Access Tuition

A-Level Physics

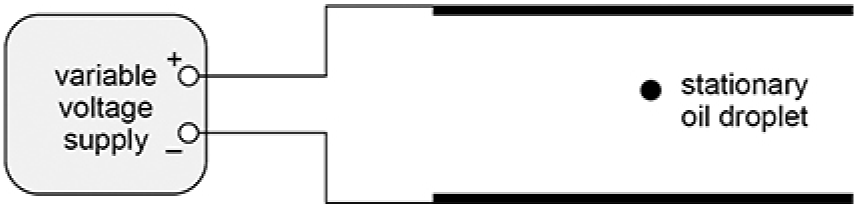
Principles of Milikan's Experiment

Question Paper

Time available: 96 minutes
Marks available: 53 marks

1. Robert Millikan experimented with oil drops to determine a value for the electronic charge.

The diagram below shows a stationary oil droplet between two horizontal metal plates. The plates are connected to a variable voltage supply so that the upper plate is positive. The oil droplet has mass m and charge Q.



(a) State and explain the sign of the charge on the oil droplet.

____

____

____

(1)

The variable voltage supply is set to zero volts. The oil drop falls. The constant speed v_1 of the falling oil droplet is found to be $3.8 \times 10^{-5}\ \mathrm{m\ s^{-1}}$ and the following measurements are recorded:

density of oil = $910\ \mathrm{kg\ m^{-3}}$
viscosity of air = $1.8 \times 10^{-5}\ \mathrm{N\ s\ m^{-2}}$

(b) Show that the mass m of the oil droplet is about $8 \times 10^{-16}\ \mathrm{kg}$.

(3)

(c) The variable voltage supply is adjusted so that the oil droplet rises at a constant speed v_2. The potential difference (pd) across the plates is V and the distance between the plates is d.

In his experiment, Millikan measured the constant speed v_1 of a falling droplet when the pd was zero. He compared this with the speed v_2 of the same droplet when the droplet was made to rise.

Show that $$\frac{v_2}{v_1} = \frac{VQ}{dmg} - 1$$

(2)

(d) The following measurements are made for the droplet in part (b) when it is rising at constant speed.

$V = 715$ V

$v_2 = 1.1 \times 10^{-4}$ m s^{-1}

The separation of the plates $d = 11.6$ mm.

Deduce, using the equation in part (c), whether the value of the charge for this droplet is consistent with the currently accepted value of the electronic charge.

(3)

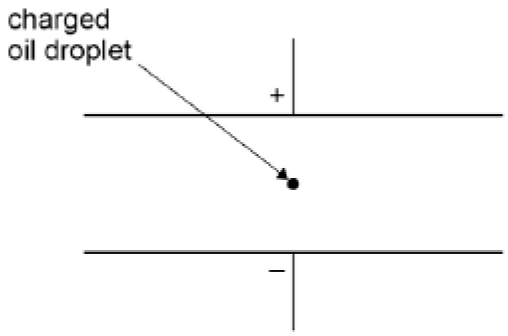
(e) After Millikan published his results, it was found that he had used a value for the viscosity of air that was smaller than the actual value.

Discuss the effect this error had on Millikan's value of the electronic charge.

(3)

(Total 12 marks)

2. In an experiment to measure the charge of the electron, a spherical charged oil droplet of unknown mass is observed between two horizontal parallel metal plates, as shown in the diagram below.



(a) The droplet falls vertically at its terminal speed when the potential difference (pd) between the plates is zero.

A droplet of radius r falls at its terminal velocity, v.

Derive an expression for r in terms of v, η , ρ and g, where η is the viscosity of air and ρ is the density of the oil droplet.

___

___

___

(2)

(b) Explain how the mass of the oil droplet can be calculated from its radius and other relevant data.

___

___

___

(1)

(c) A potential difference (pd) is applied across the plates and is adjusted until the droplet is held stationary. The two horizontal parallel metal plates are 15.0 mm apart. The mass of the droplet is 3.4×10^{-15} kg.

The droplet is held stationary when the pd across the plates is 1560 V.

