Questions on Electric Fields MS

1. The diagram shows a positively charged oil drop held at rest between two parallel conducting plates A and B.

\[ \text{Oil drop} \hspace{2cm} \text{A} \hspace{2cm} \text{B} \]

The oil drop has a mass \(9.79 \times 10^{-15}\) kg. The potential difference between the plates is 5000 V and plate B is at a potential of 0 V. Is plate A positive or negative?

Negative (1)

Draw a labelled free-body force diagram which shows the forces acting on the oil drop. (You may ignore upthrust).

\[ qE / \text{electric force} \]

\[ mg / \text{gravitational force / weight} \]

(2)

Calculate the electric field strength between the plates.

\[ E = \frac{5000V}{2.50 \times 10^{-2} m} \]

Electric field strength = \(2 \times 10^5\) V m\(^{-1}\) [OR N c\(^{-1}\)] (1)

(2 marks)

Calculate the magnitude of the charge \(Q\) on the oil drop.

\[ Mg = qE: \text{use of equation} \]

Charge = \(4.8 \times 10^{-19}\) C (1)

(3 marks)

How many electrons would have to be removed from a neutral oil drop for it to acquire this charge?

3 (1)

[Total 8 marks]

2. Calculation of potential difference:

Use of \(E = V/d\) [\(d\) in m or cm] (1)

\(V = 90\) kV (1)

Calculation of maximum kinetic energy:

Use of \(E = qV\) e.c.f. value of \(V\) \(1.4 \times 10^{-14}\) (J) (1)

[e.c.f. their \(V \times 1.6 \times 10^{-19}\)] (1)

4
Maximum speed of one of these electrons:

Use of k.e. = \( \frac{1}{2} m u^2 \) with \( m = 9.1 \times 10^{-31} \) kg \( (1) \)

[Full e.c.f. their k.e. possible; make sure \( v \) is speed term]

\( = 1.8 \times 10^8 \) m s\(^{-1} \) [u.e. but only once] \( (1) \)

Diagram:

\[ \begin{array}{c}
\text{At least 3 radial lines touching object} \\
\text{Direction towards electron} \\
\text{Expression for electric potential } V:
\end{array} \]

\[ V = \frac{1}{4\pi \varepsilon_0} \frac{1.6 \times 10^{-19}}{r} \quad \text{OR} \quad \frac{e}{4\pi \varepsilon_0} \frac{r}{r} \quad \text{OR} \quad \frac{1.44 \times 10^{-9}}{r} \]

[not \( k \) unless defined] \[ \left[ \text{Not} \frac{Q}{4\pi \varepsilon_0 r} \text{ unless } Q \text{ defined} \right] \]

[With or without “–” sign] \( (1) \)

3. Alpha particle: diagram

Curving path between plates

Towards 0 V plate

Emerging from plates and carrying on straight

Calculation

Electric field = \( \frac{2000 \text{ V}}{10 \times (10^{-3}) \text{ m}} \)

Substitution

Force = \( EQ \)

\( = \left( \frac{2000}{10 \times 10^{-3}} \right) \text{Vm}^{-1} \times (2) \times 1.6 \times 10^{-19} \text{ C} \)

Substitution [ecf their \( E \)]

\( = 6.4 \times 10^{-14} \text{ N} \)

Correct answer
4. **Diagram**

Electric pattern:
- Straight, parallel, reasonably perpendicular to plates and equispaced [Minimum 3 lines] (1)
- Correct direction labelled on one line [Downwards arrow] (1) 2

Equipotential lines:
- Any two correct equipotentials with any labelling to identify potentials (rather than field lines) (1) 1
  - [Arrows on electric field lines – none on equipotential being sufficient labelling]

**Force**

\[ E = \frac{3000 V}{25 \times (10^{-3}) \text{m}} \] [Correct substitution] (1)

Use of \( F = Ee \) even if value of “e” is incorrect (1)

\( F = 120 \times (10^3) \text{ V m}^{-1} \times 1.6 \times 10^{-19} \text{ C} \)

\[ = 1.9 \times 10^{-14} \text{ (N)} \] (1) 3

**Graph**

Straight horizontal line [Even if extending beyond 25 mm] (1)

