**7** Read the passage and answer the questions that follow.

In 1909, Robert Millikan and Harvey Fletcher developed an experiment to determine the fundamental charge of the electron. This was achieved by measuring the charge of oil drops in a known electric field. If each electron has the same charge, then the measured charge on the oil drops must be multiples of the same fundamental constant. Millikan received the Nobel Prize in Physics in 1923 for his precise measurement of this elementary electric charge and for his work on the photoelectric effect.

Fig. 7.1 shows the important features of the apparatus used by Millikan to measure the electron charge by observations on charged oil droplets.

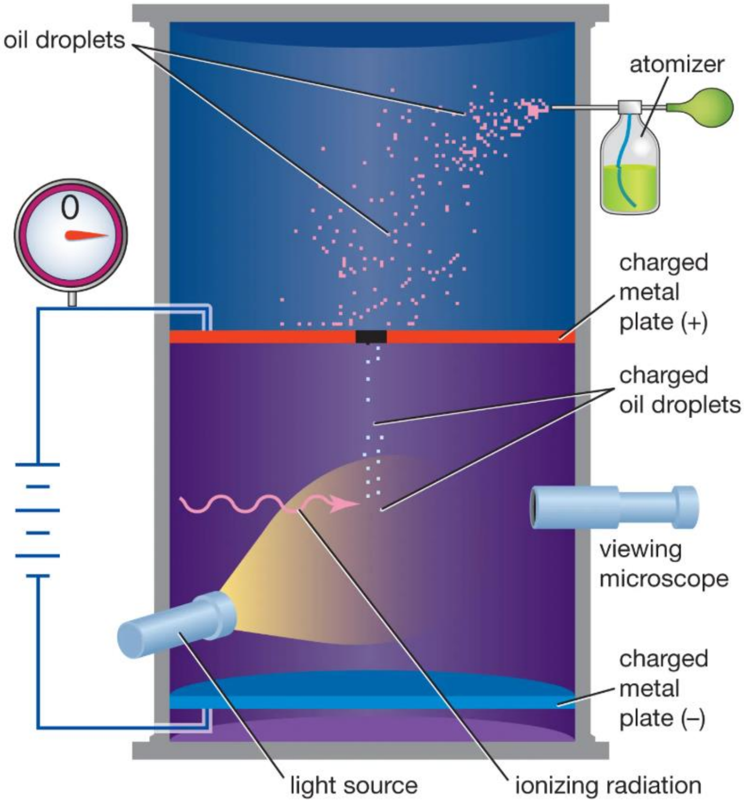



**Fig. 7.1**

In the apparatus, the viewing microscope is focused on the illuminated space under the hole through which oil droplets can enter. The atomizer introduces a mist of oil droplets through the hole in the top plate that is ionized by X-rays, making them negatively charged. When electric field is applied across the charged metal plates, the potential difference, $V$, between the plates can be adjusted until a particular oil droplet is suspended. The value $V$ that suspends that specific oil droplet can then be measured.

By repeating the experiment multiple times with differently sized oil droplets and recording the potential difference used, the charge of each oil droplet can be determined as small integer multiples of a certain base value of electronic charge. It is proposed that this base value is the elementary electric charge $e$.

In this experiment, the mass of the oil droplet is not measured directly using a scale. Instead, it is calculated after the electric field is removed, causing the oil droplets to fall. They quickly reach a terminal velocity which may be measured using a microscope and stopwatch. The weight of an oil droplet is found by timing its fall at terminal speed over a standard distance, when the potential difference across the plates is zero.

Fig. 7.2 shows the relationship between the weight *W* of oil droplets and the time *T* taken by the oil droplets to fall 1.00 mm in air.


**Fig. 7.2**

The results shown in Fig. 7.3 were obtained with a Millikan apparatus.

For each oil droplet, the experimenter measured *V* across the plates at which the droplet was observed to be stationary. The distance between the plates was 4.42 mm.

The experimenter also measured the time *T* for the droplet to fall 1.00 mm in air at terminal speed after switching off the potential difference across the plates.

| $V$ / V | $T$ / s | $W$ / $10^{-14}$ N | $Q$ / $10^{-19}$ C |
|---|---|---|---|
| 770 | 11.2 | 2.9 | 1.66 |
| 230 | 10.0 | 3.4 | 6.53 |
| 1030 | 9.4 | 3.7 | 1.59 |
| 470 | 7.6 | | |
| 820 | 6.9 | 5.9 | 3.18 |
| 395 | 6.2 | 7.0 | 7.83 |

**Fig. 7.3**

At terminal velocity, the gravitational force is balanced by the drag force, $F_D$, which is given by the following equation,

$$F_D = 6\pi \eta r v$$

where $\eta$ is the coefficient of viscosity of the fluid and $r$, the radius of the oil droplet.

The coefficient of viscosity of air at room temperature is $1.8 \times 10^{-5}$ kg m$^{-1}$ s$^{-1}$.

**(a)** **(i)** Besides the elementary charge, state another fundamental constant that Millikan's oil drop experiment helped in determining its value.

……………………………………………………………………………………………… [1]

**(ii)** Explain why the space housing the oil droplets between the metal plates should not be a vacuum.

………………………………………………………………………………………………

……………………………………………………………………………………………… [1]

**(b)** **(i)** Compute the missing values in Fig. 7.3.

$W$ = ………………….. $\times 10^{-14}$ N

$Q$ = ………………….. $\times 10^{-19}$ C [3]

**(ii)** When determining the value of $Q$ in **(b)(i)**, explain why it is reasonable to neglect the upthrust of the oil droplet.

