A-Level Physics

Principles of Milikan’s Experiment

Mark Scheme

Time available: 96 minutes
Marks available: 53 marks

Mark schemes

1. (a) Drop stationary so

Electric force is opposite (in direction) to the weight

AND

electric field downwards/top plate positive/(electric) force towards positive plate so Q negative ✓

Give credit to answers shown on the diagram

Allow forces expressed in symbols

Do not allow suggestion that viscous force is involved

Accept idea that the drop is attracted towards the positive plate.

Accept bottom plate negative as an alternative to top plate positive.

1

(b) (In free fall at terminal speed)

$mg = 6\pi\eta rv$ ✓

Use of m = volume × density AND $V = \frac{4}{3}\pi r^3$ ✓

(to give $r = 5.9 \times 10^{-7}$ m)

(use of volume of sphere and density)

to give answer that rounds to $m = 7.7 \times 10^{-16}$ (kg) ✓

At least 2 sf.

3

(c) $\frac{VQ}{d} - mg = 6\pi\eta rv_2$ ✓ ✓

Convincing algebra combining with $mg = 6\pi\eta rv_1$

to give v_2/v_1 = answer ✓

MP2 is contingent on MP1

2

(d) Use of equation from **(c)** ✓

to show $Q = 4.9 \times 10^{-19}$ C ✓

Evidence of dividing their Q by 1.6×10^{-19} to give a consistent conclusion ✓

Use of means by substitution or manipulation

Accept answer that rounds to between 4.8 and 5.0 × 10^{-19} C

Using the 'show that' value for the mass gives

$Q = 4.96 \times 10^{-19}$ C

Only condone ecf in MP3 for an arithmetic error in the determination of Q.

3

(e) Value of viscosity affects calculation of mass/radius of droplet ✓

'affects' can be either increase or decrease in MP1

Smaller value of viscosity gives smaller force on droplet so smaller calculated weight/mass ✓

In MP2 allow use of relationship between the radius of the drop and the viscosity.

Evidence of MP1 is likely to be seen in MP2.

Do not condone use of $mg = 6\pi\eta rv$ on its own

Ref to equation

AND

as mass is smaller then Q smaller (therefore e smaller). ✓

*Appropriate means either the equation from **(c)** or relationship between weight and electric field force (e.g weight = mg = EQ)*

3

[12]

2. (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 =

$$\frac{mgd}{V} = \frac{3.4 \times 10^{-15} \times 9.8(1) \times 15.0 \times 10^{-3}}{1560}$$ = **3.2×10^{-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 x 10 $^{-19}$ C as smallest quantum of charge ✓

allow multiple or n, where n is an integer

3

[8]

3. (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 = ($4\pi r^3 / 3$) × ρ , (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) ($4\pi r^3 / 3$) × $\rho g = 6\pi\eta r v$ (or rearranged) ✓

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

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

(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) $\boldsymbol{m} = ((4\pi r^3/3) \times \rho) = \frac{4}{3}\pi (1.0\times10^{-6})^3 \times 880) = 3.7\times10^{-15}$ 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)).

$$Q = \left(\frac{mgd}{V} \right) = \frac{3.7\times10^{-15} \times 9.8 \times 6.0\times10^{-3}}{680} \checkmark$$

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 = 3.2×10^{-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* $4.2 (\pm 0.2) \times 10^{-14}$ *N* ✓

Calc for Q = 1e of QV / d to give $2.6(\pm 0.2) \times 10^{-14}$ *N* ✓

Calc for Q =2e of QV / d to give $5.3 (\pm 0.2) \times 10^{-14}$*N* ✓

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

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

Max 4

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4. (a) (i) positive **(1)**

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

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

(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]

5. (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]