ELECTROMAGNETICS

2. GALVANOMETERS

POINTS TO REMEMBER

1. **Tangent Galvanometer:** If works on the principle of tangent law. The current passing through the coil given by $i = \frac{2rB_H \tan\theta}{\mu_0 n}$ or $i = K\tan\theta$.
2. **Torque Acting on the rectangular current carrying coil of N turns in uniform magnetic field is given by** $\tau = BiAN\sin\theta$

   In vector form, $\vec{\tau} = Ni\left(\vec{A}\times\vec{B}\right)$

3. **Moving Coil Galvanometer:** $i = \left(\frac{C}{BAN}\right)\theta$. Here C is the couple per unit twist on the suspension fibre, 'i' is the current passing through the galvanometer coil and θ is the angle of deflection by the needle.
4. **Shunt:** A small resistance connected in parallel to the moving coil galvanometer to protect it from high currents is called shunt. $S = \frac{i_g G}{i - i_g}$

   or $S = \frac{G}{n-1}$ Where $n = \frac{i}{i_g}$ is called the range of the ammeter.
5. Galvanometer can be converted in to Ammeter by connecting low resistance parallel to it.
6. Galvanometer is converted into voltmeter by connecting high resistance in series to it. $V = i_g\left[R+G\right]$ $\Rightarrow R = \frac{v}{i_g} - G$ = G(n – 1)

   Where $n = \frac{v}{i_g G}$ is called the range of the voltmeter.
7. In order to increase the range of the voltmeter from v_1 to v_2, then the resistance that should be connected in series is,
   R = G(n – 1)

LONG ANSWER QUESTIONS

1. **Obtain an expression for the torque on a current loop in a magnetic field. Describe the construction and working of a moving coil galvanometer. (June2010,March2010, May2009)**

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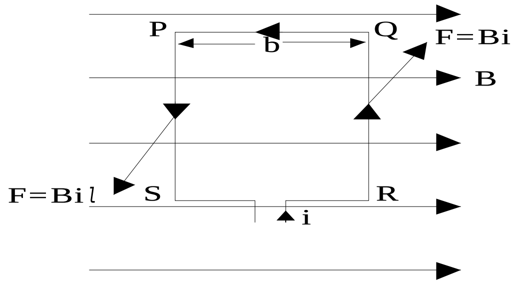
Ans Consider a rectangular current carrying coil suspended in uniform magnetic field of induction B. Let '*l*' be the length 'b' is the breadth 'A' is the area of cross – section and 'n' be the number of turns of the coil. Let 'I' be the current passing through the coil.



The force acting on the sides PQ and RS is zero because they are parallel to magnetic field. According to Flemings' left hand rule, the force F = Bil acts along QR into the plane of the paper. The force F = Bil acts along RS outside the plane of the paper. These two forces are equal, opposite, parallel and non – collinear and constitute a couple and the magnitude of the couple is given by torque

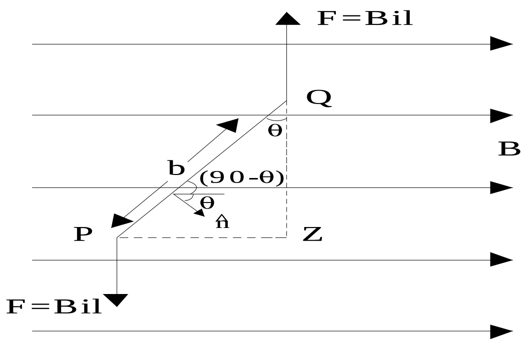
Therefore, Torque τ = F × perpendicular distance. = (Bil) (b) = BiA

If the coil has "N' turns, $\tau = BiAN$

If the plane of the coil makes some angle with the magnetic field :

Let 'θ' is the angle made by the normal to the plane of the coil with magnetic field then,

Torque acting on the coil = $(Bil)(PZ) = BiA\sin\theta \quad (\therefore PZ = b\,Sin\,\theta)$



If the coil consists of 'N' turns, $\tau = BiAN\sin\theta$

In vectorial form, $\vec{\tau} = Ni\left(\vec{A}\times\vec{B}\right)$

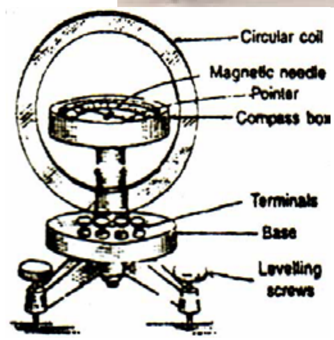
2. Describe tangent galvanometer with necessary theory? Compare it with moving coil galvanometer. (March2011)

Ans. T.G. is a moving magnet type galvanometer consisting of a vertical circular coil of certain number of turns. This circular frame is mounted vertically on a horizontal base provided with leveling screws on the base. The coil can be rotated on a vertical axis passing through its centre. A compass box is mounted horizontally at the centre of circular coil. The magnetic needle is free to rotate in horizontal at the centre of circular coil. The magnetic needle is free to rotate in horizontal plane. A long thin aluminium pointer is attached to the needle at its centre and at right angle to it. To avoid parallax error a plane mirror is mounted between the magnetic needle.

<u>Principle</u>: From the tangent law of magnetism,

$B = B_H \tan\theta$, where B is magnetic induction field due to the current carrying coil and B_H is Earth's magnetic field. 'θ' is angle made of needle from magnetic meridian.

When a current is passed through the coil a magnetic field of induction $B = \dfrac{\mu_0 ni}{2r}$ is produced perpendicular to the plane of coil at its centre.



$$\frac{\mu_0 ni}{2r} = B_H \tan\theta , \qquad \text{(or)}\ i = \left(\frac{2rB_H}{\mu_0 n}\right)\tan\theta$$

Where $\frac{2rB_H}{\mu_o n}$ is called reduction factor (K)of tangent galvanometer.

$$\therefore i = K \tan\theta$$

As current is proportional to tangent of deflection, the galvanometer is called tangent galvanometer (TG)

<u>Distinguish between M.C.G. and T.G</u>.

M.C.G.	T.G.
1. MCG is a moving coil type galvanometer and the coil rotates in a magnetic field when current is passed through the coil.	1. TG is a moving magnet type galvanometer. The magnetic needle rotates when current is passed through the coil.
2. The plane of the coil need not be aligned in magnetic induction.	2. The plane of the coil must be in magnetic meridian..
3. It is accurate and can be used to measure the currents of order 10^{-9} A.	3. It can be used to measure the currents of the order 10^{-6} A.
4. The current flowing through the coil is directly proportional	4. The current flowing in the coil is proportional to the tangent of

to the deflection. $(i \propto \theta)$	deflection. $(i \propto Tan\,\theta)$
5. Stray magnetic fields have no effect on it and can be used for the measurement of the currents even in mines.	5. External fields have effect on it and therefore TG cannot be used in mines.

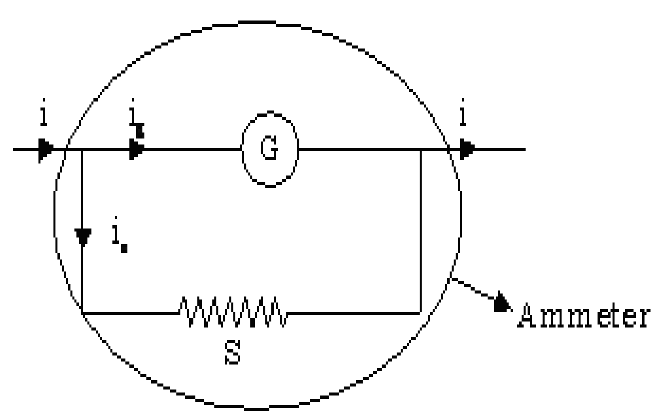
3. How is a galvanometer converted into an ammeter? Why parallel resistance is smaller than galvanometer resistance? Explain.

Ans. **Shunt :-**A galvanometer can be converted into an ammeter by connecting a suitable small resistance in parallel called shunt resistance. Ammeter is used for measuring the current in an electric circuit.

A small resistance connected in parallel to the moving coil galvanometer to protect it from high currents is called shunt.

