constant speed up to the top plate. It will require a constant force F to do this, because the electric field would push it down. The work done on it against the electric field will be the force multiplied by the distance moved, Fd. This quantity of work done can be calculated in another way. Potential difference V is always work done per unit charge, so

$\frac{Fd}{q} = V$, which can be reorganised into $\frac{V}{d} = \frac{F}{q}$

V/d is called the **potential gradient**, and we have already defined F/q (or F/Q) as the electric field strength E. We have therefore two alternative ways of finding the electric field strength E.

$E = \frac{V}{d}$ and also $E = \frac{F}{q}$

Worked example

Oil of density 810 kg m^{-3} is sprayed as a fine mist into the space between two horizontal parallel plates, which are 5.0 mm apart. One oil droplet of radius 5.6×10^{-7} m has a charge on it equal to the charge on a single electron. This droplet is observed through a microscope to remain stationary between the plates when there is a potential difference of 183 V across the plates, as shown in Figure 3. Calculate the charge on an electron.

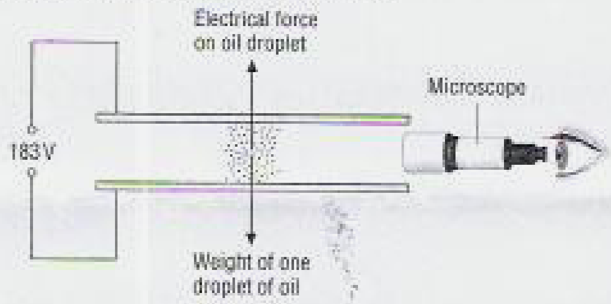

Figure 3 A fine mist of oil drops is viewed in an electric field

Answer

volume of droplet = volume of a sphere of radius r

$= 4\pi r^3/3 = 4\pi \times (5.6 \times 10^{-7})^3/3 = 7.36 \times 10^{-19}$ m^3

mass of droplet = 7.36×10^{-19} m$^3 \times 810$ kg m$^{-3} = 5.96 \times 10^{-16}$ kg

weight of droplet = $mg = 5.96 \times 10^{-16}$ kg $\times 9.81$ N kg$^{-1} = 5.84 \times 10^{-15}$ N

Since the droplet is stationary, the weight of the droplet acting downwards must be balanced by the electrical force acting upwards.

From the definition of electric field strength, $E = F/q$

giving $Eq = 5.84 \times 10^{-15}$.

Now, using the other way of finding the field, $E = V/d = 183$ V/0.0050 m

$= 36\,600$ V m^{-1}.

Finally, $36\,600 \times q = 5.84 \times 10^{-15}$ and $q = 5.84 \times 10^{-15}/36\,600 = 1.60 \times 10^{-19}$ C.

Question

1 The force between two equal point charges of 6.0×10^{-12} C a distance of 9.0 mm apart is 4.0×10^{-9} N.

(a) Calculate the force between the charges when **(i)** one charge changes to 9.0×10^{-12} C or **(ii)** the distance between them changes to 12 mm.

(b) Calculate the magnitude of the electric field strength at either charge.

(c) Use Coulomb's law and the definition of electric field strength to show that the electric field strength E at a distance r from a point charge Q is given by $E = kQ/r^2$.

Key definition

Potential gradient = electric field strength = V/d.

Examiner tip

Don't forget there are two equations for electric field strength. Some candidates remember only electric field directly from its definition as $E = F/q$. Some others remember it only as the potential gradient $E = V/d$. In practice there are many occasions when *both* equations are required.

STRETCH and CHALLENGE

Comments on worked example

The worked example is based on the first determination of the charge on the electron, achieved by Millikan. He won a Nobel prize for his work in 1923. The main difficulty he had was in measuring the size of the oil drops he was using. After measuring the p.d. required to hold a droplet still, he switched off the electric field and let them drift downwards in air and then calculated their radius from a measurement of their terminal velocity. Getting a single electron charge on a drop is not that difficult. Most drops will not stay still, because they are uncharged or are charged positively. It is therefore easy to find a drop that can be controlled by the applied voltage.

Question

Millikan, using units other than SI units, found the charge on several oil drops to be −6.0, −12.1, −15.0, −17.8, −27.1 and −32.7. What value does this give for the charge on the electron in his units?