Charged particles (answers to selected structured questions)

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Forces acting on a stationary charged droplet are weight *W*, upthrust *U* and electric force F_E. *W* acts downwards while *U* and F_E act upwards.

The relationship between them: $W = U + F_E$

If the separation of the plates were slowly reduced, keeping the p.d. between the plates constant, the electric field strength (given by $\frac{\text{p.d.}}{\text{separation}}$) between the plates would increase. The upwards electric force F_E (= charge x electric field strength) would increase. The resultant force acting on the droplet would no longer be zero but equal to the increased in F_E, acting upwards. The droplet would start to move up with acceleration (given by $\frac{\text{increased in } F_E}{\text{mass of droplet}}$).

The diffraction effects would be apparent in attempting to observe a very small droplet with diameter close to the wavelengths of visible light. The droplet would appear to be a blurred-spot and its diameter could not be measured accurately.

The smallest value is 1.97 x 10^{-9} e.s.u. To find the value of the electronic charge, we employ the following method.

Q / 10^{-9} e.s.u	Divide 1.97	Divide (1.97/2)	Divide (1.97/3)	Divide (1.97/4)
6.87	3.487	6.975	10.462	13.949
4.44	2.254	4.508	6.761	9.015
8.37	4.249	8.497	12.746	16.995
5.39	2.736	5.472	8.208	10.944
1.97	1.000	2.000	3.000	4.000
2.96	1.503	3.005	4.508	6.010

Within experimental error, the electronic charge is 4.93 x 10^{-10} e.s.u.

The conversion factor is 1 e.s.u. = 1.6 x 10^{-19}/ 4.925 x 10^{-10} = 3.25 x 10^{-10} C

Quantization of charge means that the charge is not a continuous variable, it is a discrete variable. Any charge is make up of integer multiples of a basic unit which in this case is the elementary charge 1.6 x 10^{-19} C (i.e. the possible charges in this universe are *e*, 2*e*, 3*e*, 4*e*, … *Ze*, where *Z* is an integer).

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The radius of the cylinder is R = 5 cm.

The magnetic field B is applied perpendicularly into the paper and uniformly over the cylinder.

The electron beam enters the field with a speed v. It is deflected within the cylinder and travels in a circular path of radius r, as shown in the diagram.

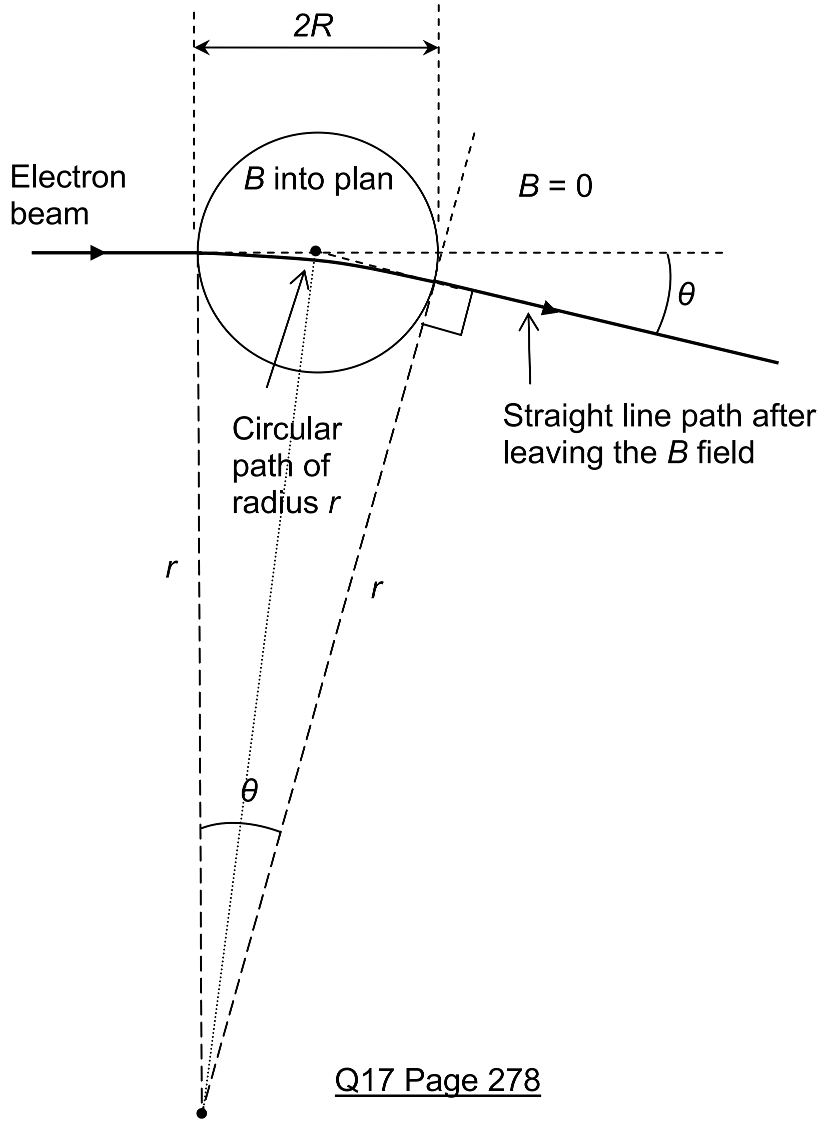
The electrons move along a straight line once they leave the region of B field. It suffers a total deflection of $\theta = 20^o$.