Let 'R' be the effective resistance between the galvanometer and shunt. Then,

$$R = \frac{GS}{G+S} \qquad \ldots\ldots (1)$$



$$V = i_g G = i_s S = iR$$

Expression for i_g :-

$$i_g G = iR \qquad \Rightarrow i_g G = i\left[\frac{GS}{G+S}\right]$$

$$\therefore i_g = \frac{iS}{G+S}$$

Expression for i_s :-

$$i_s S = iR \qquad \Rightarrow i_s S = i\left[\frac{GS}{G+S}\right]$$

$$\therefore i_s = \frac{iG}{G+S}$$

Expression for shunt:

Form $i_g = \frac{iS}{G+S}$,

$$\frac{i_g}{i} = \frac{S}{G+S} \quad \Rightarrow \frac{G+S}{S} = \frac{i}{i_g} \quad \Rightarrow \frac{G}{S} = \frac{i}{i_g} - 1 \quad \Rightarrow S = \frac{G}{\left[\frac{i}{i_g} - 1\right]}$$

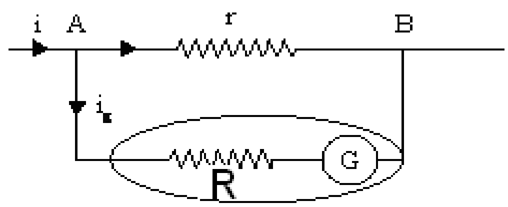
$$\Rightarrow S = \frac{i_g G}{i - i_g}$$

$or\ S = \frac{G}{n-1}$ Where $n = \frac{i}{i_g}$ is called the range of the ammeter.

The inclusion of ammeter in the circuit should not alter the current or total resistance of circuit. Therefore the ammeter should have very low resistance. As such we have parallel resistance to be smaller than galvanometer resistance.

4. How is a galvanometer converted into voltmeter? Why series resistance is greater than galvanometer resistance? Explain.

Ans. Voltmeter is the instrument used for measuring the potential difference between any two points in a circuit. A galvanometer can be converted into voltmeter by connecting a suitable



The arrangement of connecting a high resistance in series to a galvanometer is called voltmeter. A voltmeter should be always connected in parallel to the circuit. An ideal voltmeter should not draw any current hence, its resistance is infinity. In the figure, the potential difference between A and B is given by,

$$V = i_g\left[R + G\right] \quad \Rightarrow R = \frac{v}{i_g} - G = G(n-1)$$

Where $n = \frac{v}{i_g G}$ is called the range of the voltmeter.

Voltmeter has to draw a negligible amount of current from the main current. Therefore it should have very high resistance. Thus, series resistance is greater than galvanometer resistance.

VERY SHORT ANSWER QUESTIONS

1. What is the principle of a tangent galvanometer?

Ans. It works on the principle of tangent law. In a tangent galvanometer, a freely pivoted magnetic needle is placed at the centre of the coil and current 'i' is passed through the coil. Magnetic induction at centre of coil, $B = \frac{\mu_0}{2}\frac{ni}{r}$

This field is perpendicular to earth's magnetic field. So needle deflects.

At equilibrium, $B = B_H \tan\theta$ (or) $\frac{\mu_0}{2}\frac{ni}{r} = B_H \tan\theta$

$\therefore i = \frac{2rB_H}{\mu_0 N}\tan\theta$ (Or) $i = K\tan\theta$ for tangent galvanometer

1. A moving coil galvanometer can measure a current of 10^{-6} A. What is the resistance of the shunt to measure 1Amp?

Ans. $i_g = 10^{-6}\,A$ I = 1Amp; $n = \frac{i}{i_g} = \frac{1}{10^{-6}} = 10^{6}$

$$S = \frac{G}{n-1} = \frac{G}{10^{6}-1} = \frac{G}{99999}\,ohm.$$

3. Distinguish between ammeter and voltmeter

Ans.

Ammeter	Voltmeter
1) Ammeter is a device used to measure current. in amperes.	1) Voltmeter is a device used to measure potential difference in volts.
2) Ammeter is always connected in series in the circuit..	2) Voltmeter is always connected in parallel in the circuit.
3) The resistance of an ammeter is low.	3) The resistance of an voltmeter is high.

