Mark schemes

1

(a) force due to electric field = $\frac{qv}{d}$ **(1)**

force due to electric field = weight or $\frac{qv}{d} = mg$ **(1)**

for stationary droplet **(1)**

$$q = \frac{mgd}{V} = \frac{7.3 \times 10^{-15} \times 9.8 \times 5.0 \times 10^{3}}{750} = 4.8\ (+\ 0.1) \times 10^{-19}\ \text{C}\ \textbf{(1)}$$

(b) 1.6×10^{-19} C is the charge of the electron [or quantum of charge] **(1)**

[max 4]

2

(a) (i) (vertically) upwards **(1)**

(ii) $mg = qE$, $\therefore \frac{q}{m} = \frac{g}{E}$ **(1)**

$\frac{9.8}{4.9 \times 10^{5}}$ (1) (= 2.0×10^{-5} C kg^{-1})

3

(b) initial downwards acceleration due to weight (or gravity) **(1)**
viscous force/drag/friction (or resistance) due to air
increases with increase in speed **(1)**
speed increases until drag become equal to (and opposite to) weight
(no resultant force) hence no acceleration **(1)**

max 3

[6]

3

(a) force due to electric field is vertically upwards and proportional
(or related to) plate pd **(1)**
at $V = V_c$, force due to field is equal and opposite to the weight of
the droplet **(1)**
no resultant force (or forces balance) at V_c (droplet remains stationary) **(1)**

3

(b) (i) electric force (or qV/d) = weight (or mg) **(1)**

$$q\left(=\frac{mgd}{V}\right) = \frac{6.2\times10^{-14}\times9.8\times6.0\times10^{-3}}{5700}$$ **(1)**

$= 6.4 \times 10^{-19}$C **(1)**

(ii) for pd > 5700 (V), droplet moves upwards **(1)**
due to increased electric force **(1)**
droplet reaches terminal velocity **(1)**

max 5

[8]

4 (a) (i) **either**

(at terminal speed (v)) the viscous force on the droplet = its weight (or mg or the force of gravity on it)

or

viscous force = $6\pi\eta rv$ (where r is the radius of the droplet and η is its viscosity) and weight (= mg) = $4\pi r^3\rho g/3$ ✓

$4\pi r^3\rho g/3 = 6\pi\eta rv$ ✓

(which gives $r = (9\eta v/2\rho g)^{½}$)

2

(ii) r (can be calculated as above then) used in the formula m = $4\pi r^3\rho/3$ to find the droplet mess, m [owtte] ✓

alternatively; (from $6\pi\eta rv = mg$) (as all values are known use) $m = 6\pi\eta rv/g$ ✓

1

(b) (i) electric force (or QV/d) = the droplet weight (or mg) ✓

$$Q = \frac{mgd}{v} = \frac{6.8\times10^{-15}\times9.8(1)\times5.0\times10^{-3}}{690} = 4.8\times10^{-19}\text{ C}$$ ✓

2 sf answer ✓

3

(ii) **any two from**

the charge on each droplet is a whole number × 1.6×10^{-19} C (or × charge of the electron) ✓

the least amount of charge (or the quantum of charge) is the charge of the electron ✓

the quantum of charge is 1.6×10^{-19} C [owtte] ✓

max 2

[8]

5

(a) (i) positive **(1)**

(ii) $QE\left(=\frac{QV}{d}\right) = mg$ **(1)**

$Q\left(=\frac{mgd}{V}\right) = \frac{4.6\times10^{-16}\times9.8\times40\times10^{-3}}{565}$ **(1)** $= 3.2\times10^{-19}$ C **(1)**

(iii) two electrons **(1)**
missing **(1)**

(max 5)

(b) upwards **(1)**

the electrical force is increased **(1)**

so there is a net upward force **(1)**

as the weight and upthrust are the same **(1)**

(max 2)

[7]

6

(a) (use of $v = \frac{s}{t}$ gives) $v = \frac{2.0\times10^{-3}}{18.3} = 1.11\times10^{-4}$ m s^{-1} **(1)**

1

(b) $^4/_3\ \pi r^3 \rho g = 6\ \pi v r$ **(1)**

$r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$ **(1)**

$= \left(\frac{9\times1.8\times10^{-5}\times1.11\times10^{-4}}{2\times970\times9.81}\right)^{1/2}$ **(1)** (= 9.7×10^{-7}m)

(allow C.E for v from (a))

(c) $qE = mg$ **(1)**

$m = {}^4/_3\ \pi r^3\ \rho = {}^4/_3\ \pi\ (9.7 \times 10^{-7})^3 \times 970 = 3.7 \times 10^{-15}$ kg **(1)**