Calculate the charge of the oil droplet.

charge = ____________________ C

(2)

(d) A student carries out Millikan's oil drop experiment and obtains the following results for the charges on the oil drops that were investigated.

-9.6×10^{-19} C -12.8×10^{-19} C -6.4×10^{-19} C

Discuss the extent to which the student's results support Millikan's conclusion and how the student's conclusion should be different.

____

____

____

____

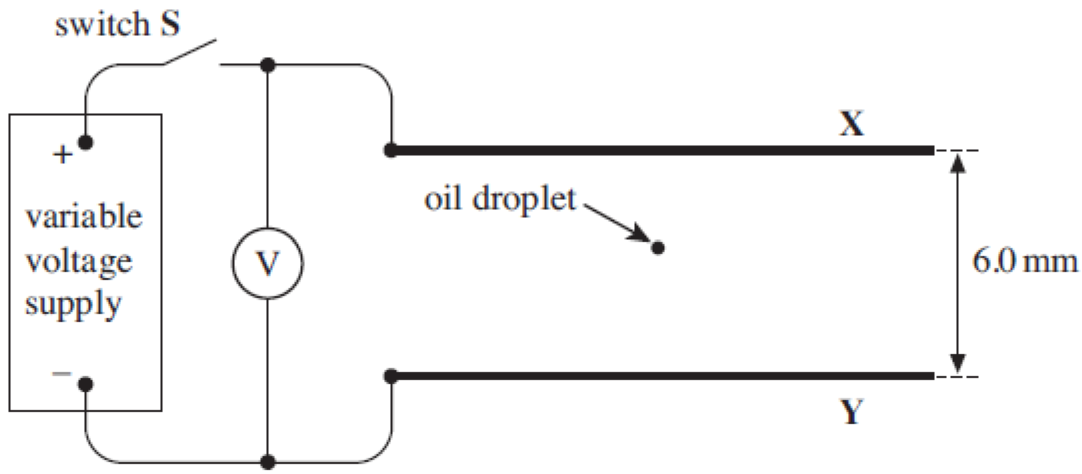
____

____

(3)

(Total 8 marks)

3. A charged oil droplet was observed between two horizontal metal plates **X** and **Y**, as shown in the diagram below.



(a) (i) With the switch **S** open, the droplet fell vertically at a constant velocity of 1.1×10^{-4} ms^{-1}. Show that the radius of the droplet is about 1.0×10^{-6} m. Assume the droplet is spherical.

density of oil, $\rho = 880$ kg m^{-3}
viscosity of air, $\eta = 1.8 \times 10^{-5}$ N s m^{-2}

(4)

(ii) Calculate the mass of the droplet.

mass ____________________ kg

(1)

(iii) The switch **S** was closed and the potential difference from the voltage supply was adjusted gradually to reduce the downward motion of the droplet. The droplet stopped moving when the potential difference across the plates was 680 V. The spacing between the plates was 6.0 mm.

Calculate the magnitude of the charge on the droplet.

charge ____________________ C

(3)

(b) The mass of another charged droplet was found to be 4.3×10^{-15} kg. With switch **S** closed and the voltage supply at its maximum value of 1000 V, this droplet fell more slowly than when the switch was open but it could not be stopped.

Explain why this droplet could not be held at rest and show that the magnitude of the charge on it was 1.6×10^{-19} C.