Value of \( F \) marked [e.e.f. their value] provided graph begins on force axis and is marked at this point (1) 2

**Speed**

Use (1)

\[ eV = \frac{1}{2} \text{ mv}^2 \]

\[ v^2 = 2 \text{ eV/m} \]

\[ Fd = \frac{1}{2} \text{ mv}^2 \]

\[ v^2 = 2Fd/m \]

Substitution (1)

\[ v^2 = \frac{2 \times 1.6 \times 10^{-19} \text{ (C)} \times 3000 \text{ (V)}}{9.11 \times 10^{-31} \text{ kg}} \]

\[ = \frac{1.92 \times 10^{-14} \text{ (N)}}{9.11 \times 10^{-31} \text{ kg}} \times 25 \times 10^{-3} \text{ m} \]

\[ = \frac{2 \times 1.92 \times 10^{-14} \text{ N} \times 25 \times 10^{-3} \text{ m}}{9.11 \times 10^{-31} \text{ kg}} \]

Answer: \( V = 3.2 \times 10^7 \text{ ms}^{-1} \) (1) 3

[If \( F = 2 \times 10^{-14} \text{ N}, \) then \( V = 3.3 \times 10^7 \text{ ms}^{-1} \)]

5. **Explanation**

Electrons are transferred from / move from/ rubbed off the rod to the duster (1)

Same amount of charge on each/duster becomes negative (1) 2

**Polystyrene**

Polystyrene is an insulator / non conductor [NOT bad or poor conductor] (1)

Prevents loss of charge/rod discharging/prevents conduction or charge low from metal plate (1) 2

Reading on balance
Quality of written communication (1)

Any three from:

- Reading increases (1)
- There is a (mutual) force of repulsion/like charges repel/rods (they) repel (1)
- Because by Coulomb’s law/inverse square law \( \frac{kQ_1Q_2}{r^2} / \frac{1}{r^2} \) as \( r \) decreases force must increase (1)
- Reading increases at a greater rate/more rapidly [but accept if say “much more”] as distance reduces/when closer (1)

Max 3

6. (a) Direction of field lines
Downwards (1)  

(b) (i) Calculation of force
Use of \( V/d \) i.e. 250 V/0.05 m [if 5 used mark still awarded] (1)
Use of \( \frac{V}{d} \) \( e \) [Mark is for correct use of \( 1.6 \times 10^{-19} \) C] (1)
\[ = 8.0 \times 10^{-16} \text{ N} \] (1)

(ii) Direction and explanation
(Vertically) upwards / towards AB (1)
No (component of) force in the horizontal direction OR because (1)
(the force) does no work in the horizontal direction

(c) Calculation of p.d.
Use of \( \Delta E_K = \frac{1}{2} mv^2 / \frac{1}{2} \times 9.11 \times 10^{-31} \text{ (kg)} \times (1.3 \times 10^7)^2 \) (1)
Use of \( \frac{Ve}{V} \times 1.6 \times 10^{-19} \text{ (C)} \) (1)
\[ = 480 \text{ V} \] (1)

(d) Beam of electrons
Diagram showing:
Spreading out from one point (1)
fastest electrons labelled (1)

[4.2 (4.19) \times 10^7 \text{ (m s}^{-1}) \), no ue] to at least 2 sf (1) 

7. (a) Electron speed
Substitution of electronic charge and 5000V in \( eV \) (1)
Substitution of electron mass in \( \frac{1}{2} mv^2 \) (1)
Correct answer \[ 4.2 \times 10^7 \text{ (m s}^{-1}) \), no ue] to at least 2 sf (1) 

[11]
Example of answer:
\[ v^2 = \frac{(2 \times 1.6 \times 10^{-19} \text{C} \times 5000 \text{ V})}{(9.11 \times 10^{-31} \text{ kg})} = 1.76 \times 10^{15} \]
\[ v = 4.19 \times 10^7 \text{ m s}^{-1} \]

(b) (i) **Value of \( E \)**

Correct answer \[2.80 \times 10^4 \text{ V m}^{-1}/\text{N C}^{-1} \text{ or } 2.80 \times 10^2 \text{ V cm}^{-1}\] \( \text{(1)} \)