4. What is the principle of moving coil galvanometer?

Ans. It works on the principle that a rectangular current carrying coil suspended in uniform magnetic field deflects in the direction perpendicular to both the direction of current and magnetic field. At equilibrium $C\theta = ni\,BA$ or $i = \frac{C}{nBA}\theta$ or $i \propto \theta$.

This is the principle of moving coil galvanometer.

5. What is the smallest value of current that can be measured with a moving coil galvanometer, tangent galvanometer?

Ans. The smallest current that can be measured with a moving coil galvanometer is, $i = 10^{-9}$ amp and few microamperes.

6. How do you convert a moving coil galvanometer into an ammeter?

Ans. To convert a galvanometer into an ammeter, a low resistance called shunt (S) is connected in parallel to galvanometer. Shunt resistance, $S = \frac{G}{n-1}$

7. How do you convert a moving coil galvanometer into a voltmeter? (March2011)

Ans. To convert a galvanometer into voltmeter, a high resistance is connected in series with the galvanometer. Series resistance R = G(n – 1)

SOLVED PROBLEMS

1. A tangent galvanometer has 500 turns, each of radius 2π cm. If $B_H = 3.6\times10^{-5}\,Wb/m^2$ find its reduction factor. Find the deflection due to a 12 mA current.

Sol: i) N = 500, $r = 2\pi\,cm = 2\pi\times10^{-2}\,m, B_H = 3.6\times10^{-5}\,Wb/m^2$.

$$K = \frac{2rB_H}{\mu_0 N} = \frac{2\times2\pi\times10^{-2}\times3.6\times10^{-5}}{4\pi\times10^{-7}\times500} = 7.2\times10^{-3}\,A$$

ii) $i = K\tan\theta$

But i = 12mA $= 12\times10^{-3}\,A$; $K = 7.2\times10^{-3}\,A$

$12\times10^{-3} = 7.2\times10^{-3}\tan\theta$

$\tan\theta = \dfrac{12}{7.2} = 1.6667 \quad \Rightarrow \; \theta = 59^0 2'$.

2. **A tangent galvanometer has 50 turns each of diameter 15cm. when a certain current is passed through its coil, the deflection of the needle is 45^0. If $B_H = 2\times10^{-5}\,Wb/m^2$ and $\mu_0 = 4\pi\times10^{-7}\,Wb/Am$, calculate the value of current.**

Sol: N = 50 ; $r = \dfrac{15}{2} = 7.5\times10^{-2}\,m$

$\theta = 45^0$; $B_H = 2\times10^{-5}\,Wb/m^2$; $\mu_0 = 4\pi\times10^{-7}\,Wb/Am$.

$$i = \frac{2rB_H}{\mu_0 N}\tan\theta = \frac{2\times7.5\times10^{-2}\times2\times10^{-5}}{4\pi\times10^{-7}\times50} = 47.74 \text{ mA}$$

3. **When a current of 20 mA flows through a tangent galvanometer the deflection of the needle is 30^0. When the current is increased to 40 mA what will be the deflection of the needle?**

Sol: i_1 =20 mA= $20\times10^{-3}\,A$; i_2 =40 mA= 40×10^{-3} A; $\theta_1 = 30^0$; $\theta_2 = ?$

$$i = K\tan\theta \quad \Rightarrow \quad \frac{i_1}{i_2} = \frac{\tan\theta_1}{\tan\theta_2}.$$

$$\frac{20\times10^{-3}}{40\times10^{-3}} = \frac{\tan 30^0}{\tan\theta_2}$$

$$\tan\theta_2 = 2\tan\tan 30^0 = 2\times0.5774 = 1.1548;$$

Deflection $\theta_2 = 49^0$.