Within the cylinder, the magnetic force provides the centripetal force:

$$evB = \frac{m_e v^2}{r} \text{ or } v = \frac{erB}{m_e} = (\frac{e}{m_e})rB$$

From the sketch, $\tan\frac{\theta}{2} = \frac{R}{r}$, so $r = \frac{R}{\tan\frac{\theta}{2}} = \frac{0.05}{\tan 10^o} = 0.284$

Thus, $v = (1.8x10^{11})(r)(1x10^{-3}) = 5.1x10^7 \text{ ms}^{-1}$



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In 1909, Millikan did the oil-drop experiment to measure the charge of the electron. Repeating the experiment for many charged oil droplets, he showed that the results were always integer multiples of a common value. This was taken to be the charge on a single electron.

The actual discovery of the electron, however, was made in 1897 by J. J. Thomson, who showed that cathode rays are composed of electrons and who measured the ratio of charge to mass for the electron. Combining this result and that of Millikan's oil-drop experiment gives the mass of the electron (about 1/1,840 of the mass of the proton).

(a) The magnetic force, being perpendicular to both electron velocity and magnetic field at every instant, changes only the direction of electron velocity. The magnitude of electron velocity remains constant. The magnitude of the magnetic force, given by *evB*, is thus constant. This force causes the direction of electron velocity to change at a constant rate at every point of the motion, i.e. the electrons go round in a path of constant curvature – a circle.

(b) According to Fleming's left-hand rule, the direction of the magnetic flux is perpendicular to and into the plane of diagram.

(c) $eV = \frac{1}{2}m_e v^2$ or $v = \sqrt{\frac{2eV}{m_e}} = \sqrt{2(\frac{e}{m_e})V}$

(d) $evB = \frac{mv^2}{R}$ or $\frac{e}{m_e} = \frac{v}{BR} = \frac{\sqrt{2(\frac{e}{m_e})V}}{BR}$, i.e. $\frac{e}{m_e} = \frac{2V}{B^2R^2}$

For the proton beam, the *B* is reversed and *R* remains the same.

$$\frac{e}{m_p} = \frac{2V'}{B^2R^2}$$

Taking the ratio of specific charges, we have $\frac{\frac{e}{m_e}}{\frac{e}{m_p}} = \frac{V}{V'}$

or $V' = (\frac{m_e}{m_p})V \approx (\frac{1}{1833})V$

Changes needed to measure specific charge of a proton: apply a smaller p.d. (about $\frac{1}{1833}$ times that for electrons) and reverse its polarities between *C* and S_1: