19. An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV. enters a region with uniform magnetic field of 0.15 T. Determine the trajectory of the electron, if the field (a) is transverse to its initial velocity (b) make an angle of 30° with the initial velocity.

Ans Given potential difference $V = 2kV = 2000V$,

Charge on electron $e = 1.6 \times 10^{-19} C$,

Mass of electron $m_e = 9.1 \times 10$

The electron is accelerated due to the applied potential difference which gives the kinetic energy to the electron. let v be the velocity of electron.

$$eV = \frac{1}{2} m_e v^2$$

$$1.6 \times 10^{-19} \times 2000 = \frac{1}{2} \times 9.1 \times 10^{-31} v^2$$

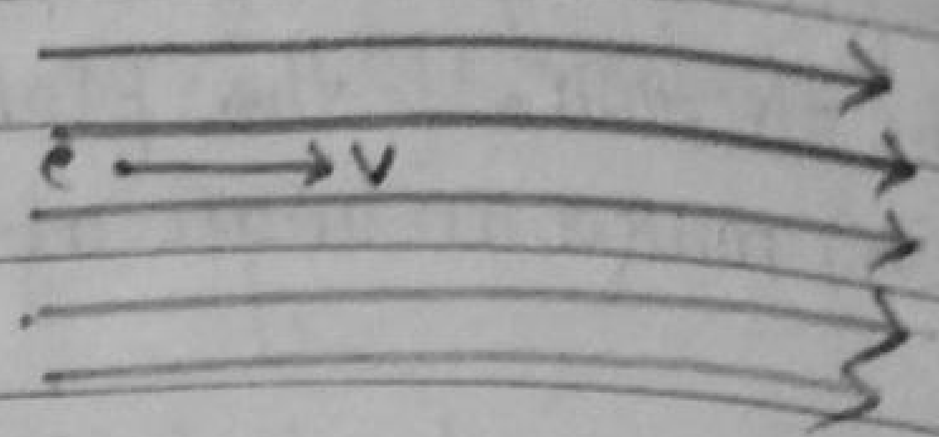
$$v^2 = \frac{1.6 \times 10^{-19} \times 2000 \times 2}{9.1 \times 10^{-31}}$$

$$v = \frac{8 \times 10^7}{3} m/s = 2.7 \times 10^7 m/s.$$

(a) Magnetic field $B = 0.15T$, the direction of field is transverse to the initial velocity of the electron.

Here the magnetic Force $F = Bev$ and the direction of force perpendicular to the magnetic (by right hand palm rule) the electron moves on a circular path. The magnetic force provides the centripetal force to the electron.

$$Bev = \frac{mv^2}{r}.$$



Where r is the radius of circular path.

$$r = \frac{mv}{Be}$$

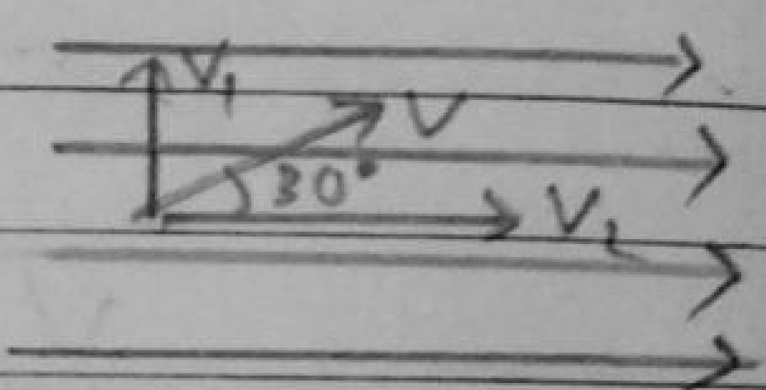
$$= \frac{9.1 \times 10^{-31} \times 8 \times 10^{7}}{3 \times 10.15 \times 1.6 \times 10^{-19}}.$$

$$= 10^{-3} m$$

$$= 1 mm.$$

(b) As the electron enters in the magnetic field at an angle 30° to the field.