4. **A rectangular coil of wire of 500 turns of area $10\times5\,cm^2$ carries a current of 2 A in a magnetic induction of $2\times10^{-3}T$. If the plane of the coil is (a) parallel to the field, (b) makes an angle 30^0 to the field calculate the torque on the coil? (March2010)**

Sol: $A = 10\times5\,cm^2 = 50\times10^{-4}\,m^2$; n = 500; B = $2\times10^{-3}\,T$; i =2A

(a) $\theta = 0^0, \tau = ?$

$\tau = BiAn\cos\theta = 2\times10^{-3}\times2\times50\times10^{-4}\times500\times\cos 0^0 = 0.01\,Nm.$

(b) i = 2 A, B= $2\times10^{-3}\,T$, A= $50\times10^{-4}\,m^2$, n = 500, $\theta = 30^0, \tau = ?$

$\tau = B\,i\,An\cos\theta = 2\times10^{-3}\times2\times50\times10^{-4}\times500\times\cos 30^0 = 8.66\times10^{-3}\,Nm$

5. **The coil in a moving coil galvanometer has an area of $4\,cm^2$ and 500 turns. The intensity of magnetic induction is 2T. When a current of 10^{-4} A is passed through it, the deflection is 20^0, find the couple per unit twist.**

Sol: A = $4\,cm^2$ = $4\times10^{-4}\,m^2$, n = 500, B = 2T, $i = 10^{-4}\,A, \theta = 20^0$, C=?

The couple per twist $C = \dfrac{BiAn}{\theta} = \dfrac{2\times10^{-4}\times4\times10^{-4}\times500}{20} = 2.0\times10^{-6}\,Nm$ per degree.

6. **The resistance of a moving coil galvanometer is 0.5 ohm. The maximum current it can measure is 0.015 A. How would you convert it into (a) an ammeter to measure 1.5 A and (b) a volt meter to measure 1.5 V?**

Sol: i =1.5A ; $i_g = 0.015\,A$;G = 5 ohm ; S = ? ; R = ?

(a) $S = \dfrac{Gxi_g}{(i - i_g)} = \dfrac{5\times0.015}{(1.5-0.015)} = 0.0505\,ohm.$

A shunt of value o.0505 ohm must be connected in parallel to the galvanometer.

(b) V = 1.5 V ; i_g = 0.015 A ; G = 5 ohm

$V = i_g (R+G)$

$\therefore 1.5 = 0.015(R+5)$

$R+5 = \frac{1.5}{0.015} = 100$

$\therefore R = 100 - 5 = 95$ ohm.

A resistance value of 95 ohm is connected in series with the voltmeter.

7. A galvanometer of resistance 50 Ω gives full scale deflection when a current 10^{-3} A is passed through it. How can it be converted into an ammeter to measure 0.5 A current?

Sol: G = 50 Ω, $i_g = 0.001 A$, i =0.5 A, S=?

$$S = \frac{Gi_g}{i-i_g} = \frac{50\times 0.001}{0.5-0.001} = \frac{50}{490}\Omega.$$

A shunt of value $\frac{50}{490}\Omega$ in parallel to the galvanometer an ammeter can be constructed to measure 0.5 A current.

8. A galvanometer of resistance 20 Ω is to be shunted so that only 1% of the current passes through it. Calculate the value of shunt?

Sol: G = 20 Ω, If i = 100, then i_g =1.

$$S = \frac{G\ i_g}{i-i_g} = \frac{20\times 1}{100-1} = \frac{20}{99}\Omega.$$

9. A galvanometer has a resistance of 400 Ω. What should be the value of shunt so that its sensitivity is to be reduced by $\frac{1}{50}$ times?

Sol: G = 400 Ω, Sensitivity $= \frac{i_g}{i} = \frac{1}{50}$, S = ?

$$S = \frac{G\ i_g}{i-i_g} = \frac{400}{50-1} = 8.16\Omega$$

UNSOLVED PROBLEMS

1. The area of the coil in a moving coil galvanometer is $16 cm^2$ and has 20 turns. The magnetic induction is 0.2T and the couple per unit twist of the suspended wire is $10^{-6} Nm$ per degree. If the deflection is 45^0, calculate the current passing through it.

Sol: $A = 16\times 10^{-4} m^2$, N = 20, B = 0.2T

$C = 10^{-6} N-m/^0$, $\theta = 45^0$; I = ?

$$NiAB = C\theta \Rightarrow i = \frac{C\theta}{NAB} = \frac{10^{-6}\times 45}{20\times 16\times 10^{-4}\times 0.2} = 0.703\times 10^{-2}\ amp$$

2. A coil of area $100 cm^2$ having 500 turns carries a current of 1mA. It is suspended in a uniform magnetic field of induction $10^{-3} T$. Its plane makes an angle of 60^0 with the lines of induction. Find the torque acting on the coil.

