plates is d.

Determine an expression which relates the velocity the oil drop moves upwards when the potential difference between the plates changes to the constant k.

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(2 marks)