Here the vertical component of velocity is v_1 and the horizontal component of velocity is v_2.



$$v_1 = V \sin 30° = \frac{8 \times 10^{7} \times 1}{3 \times 2}$$

$$= \frac{4 \times 10^{7}}{3} m/s.$$

$$V_2 = V \cos 30° = \frac{8 \times 10^{7} \times \sqrt{3}}{3 \times 2}$$

$$= \frac{4\sqrt{3} \times 10^{7}}{3} m/s.$$

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There is no force acting on the particle due to the horizontal component of velocity as v_2 is parallel to B and $F = q(v_2 \times B)$ is zero. The force on the electron is only due to the vertical component the velocity i.e v_1

$$F = e(v_1 \times B) = ev_1 B \sin 90^\circ$$

This force gives the centripetal force to the electron.

$$ev_1 B = \frac{mv_1^2}{r'}$$

$$= \frac{mv_1}{eB} = \frac{9.1 \times 10^{-31} \times 4 \times 10^7}{3 \times 1.6 \times 10^{-19} \times 0.15}$$

$$r' = 0.5 \times 10^{-3}\, m = 0.5\, mm.$$

20. A magnetic field using Helmholtz coils (described in Q.16) is uniform in a small region and has a magnitude of 0.75 T. In the same region, uniform electrostatic field is maintained in a direction normal to the common axis of the coils. A narrow beam of (single species) charged particle all accelerated through 15 kV enters this region in a direction perpendicular to both the axis of the coil and the electrostatic field. If the beam remains undeflected when the electrostatic field is 9×10^{-5} V/m make a simple guess as to what the beam contains. why is the answer not unique.

Ans Given, the magnitude of magnetic field $B = 0.75T$.

Potential difference $V = 15kV = 15 \times 10^3 V$.

Electric field $E = 9 \times 10^{-5} V/m$.

Let q be the charge and m be the mass of the particle and the velocity acquired by the particle is v as they are accelerated by potential difference of 15kV.

The energy due to the potential difference gives the kinetic energy to the particle.

$$qV = \frac{1}{2} mv^2.$$

As the charge particle is not deflected as magnetic and electric field apply. That means the force due to the magnetic force is balanced by the force due to electric field.

$$qE = q(v \times B)$$

$$qE = qvB.$$

$$v = \frac{E}{B}.$$

Putting this value in eq (1) we get:

$$\frac{1}{2} m \left(\frac{E}{B}\right)^2 = eV.$$

$$\frac{e}{m} = \frac{E^2}{2VB^2} = \frac{(9 \times 10^5)^2}{2 \times 15000 \times (0.75)^2} = 4.8 \times 10^7 \, C/kg.$$