$q(= \frac{mg}{E}) = \frac{3.7 \times 10^{-5} \times 9.81}{57 \times 10^3} = 6.37 \times 10^{-19}$ C **(1)**

(allow C.E. for value of mass m)

3

[7]

7 (a) (i) positive **(1)**

(ii) electric force directed **upwards** = weight **(1)**

[or $\frac{QV}{d} = mg$]

2

(b) (i) $v = \frac{1.20 \times 10^{-3}}{13.8} = 8.7 \times 10^{-5}$ m s^{-1} **(1)**

(ii) weight [or mg] = ${}^4/_3\ \pi r^3\ \rho g$ **(1)**
(since speed constant) viscous force = $6\pi\eta rv$ **(1)**
$\therefore {}^4/_3 p r^3\ rg = 6\pi\eta rv$ to give desired equation **(1)**

(iii) rearrange equation to give $r = \left(\frac{9\eta v}{2\rho g}\right)^{1/2}$ **(1)**

$\left\{= \left(\frac{9 \times 1.8 \times 8.7 \times 10^{-5}}{2 \times 960 \times 9.8}\right)^{1/2}\right\} = 8.7 \times 10^{-7}$ m **(1)** (8.65×10^{-7} m)
(allow C.E. for value of v from (i), but not 3rd mark)
$m\ (= {}^4/_3\ \pi r^3\ \rho) = {}^4/_3\ \pi\ (8.65 \times 10^{-7})^3 \times 960$ **(1)** ($= 2.6 \times 10^{-15}$ kg)

(iv) $\frac{QV}{d} = mg$ **(1)**

$Q = \frac{2.6 \times 10^{-15} \times 9.8 \times 6.0 \times 10^{-3}}{320}$ **(1)**

$= 4.8 \times 10^{-19}$ C **(1)** (4.78×10^{-19} C)

10

[12]

8 (a) (i) There is a (constant) force acting which is (always) at right angles / perpendicular to the path / motion / velocity / direction of travel / to the beam
Or mentions a centripetal force ✓

First mark is for condition for circular motion

Not speed

Second mark is for a statement relating to the origin of the force

Force is at right angles to the magnetic field <u>and</u> the electron motion
Or
<u>direction</u> given by left hand rule ✓

Any mention of attraction to the plates is talk out (TO)

2

(ii) States $Bev = \frac{mv^2}{r}$ and evidence of correct intermediate stage showing manipulation of the formula
or

Quotes $r = \frac{mv}{Be}$ from formula sheet and change of subject to $v = Ber / m$ seen

Accept delete marks

or rewrite as $Be = \frac{mv}{r}$

or rearrangement as $\frac{v^2}{v} = \frac{Ber}{m}$

1

(iii) States $Bev = \frac{eV}{d}$

or $F = Bev$ $F = \frac{eV}{d}$ (or $F = Ee$ and $E = \frac{V}{d}$ in any form)

Allow use of e *or* Q

<u>and</u>

states $v = \frac{V}{Bd}$ ✓

No mark for just quoting final equation. There must be evidence of useful starting equations

1

(b) Equates the formulae for *v* and shows $\frac{e}{m}$ equated to $\frac{V}{B^2 rd}$

Must include 'e / m =' not just 'specific charge ='

Note there is no ecf. Candidates who use an incorrect equation in (a) (iii) will lose this mark unless they restart from first principles

Condone Q / m

1

(c) Using band marking

Marks awarded for this answer will be determined by the Quality of Written Communication (QWC) as well as the standard of the scientific response.
Level 1 (1−2 marks)
Answer is largely incomplete. It may contain valid points which are not clearly linked to an argument structure. Unstructured answer. Errors in the use of technical terms, spelling, punctuation and grammar or lack of fluency.
Level 2 (3−4 marks)
Answer has some omissions but is generally supported by some of the relevant points below: - the argument shows some attempt at structure - the ideas are expressed with reasonable clarity but with a few errors in the use of technical terms, spelling, punctuation and grammar.
Level 3 (5−6 marks)
Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below: - argument is well structured with minimum repetition or irrelevant points - accurate and clear expression of ideas with only minor errors in the use of technical terms, spelling and punctuation and grammar.

A
Measure the terminal speed of the falling droplet
At the terminal speed weight = viscous force (+ upthrust)

$mg = 6\pi\eta rv$ and $m = 4\pi r^3\rho / 3$ so $r^2 = \frac{9\eta v}{2\rho g}$
r could be determined as density of drop, viscosity of air and *g* are known (*r* is the only unknown)

B
m can be determined if *r* is known
Apply pd between the plates so electric field = V / d and adjust until droplet is stationary
$QV / d = mg$ so *Q* can be found

C
Make a number of measurements to find *Q*
Results for *Q* are in multiples of 1.6×10^{-19}C so *Q* can be found

e.g.