Example of answer:
\[ E = \frac{V}{d} = \frac{1400 \text{ V}}{5.0 \times 10^{-2}} = 28000 \text{ V m}^{-1} \]

(ii) **Value of force \( F \)**

Correct answer \[4.5 \times 10^{-15} \text{ N}, \text{ ecf for their } E\] \( \text{(1)} \)

Example of answer:
\[ F = Ee = 2.80 \times 10^4 \text{ V m}^{-1} \times 1.6 \times 10^{-19} \text{ C} = 4.48 \times 10^{-15} \text{ N} \]

(c) **Calculation of \( h \)**

See \( a = \text{their } F / 9.11 \times 10^{-31} \text{ kg}\) \( \text{(1)} \)

\[ \rightarrow a = 4.9 \times 10^{15} \text{ m s}^{-2} \]

See \( t = 12 \times 10^{-2} \) m / \( 4 \times 10^7 \) m s\(^{-1}\) (or use \( 4.2 \times 10^7 \) m s\(^{-1}\)) \( \text{(1)} \)

\[ t = \frac{d}{v}, \text{ with } d = \text{plate length}; 12 \text{ cm} \]

\[ \rightarrow t = 3.0 \times 10^{-9} \text{ s}, \text{ or } 2.86 \times 10^{-9} \text{ s} \]

See substitution of \( a \) and \( t \) values **arrived at by above methods** into \( \frac{1}{2} at^2 \) \( \text{(1)} \)

Correct answer \[ h = 0.020 \text{ m} – 0.022 \text{ m} \] \( \text{(1)} \)

[Full ecf for their value of \( F \) if methods for \( a \) and \( t \) correct and their \( h \leq 5.0 \text{cm} \)]

Example of answer:
\[ h = \frac{1}{2} a t^2 \]
\[ = \frac{1}{2} \times 4.9 \times 10^{15} \text{ m s}^{-2} \times (2.86 \times 10^{-9} \text{ s})^2 \]
\[ = 2.0 \times 10^{-2} \text{ m} \]

(d) (i) **Path A of electron beam**

Less curved than original \( \text{(1)} \)

(ii) **Path B of electron beam**

More curved than original, curve starting as beam enters field [started by \( H \) of the Horizontal plate label] \( \text{(1)} \)

[For both curves:

- ignore any curvature beyond plates after exit
- new path must be same as original up to plates]

[No marks if lines not identified, OK if either one is labelled]
8. Draw diagrams to represent
   (i) the gravitational field near the surface of the Earth,
   [Diagram not provided]

   Direction
   Lines: at least 3 parallel perpendicular equally spaced

   (ii) the electric field in the region of an isolated negative point charge.
   [Diagram not provided]

   Direction
   Lines: at least 3 radial equally spaced

   How does the electric field strength $E$ vary with distance $r$ from the point charge?
   
   $E \propto \frac{1}{r^2}$ (1)

   (1 mark)

   Give an example of a region in which you would expect to find a uniform electric field.
   Between charged parallel plates (1).

   (1 mark)
   [Total 6 marks]

9. Cathode Ray Tube

Electron emission
- Heating effect (due to current) (1)
- (Surface) electrons (break free) because of energy gain (1) [Thermionic emission scores both marks]

Electron motion towards anode
The electrons are attracted to/accelerated by the positive anode (1)

Energy
Electron energy $= (10 \times 10^3 \text{ V}) (1.6 \times 10^{-19} \text{ C})$

$= 1.6 \times 10^{-15} \text{ J}$

Correct use of $1.6 \times 10^{-19}$ OR use of $10 \times 10^3$ (1)

Answer (1)

Number of electrons per second

Number each second $= \frac{1.5 \times 10^{-3} \text{ A}}{1.6 \times 10^{-19} \text{ J}}$
9.4×10^{15}\text{ s}^{-1}

Correct conversion mA → A

Answer (1)

2

Rate

Energy each second = (9.4 × 10^{15} \text{ s}^{-1}) (1.6×10^{-15} \text{ J}) (1)

= 15 \text{ Js}^{-1} (\text{W}) / 14.4 \text{ Js}^{-1} (1)