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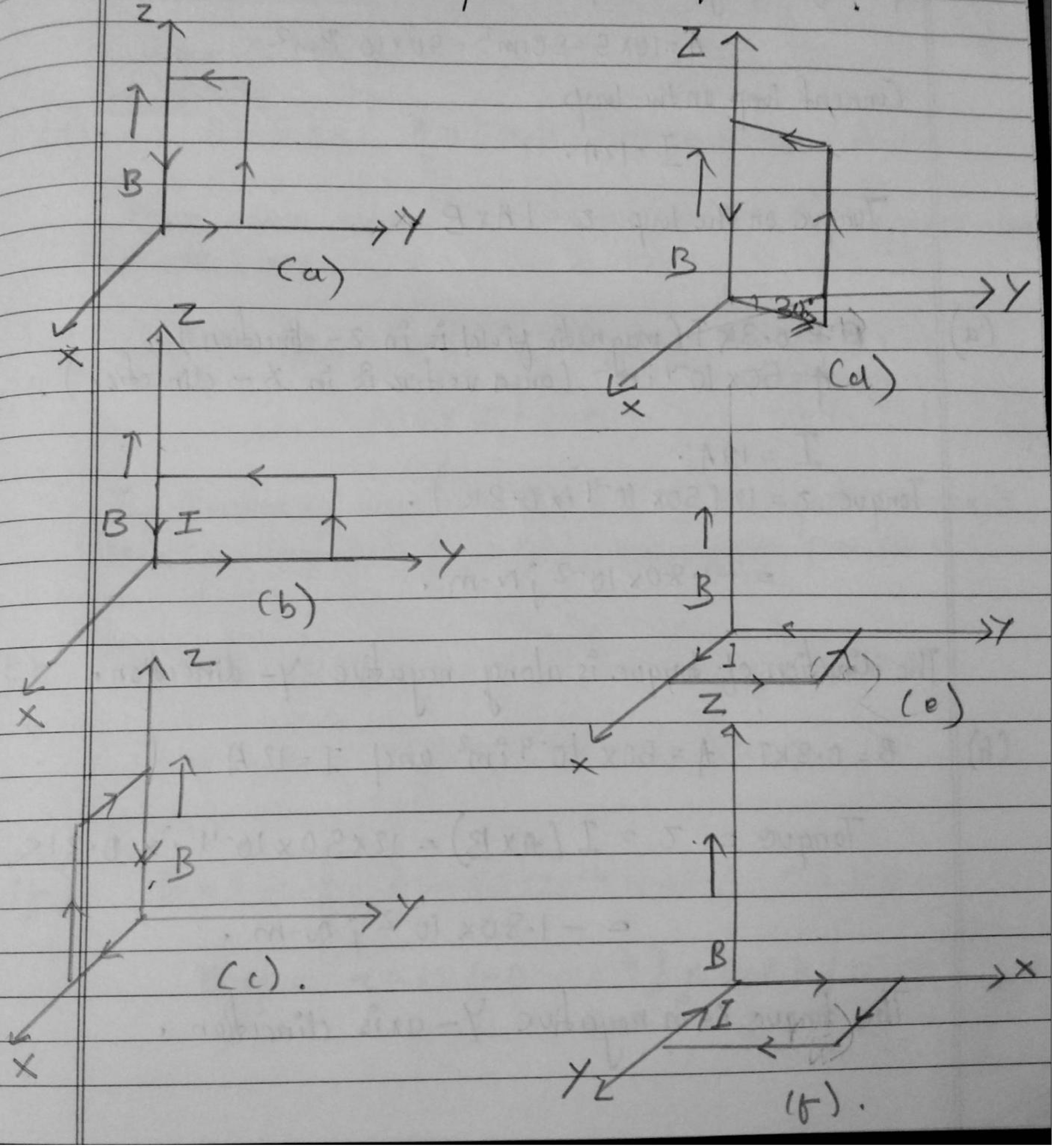
24. A uniform magnetic field of 3000 G is established along the positive Z-direction. A rectangular loop of sides 10 cm and 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in figures. What is the force in each case? Which case corresponds to stable equilibrium?



Ans Given uniform magnetic field along z-axis.

$B = 3000\,G = 3000 \times 10^{-4}$
$= 0.3T$.

Area of rectangular loop.

$A = 10 \times 5 = 50\,cm^2 = 50 \times 10^{-4} m^2$

Current loop on the loop

$I = 12A$.

Torque on the loop $\tau = IA \times B$.

(a) $B = 0.3k\,T$ (magnetic field is in z-direction).
$A = 50 \times 10^{-4}\, i\, m^2$ (area vector is in x-direction).

$I = 12A$.

Torque $\tau = 12(50 \times 10^{-4}\, i \times 0.3k)$.

$= -1.80 \times 10^{-2}\, j\, N\text{-}m$.

The direction of torque is along negative Y-direction.

(b) $B = 0.3kT$, $A = 50 \times 10^{-4}\, i m^2$ and $I = 12A$.

Torque $= \tau = I(A \times B) = 12 \times 50 \times 10^{-4}\, i \times 0.3k$

$= -1.80 \times 10^{-2}\, j\, N\text{-}m$.

The torque is in negative Y-axis direction.

(c) $B = 0.3\hat{k}T$ $A = 50\times10^{-4}(-\hat{j})m^2$ $I = 12A$.

Torque $\tau = 12(-50\times10^{-4}\hat{j}\times0.3\hat{k})$.

$= -1.80\times10^{-2}\hat{i}$ N.m.

Torque is in negative X-axis direction.

(d) $B = 0.3\hat{k}T$ $A = 50\times10^{-4}m^2$ and $I = 12A$.

Here, area vector is in xy-plane which is perpendicular to z-axis.

Torque $\tau = 12\times50\times10^{-4}\times0.3$

$= 1.80\times10^{-2}$ N.m.