1-2

Superficial with some sensible comments about the procedure with significant errors in attempts at use of equations. May do one part of A B or C reasonably well. Relevant Equations without little explanation may be worth 1

3-4

Should cover most of the point in two of A, B & C coherently

A & B may be well done in an answer that is easy to follow

OR B and C may be well explained but there may be significant errors or omissions in the determination of r

OR a bit of all A B and C with significant errors or omissions

5-6

Will cover the points made in A B & C with few omissions in an answer that is easy to follow

The candidate will define some terms used in equations

1-2

Attempt to explain how to determine radius with detail of how to use data

OR

Makes a relevant point about some part of the procedure about the determination

3-4

Radius determination explained with sensible equations

Explanation of how to use data to find mass of the drop

Idea of holding the drop stationary

5-6

Answer includes all steps to determine the charge of a droplet with correct equations showing how to use the measurements

For highest mark the answer should include idea of interpreting results of many measurements

6

[11]

9 (a) (i) (at terminal velocity v), weight of droplet (or mg) = viscous drag (or $6\pi\eta r v$) ✓

Backward working 3 marks max;

viscous force ($= 6\pi\eta r v$) $= 6\pi \times 1.8 \times 10^{-5} \times 1.0 \times 10^{-6} \times 1.1 \times 10^{-4}$
$= 3.7 \times 10^{-14}$ N ✓

mass (m) of droplet = $(4\pi r^3 / 3) \times \rho$, (where r is the droplet radius) ✓

weight = mg =

$$\frac{4}{3}\pi(1.0 \times 1.0^{-6})^3 \times 880 \times 9.8 = 3.6 \times 10^{-14}\text{N}$$ ✓

(allow 3.7)

(therefore) $(4\pi r^3 / 3) \times \rho g = 6\pi\eta r v$ (or rearranged) ✓

(hence) $r (= (9\eta v / 2\rho g)^{1/2}$

$$= \frac{9 \times 1.8 \times 10^{-5} \times 1.1 \times 10^{-4}}{2 \times 880 \times 9.8}) \text{ gives } \quad r = 1.0(3) \times 10^{-6}\ m$$ ✓

(therefore) viscous force = weight as required for constant velocity ✓

note; some evidence of calculation needed to give final mark

Allow final answer for r in the range 1 to 1.05 × 10^{-6} to any number of sig figs

4

(ii) $$\boldsymbol{m} = ((4\pi r^3/3) \times \rho) = \frac{4}{3}\pi(1.0 \times 10^{-6})^3 \times 880) = 3.7 \times 10^{-15} \text{ kg}$$ ✓

Allow ecf for r from a(i) in a correct calculation that gives m in the range 3.6 to 4.0 × 10^{-15} kg

(or correct calculation of $6\pi\eta r v / g$)

1

(iii) electric force (or QV / d) = droplet weight (or *mg*) ✓

Allow ecf m (or r) from a(ii) (or a(i)).

$$Q = \left(\frac{mgd}{V} \right) = \frac{3.7\times10^{-15}\times9.8\times6.0\times10^{-3}}{680}$$ ✓

Accept values in 1st mark line

[or Q (= viscous force × *d / V*

Use of e instead of Q or q = 2 marks max

$= 6\pi \times 1.8 \times 10^{-5} \times 1.0 \times 10^{-6} \times 1.1 \times 10^{-4} \times 6.0 \times 10^{-4} / 680$ ✓]

For the 2nd mark, allow use of viscous force calculation. Use of viscous force method does not get 1st mark.

$Q = 3.2 \times 10^{-19}$C ✓

If both methods are given and only one method gives Q = ne (where n = integer >1), ignore other method for 2nd mark and 3rd mark.

For the final mark, Q must be within n e ± 0.2×10^{-19} from a correct calculation.

3

(b) The weight of the second droplet is greater than the maximum electric force on it ✓

Alternative for 1st mark;

weight = drag force + elec force (owtte)

Scheme using V for next 5 marks;

If n =1 for the second droplet , pd to hold it = 1580 V (= *mgd / e*) ✓

which is not possible as V max = 1000 V ✓

If n = 2 , it would be held at rest by a pd of 790 V (= 1580 / 2 or 680 × 4.3 / 3.7 V) ✓

if n > 2 , it would be held at rest by a pd of less than 790 V (or 790 / n V) ✓

So n =1(e) must be the droplet charge ✓

Alternative schemes for last 5 marks

Q scheme *Using QV /d = mg for a stationary droplet gives Q = mgd / V = 2.53 − 10^{-19} C* ✓

which is not possible as Q = integer x e ✓

(so) Q (=ne) < 2.53 × 10^{-19} C ✓ *owtte)*

Calculation to show

Q= 1e fits above condition ✓

Q= 2e does not fit above condition ✓

F scheme*;- Calc of mg to give 4.2 (±0.2) × 10^{-14} N* ✓

Calc for Q = 1e of QV / d to give 2.6(±0.2) × 10^{-14} N ✓

Calc for Q =2e of QV / d to give 5.3 (±0.2)× 10^{-14}N ✓

mg> elec force for Q =1e or <2e for Q=2e ✓

So n =1(e) must be the droplet charge ✓

Max 4

[12]