………………………………………………………………………………………………

……………………………………………………………………………………………… [1]

**(iii)** Using Fig. 7.3, determine, to four significant figures, the value of the elementary charge *e* from this experiment.

*e* = …………………... x $10^{-19}$ C [2]

**(c)** **(i)** Measuring the terminal velocity of the droplet using the microscope and stopwatch can be difficult.

Suggest an instrument that can be used to make this measurement more easily.

……………………………………………………………………………………………….. [1]

**(ii)** Suggest why the oil droplets reach terminal velocity so quickly.

…………………………………………………………………………………………………

……………………………………………………………………………………………….. [1]

**(iii)** Calculate the radius of the oil droplet for the last row in Fig. 7.3.

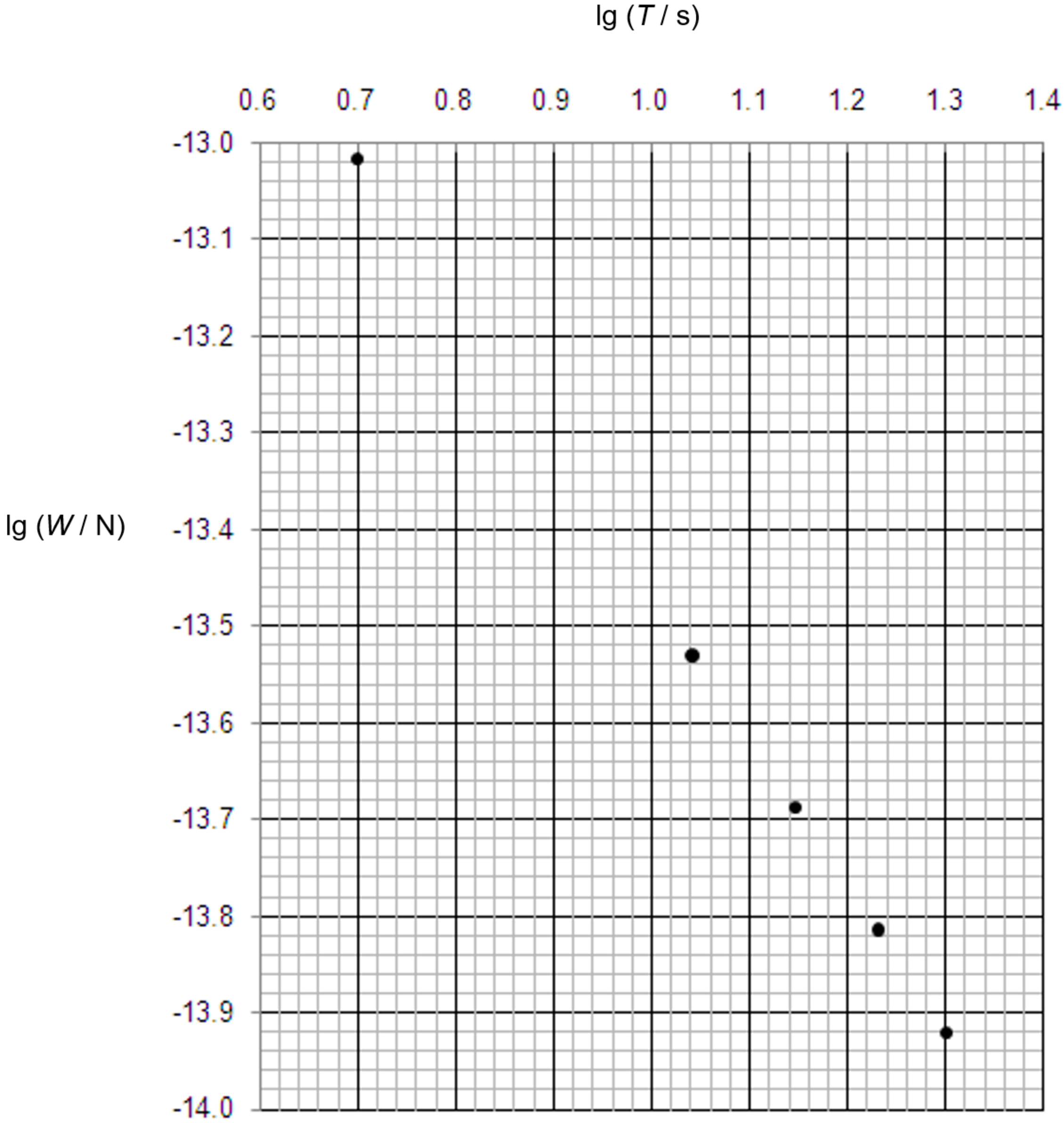
radius = ……………………… m [3]

**(d)** It is thought that, when the potential difference between the plates is zero, the weight $W$ of an oil droplet varies with time, $T$, of its fall (at terminal speed over a standard distance) according to the equation

$$W = aT^{b} \qquad \text{----------} \qquad (1)$$

where $a$ and $b$ are constants.

Some data from Fig. 7.2 are used to plot the graph of Fig. 7.4




**Fig, 7.4**

**(i)** Use Fig. 7.2 to determine lg ($W$ / N) for $T$ = 8.0 s.

lg ($W$ / N) = …………………………………… [1]

**(ii)** On. Fig. 7.4,

**1.** plot the point corresponding to $T$ = 8.0 s, [1]

**2.** draw the line of best fit for the points. [1]

**(iii)** Use the line drawn in **(d)(ii)** to determine the constant $b$ in equation (1).

$b$ = ………………………… [2]

**(iv)** Deduce, from your value of $b$ in **(d)(iii)**, how the weight $W$ of oil drop would depend on its terminal speed $v$.

[2]

**End of paper**