[cf their energy]

10. Evenly distributed spray:

The drops repel [i.e. something repels] (1)

Explanation:

Electrons/negative charge move upwards from Earth on to object (1)
as positive/drops induce negative on object (1)
negatives attract positive/drops [not “neutralised”] (1)

Positive builds up on object OR no electrons move upwards from Earth (1)

OR negative can no longer flow (1)

Positive repels approaching drops (1)

2

11. How electron gun creates beam of electrons

Any four from:

1. hot filament (1)
2. thermionic emission / electrons have enough energy to leave (1)
3. anode and cathode / ± electrodes [identified] (1)
4. E–field OR force direction OR cause of acceleration (1)
5. collimation [eg gap in anode identified as causing beam] (1)
6. need for vacuum (1)

Max 4

Speed of electrons

(eV =) \frac{1}{2} mv^2 (1)

Use of eV [ie substituted or rearranged] (1)

Answer [1.09 × 10^7 \text{ m s}^{-1}] (1)

1.6 × 10^{-19} × 340 (J) = \frac{1}{2} \times 9.11 × 10^{-31} (\text{kg}) \times v^2

v =1.09 × 10^7 \text{ m s}^{-1}

3

Definition of term electric field

Region/area/space in which charge experiences force (1)

terical acceleration of electrons due to field (1)

[Bald answer =0]

Use of equation $E = V/d$ (1)
\[ E = \frac{V}{d} = 2500 \text{ V} \div 0.09 \text{ m} = 28 \text{ (kV m}^{-1}) \]

Rearranged equation \( E = \frac{F}{q} \) or substitution into it (I)

\[ F = Eq = 28000 \times 1.6 \times 10^{-19} \text{ (N)} \times 4.4 \times 10^{-15} \text{ (N)} \]

Equation \( F = ma \) seen or substitution into it (I)

\[ A = \frac{F}{m} = \frac{4.4 \times 10^{-15} \text{ (N)}}{9.11 \times 10^{-31} \text{ (kg)}} \]

\[ = 4.9 \times 10^{15} \text{ (m s}^{-2}) \text{ (I)} \]

[at least 2 sig fig needed] [No u.e.] [Reverse calculation max 3]

12. Electric field

\[
\frac{100 \text{ (V)}}{300 \times 10^{-6} \text{ (m)}} \quad \text{(I)}
\]

\[ = 3.3 \times 10^5 \text{ V m}^{-1} \text{ (I)} \]

Force

\[ F = Eq = 3.3 \times 1.6 \times 10^{-19} \text{ (N)} \]

\[ = 5.3 \times 10^{-14} \text{ N} \text{ [Allow e.c.f]} \text{ (I)} \]

Why force has this direction

Vertical line ↑ (I)

Attracted to positive plate \{ (I)

OR in terms of field direction \}

How much energy hole gains

\[ W = F \times d = 5.3 \times 10^{-14} \times 2.8 \times 10^{-10} \text{ (J)} \text{ (I)} \]

\[ = 1.5 \times 10^{-23} \text{ J} \text{ [Allow e.c.f]} \text{ (I)} \]

[8]

13. Forces acting on molecule, shown on diagram A:

Forces not collinear and sense correct (I)

Explanation of why molecules align with field:

Forces not in same line (I)

Hence turning effect [OR torque]

Field lines shown on diagram B:

At least three lines drawn equidistant(I)

Direction correct (I)

Calculations of electric field strength:

\[ E = \frac{V}{d} = \frac{1.5 \text{ V}}{1.0 \times 10^{-5} \text{ m}} \quad \text{(I)} \]

\[ = 1.5 \times 10^5 \text{ V m}^{-1} \text{ (I)} \]

[7]
14. Credit to be given for all good, relevant Physics Examples of mark scoring points [each relevant formula is also worth 1 mark]:

Between plates field is uniform
Acceleration is constant
Energy gained = 2000e
All ions have same F or same energy
From hole to detector is zero field/force
Ion travels at constant speed
g negligible
time proportional to 1 /velocity
time proportional to 1 /mass
in a vacuum there are no collisions or friction forces

[Max 7]