10 (a) (i) field strength is the same everywhere / at any position

B1

field strength is force per coulomb

or force experienced by a charged particle

(not just force)

B1

(2)

(ii) lines parallel in central region

- must be shown throughout region between plates and start and end on plates **B1**

curved at edges **B1**

(allow if only curved at one end)

arrows correct **B1**

(3)

(b) (i) field strength $E = V / d$ **C1**

95 000 V m^{-1} **or** NC^{-1} **A1**

(2)

(ii) weight = Eq **C1**

3.16 (3.2) × 10^{-19} C e.c.f. for E **A1**

(2)

(iii) charge is negative **M1**

force must be upwards to oppose gravity or oppose weight **A1**

charge must be attracted to positive (top)(upper) plate **A1**

or force is opposite to direction of electric field

(3)

(c) force = $q^2 / 4\pi\varepsilon_0 r^2$ e.c.f. for q **C1**

correct substitution of data **C1**

$(9 - 10) \times 10^{-20}$ N **A1**

compares answer with weight **B1**

N.B. no s.f. penalty here

use of charge that has not been **calculated** in (b)(ii)

gets 2 max of first 3 marks

(4)

[16]

11 (a) (i) weight [or force of gravity] pulls droplet down **(1)**
no electric force to counteract weight s **(1)**
viscous force increases with speed**(1)**
weight = viscous force at terminal speed**(1)**

(ii) viscous force = $6\pi\eta\, rv$ **(1)**

weight = $\frac{4}{3}\pi r^3 \rho g$ **(1)**

$\frac{4}{3}\pi r^3 \rho g = 6\pi\eta\, rv$ to give desired equation showing working **(1)**

max 6

(b) (i) $r^2 \left(= \frac{9\eta v}{2\rho g}\right) = \frac{9 \times 1.8 \times 10^{-5} \times 1.20 \times 10^{-3}}{2 \times 9.8 \times 950 \times 15.5}$ **(1)** (= 6.7×10^{-13} m^2)

$r = 8.2 \times 10^{-7}$ (m) **(1)**

$m \left(= \frac{4}{3}\pi r^3 \rho\right) = \frac{4}{3}\pi \times (8.2 \times 10^{-7})^3 \times 950$ **(1)** (= 2.2×10^{-15}` kg)

(ii) $\frac{QV}{d} = mg$ [or $Q = \frac{mgd}{V}$] **(1)**

$Q \left(= \frac{mgd}{V}\right) = \frac{2.2 \times 10^{-15} \times 9.8 \times 5.0 \times 10^{-3}}{225}$ **(1)**

$Q = 4.8 \times 10^{-19}$ **(1)**

6

(c) charge on oil droplet always a multiple of a basic amount **(1)**
basic amount = 1.6×10^{-19} C **(1)**
which is the charge of the electron **(1)**

max 2

[14]

12 (a) At terminal speed (v)), the viscous force on the droplet = its weight

For weight: allow mg or the force of gravity on it

For viscous force: allow 'drag' or 'resistance' or 'friction'

Not upthrust.

$6\pi\eta rv = 4\pi r^3\rho g / 3$ ✓

1

Manipulation leading to $r = (9\eta v / 2\rho g)^{1/2}$) ✓

1

(b) r (can be calculated as above then) used in the formula $m = 4\pi r^3\rho / 3$ to find the droplet mass, m ✓ (WTTE)
Alternative ; (from $6\pi\eta rv = mg$: as all values are known use) $m = 6\pi\eta rv / g$ ✓

1

(c) electric force (or QV / d) = the droplet weight (or mg) ✓

Do not give 1st mark if ***e****V / d given instead of Q V / d*

1

Q =

$$\frac{mgd}{V} = \frac{3.4 \times 10^{-15} \times 9.8(1) \times 15.0 \times 10^{-3}}{1560} = \mathbf{3.2 \times 10^{-19}\ C}\ ✓$$

1

(d) Millikan's conclusion: Electron charge is (-)1.6×10^{-19} C (WTTE) ✓

The charge on each droplet is a whole number × 1.6×10^{-19} C which agrees with Millikan ✓

Student's results suggest -3.2×10^{-19} C as smallest quantum of charge ✓

allow multiple or n, where n is an integer

3

[8]