The direction of torque is $(90^\circ + 30^\circ)$ from negative x-axis or we can say that $360^\circ - 120^\circ = 240^\circ$ from positive x-axis.

(e) $B = 0.3\hat{k}T$ $A = 50\times10^{-4}\hat{k}m^2$ and $I = 12A$.

Torque $\tau = 12(50\times10^{-4}\hat{k}\times0.3\hat{k}) = 0$.

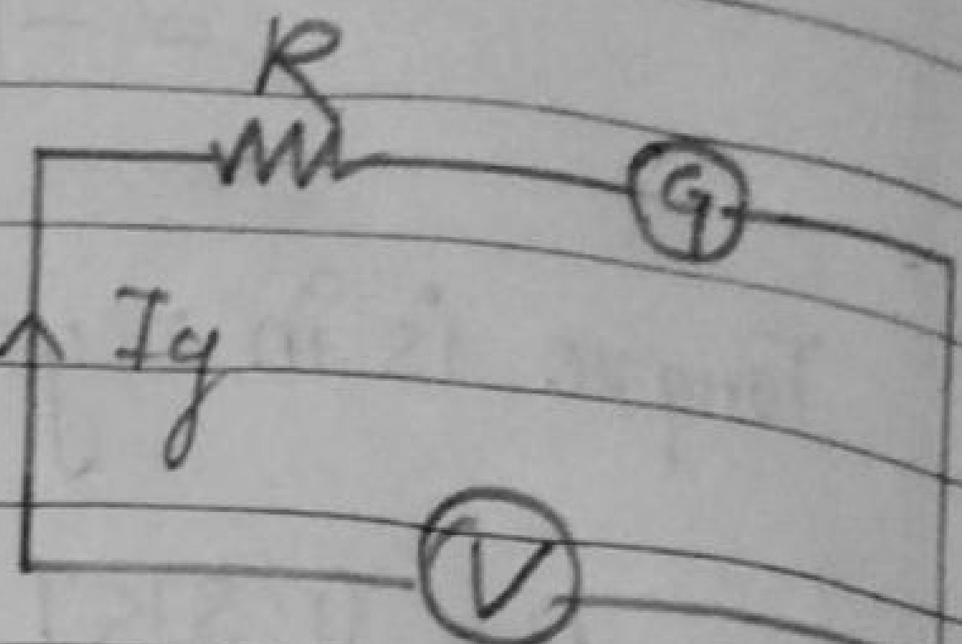
(f) $B = 0.3\hat{k}T$ $A = -50\times10^{-4}\hat{k}m^2$ $I = 12A$.

Torque $\tau = 12(-50\times10^{-4}\hat{k}\times0.3\hat{k}) = 0$.

27. A galvanometer coil has a resistance of 12 Ω and the meter shows full scale deflection for a current of 3mA. How will you convert the meter into a voltmeter of range 0 to 18 V?

Ans Given resistance of galvanometer coil

$G = 12\ \Omega$.



Current in galvanometer $I_g = 3\,mA$

$= 3 \times 10^{-3}\,A$.

potential difference $V = 18\,V$.