____

____

____

____

____

____

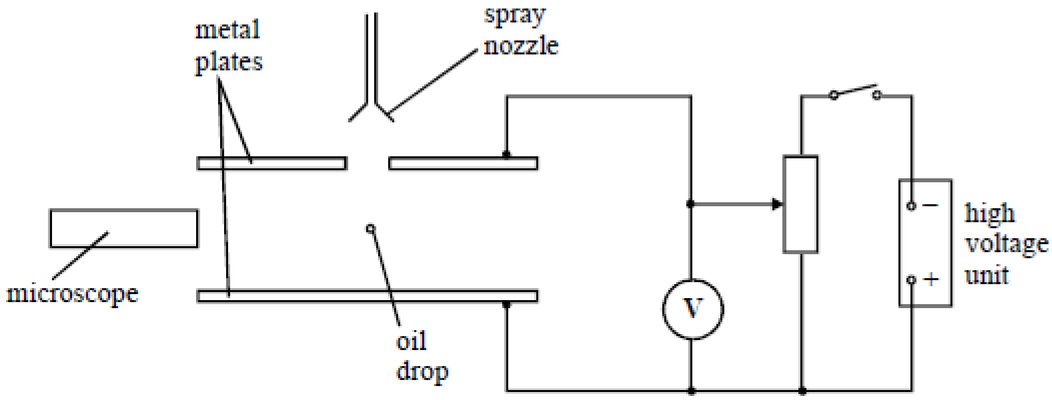
____

____

(4)

(Total 12 marks)

4. A charged oil droplet of mass 46×10^{-16} kg is observed between two horizontal metal plates spaced 40 mm apart.



(a) The droplet is held stationary with the top plate at a potential of −565 V relative to the lower plate.

(i) What is the sign of the charge carried by the droplet?

____

(ii) Calculate the magnitude of the charge on the droplet. Ignore buoyancy effects

____

____

____

____

____

____

(iii) Comment on the significance of this result

____

____

____

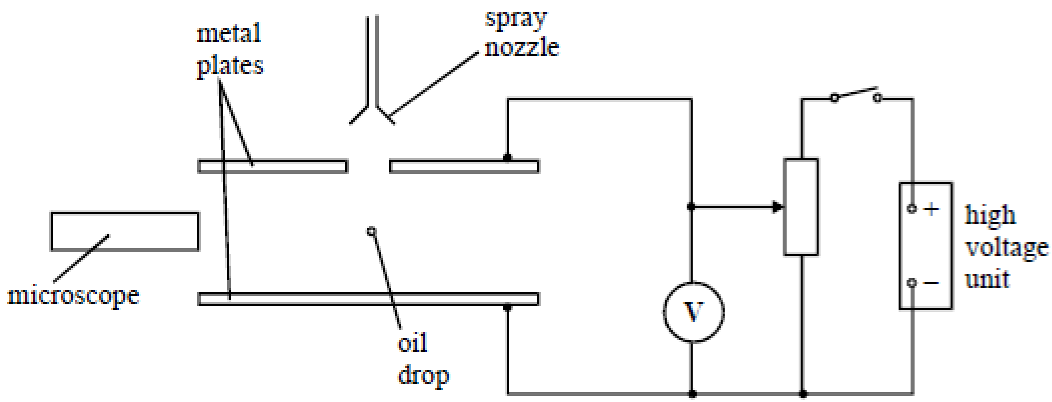
(5)

(b) State and explain the direction in which the droplet would move if the top plate were made more negative relative to the lower plate.

(2)

(Total 7 marks)

5. Millikan determined the charge on individual oil droplets using an arrangement as represented in the diagram. The plate voltage necessary to hold a charged droplet stationary was measured. The time the droplet took to fall a known distance with the plate voltage off was then measured.



(a) (i) Explain why a charged oil droplet reaches a constant speed when the plate voltage is switched off.

(ii) By considering the forces on such a droplet, show that the radius, r, of the droplet is related to the speed, v by

$$r^2 = \frac{9\eta v}{2\rho g},$$

where η is the viscosity of air and ρ is the density of the oil. Ignore the effects of buoyancy.

____

____

____

____

____

____

____

(6)

(b) In an experiment to measure the charge on an oil droplet, a charged droplet was held stationary by a voltage of 225 V between two plates at a separation of 5.0 mm. When the plate voltage was switched off, the droplet descended a vertical distance of 1.20 mm in a time of 15.5 s.
Ignore the effect of buoyancy of the air.

density of oil = 950 kg m^{-3}
viscosity of air = 1.8×10^{-5} N s m^{-2}

(i) Show that the mass of this droplet was 2.2×10^{-15} kg.

____

____

____

____

____

____

____

____

____

(ii) Calculate the charge carried by this droplet.

____

____

____

____

____

(6)

(c) Millikan measured the charge on each of many oil droplets. Explain what he concluded from his measurements.

____

____

____

____

(2)

(Total 14 marks)