Sol: $A = 10^{-2} m^2$, N = 500, $i = 10^{-3} amp$, $B = 10^{-3} T$

$\theta = 90^0 - 60^0 = 30^0$

Torque, $\tau = NiAB\sin\theta = 500\times10^{-3}\times10^{-2}\times10^{-3}\times\frac{1}{2} = 250\times10^{-8}\ Nm$

3. A galvanometer of resistance 20Ω is shunted by a 2Ω resistor. What part of the main current flows through the meter?

Sol: $G = 20\Omega$, $S = 2\Omega$

$\frac{i_g}{i} = \frac{S}{G+S} = \frac{2}{22} = \frac{1}{11}$

$\therefore i_g = \frac{1}{11}$ th part .

4. A maximum current of 0.5mA can be passed through a galvanometer of resistance 20Ω. Calculate the resistance to be connected in series to convert it into a voltmeter of range 0 - 5v. (May2009)

Sol: $i_g = 0.5\times10^{-3} A$, $G = 20\Omega$, V = 5 volt

$R = \frac{V}{i_g} - G = \frac{0.5}{5\times10^{-4}} - 20 = 9980\Omega$

5. A galvanometer has a resistance of 500 ohm. It is shunted so that its sensitivity decreases by 100 times. Find the shunt resistance.

Sol: $G = 500\Omega$; $n = \frac{i}{i_g} = 100$; S = ?

$S = \frac{G}{n-1} = \frac{500}{99} = 5.05\Omega$ in parallel

6. A galvanometer has a resistance of 100Ω. A current of $10^{-3} A$ pass through the galvanometer. How can it be converted into (a) Ammeter of range 10A and (b) voltmeter of range 10V? (March2010)

Sol: $G = 100\Omega$; $i_g = 10^{-3}\ amp$

a) $i = 10 amp\ n = \frac{i}{i_g} = \frac{10}{10^{-3}} = 10^{-4}$

Shunt, $S = \frac{G}{n-1} - \frac{100}{10^{-4}-1} = \frac{100\Omega}{9999}\Omega$ in parallel

b) V = 10V

$R = \frac{V}{i_g} - G = \frac{10}{10^{-3}} - 100 = 10^4 - 100 = 9900\Omega$ in series

7. The resistance of a galvanometer is 999Ω. A shunt of 1Ω is connected to it. If the main current is 10^{-2} A. What is the current flowing through the galvanometer?

Sol: $G = 999\Omega$; $S = 1\Omega$

$i = i_g + i_g = 1amp$; $i_g = ?$

$i = i_g\left(1 + \frac{G}{S}\right) \Rightarrow 10^{-2} = i_g\ (1000)$

$\therefore i_g = 10^{-5}\ amp$

8. A galvanometer has a resistance of 98Ω. If 2% of the main current is to be passed through the meter, what should be the value of the shunt?

Sol: $G = 98\Omega$; S = ?

$$i_g = \frac{2}{100} i \quad \Rightarrow \frac{i}{i_g} = 50$$

$$S = \frac{G}{n-1}$$

$$\therefore S = \frac{98}{50-1} = \frac{98}{49} = 2ohm$$

ASSESS YOURSELF

1. It is possible to use a tangent galvanometer at poles?

Ans. No.

2. For what deflection the accuracy of tangent galvanometer is maximum?

Ans. 45^0 since the error in the measurement of current di/i is minimum when $\theta = 45^0$.

3. Does the torque on a current loop in magnetic field charge, when its shape is changed without changing its face area?

Ans. No.

4. A current carrying loop area to turn is placed in a uniform magnetic field. What will be its orientation relative to the direction of magnetic field in the equilibrium state?

Ans. The plane of the loop is perpendicular to the direction of magnetic field because the torque on the loop in this orientation is zero.

5. Is the resistance of an ammeter greater than or less than that of the galvanometer of which it is formed?

Ans. It is always less than the resistance of the galvanometer.

6. Is the resistance of a voltmeter greater than or less than that of the galvanometer of which it is formed?

Ans. It is always greater than the resistance of the galvanometer.