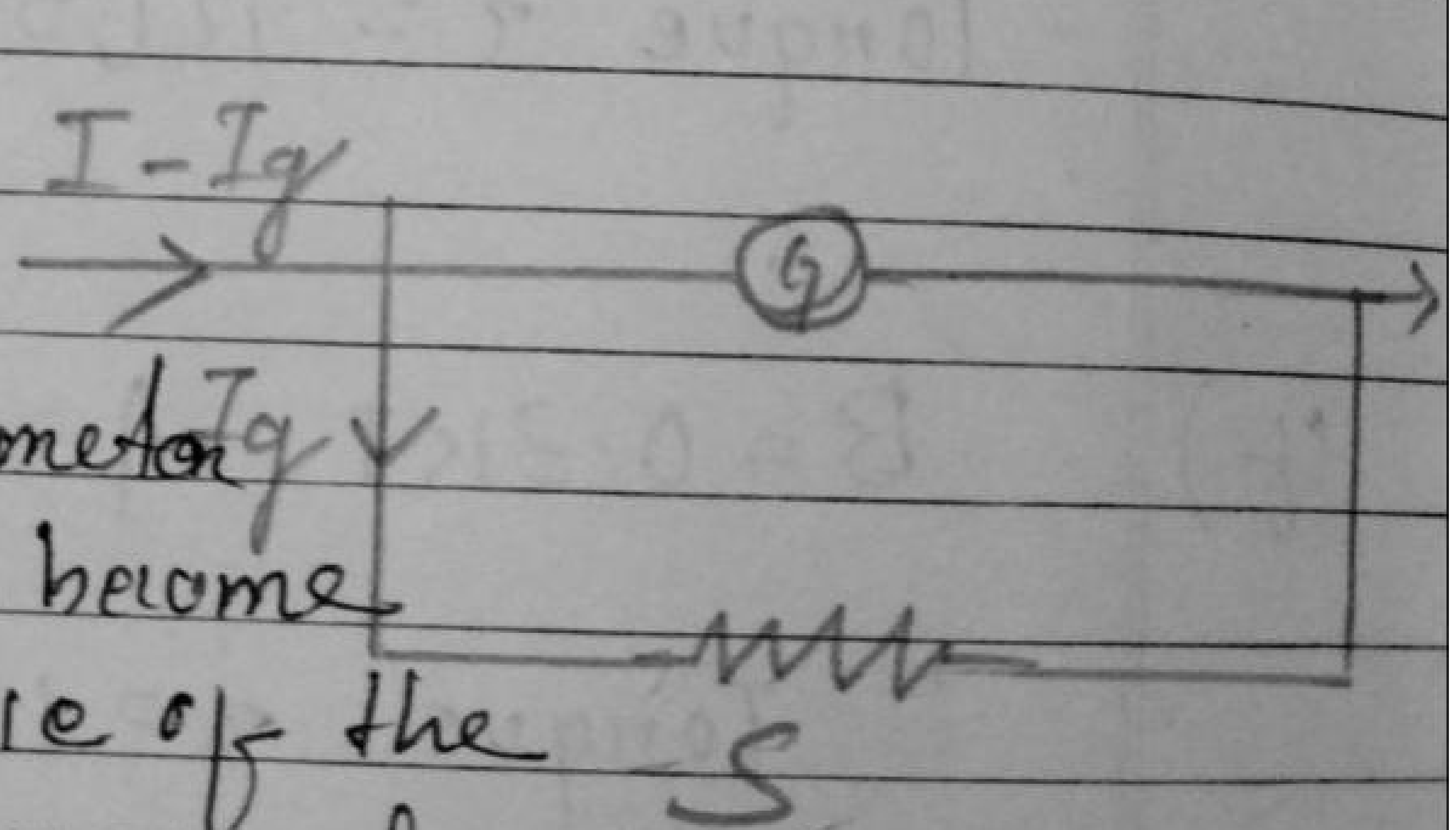
We can convert the galvanometer into voltmeter by using a large resistance R in series. The resistance can be converted using the formula.

$$R = \frac{V}{I_g} - G$$

$$R = \frac{18}{3 \times 10^{-3}} - 12.$$

$$= 5988\ \Omega.$$

This resistance ($R = 5988\ \Omega$) is connected in series with the galvanometer. The resistance is connected in series because we have to increase the resistance of the galvanometer, so that almost no current



flows through it and it gives the exect value of potential difference.

28. A galvanometer coil has a resistance of 15Ω and the meter shows full scale deflection for a current of 4mA. How will you convert the meter into an ammeter of range 0 to 6A?

Ans Given Resistance of galvanometer coil $G = 15\Omega$.

Current in galvanometer $I_g = 4 \times 10^{-3}$ A; Current range $I = 6$ A

By connecting a small resistance S called shunt in parallel to the galvanometer it is converted into ammeter.

The required resistance (shunt) can be calculated by the formula

$$\text{Shunt } S = \frac{I_g \cdot G}{I - I_g} = \frac{4 \times 10^{-3} \times 15}{6 - 4 \times 10^{-3}} = 0.01\Omega.$$

This resistance ($S = 0.01\Omega$) is connected in parallel with the galvanometer. The small resistance is connected in parallel, become we have to decrease the resistance of the galvanometer, so the most of the current passes through it and it gives the exact value of the current