**Module detail and its structure**

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| Subject Name | Physics |
| Course Name | Physics 03 (Physics Part 1Class XII) |
| Module Name/Title | Unit-03, **Module-07: Moving Coil Galvanometer**<br>Chapter-04: Moving Charges and Magnetism |
| Module Id | Leph_10407_eContent |
| Pre-requisites | Magnetic field due to straight conductor, Lorentz magnetic force, Force acting on current carrying conductor in magnetic field, Direction of force acting on current carrying conductor in magnetic field, Magnetic moment, Torque acting on a current carrying loop in magnetic field. |
| Objectives | **After going through this module, the learners will be able to**<br>• **State** the principle of Moving Coil Galvanometer<br>• **Justify** the need for radial magnetic field<br>• **Explain** the working of Moving Coil Galvanometer.<br>• **Derive** relationship between deflection in the galvanometer and the current.<br>• **Understand** the meaning of current sensitivity and voltage sensitivity<br>• **Apply** the knowledge of resistances in parallel and series to convert galvanometer into ammeter and voltmeter |
| Keywords | Radial Magnetic Field, Torque on coil, Restoring Torque, Sensitivity of Galvanometer. Ammeter, Voltmeter, figure of merit ,galvanometer constant |

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## 1. UNIT SYLLABUS

**UNIT –III: Magnetic Effects of Current and Magnetism, 10 Modules**

**Chapter-4: Moving Charges and Magnetism**

Concept of magnetic field, Oersted's experiment.

Biot-Savart law and its application to current carrying circular loop.

Ampere's law and its applications to infinitely long straight wire. Straight and toroidal solenoids, Force on a moving charge in uniform magnetic and electric fields. Cyclotron.

Force on a current-carrying conductor in a uniform magnetic field. Force between two parallel current-carrying conductors-definition of ampere. Torque experienced by a current loop in uniform magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter.

**Chapter-5: Magnetism and Matter**

Current loop as a magnetic dipole and its magnetic dipole moment. Magnetic dipole moment of a revolving electron. Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. Torque on a magnetic dipole (bar magnet) in a uniform magnetic field; bar magnet as an equivalent solenoid, magnetic field lines; Earth's magnetic field and magnetic elements.

Para-, dia- and ferro - magnetic substances, with examples. Electromagnets and factors affecting their strengths. Permanent magnets.

## 2. MODULE WISE DISTRIBUTION OF UNIT SYLLABUS 10 MODULES

**The above unit is divided into 10 modules for better understanding**

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| Module 1 | • Introducing moving charges and magnetism<br>• Direction of magnetic field produced by a moving charge<br>• Concept of Magnetic field<br>• Oersted's Experiment<br>• Strength of the magnetic field at a a point due to current carrying conductor<br>• Biot-Savart Law<br>• Comparison of coulomb's law and Biot Savarts law |
| Module 2 | • Applications of Biot- Savart Law to current carrying circular loop, straight wire<br>• Magnetic field due to a straight conductor of finite size<br>Examples |
| Module 3 | • Ampere's Law and its proof<br>• Application of amperes circuital law: straight wire,straight and toroidal solenoids.<br>• Force on a moving charge in a magnetic field<br>• Unit of magnetic field<br>Examples |

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| Module 4 | • Force on moving charges in uniform magnetic field and uniform electric field.<br>• Lorentz force<br>• Cyclotron |
| Module 5 | • Force on a current carrying conductor in uniform magnetic field<br>• Force between two parallel current carrying conductors<br>• Definition of ampere |
| Module 6 | • Torque experienced by a current rectangular loop in uniform magnetic field<br>• Direction of torque acting on current carrying rectangular loop in uniform magnetic field<br>• Orientation of a rectangular current carrying loop in a uniform magnetic field for maximum and minimum potential energy |
| Module 7 | • Moving coil Galvanometer-<br>• Need for radial pole pieces to create a uniform magnetic field<br>• Establish a relation between deflection in the galvanometer and the current<br>• its current sensitivity<br>• Voltage sensitivity<br>• conversion to ammeter and voltmeter<br>Examples |
| Module 8 | • Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis.<br>• Torque on a magnetic dipole in uniform magnetic field.<br>• Explanation of magnetic property of materials |
| Module 9 | • Dia, Para and ferro-magentic substances with examples. Electromagnets and factors affecting their strengths, permanent magnets. |

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| Module 10 | • Earth's magnetic field and magnetic elements. |

## MODULE 7

### 3. WORDS YOU MUST KNOW

Let us remember the words we have been using in our study of this physics course

- **Magnetic field**: The magnetic field at a point may be defined as the force acting on a unit charge moving with a unit velocity at right angle to the direction of the field.
- **S I unit of Magnetic field**: SI unit of magnetic field is tesla (T). The magnetic field is said to be one tesla if a charge of one coulomb moving with a speed of 1 m/s at right angles to the field experience a force of one newton.
- **C G S unit of magnetic field**: cgs unit of magnetic field is gauss (G). 1T = $10^{-4}$G
- **Lorentz magnetic force**: The force acting on moving charge in magnetic field is called Lorentz magnetic force. This force is maximum when the direction of motion of charge particle is perpendicular to the direction of magnetic field.
- **Right hand thumb rule**: Direction of force acting on a current carrying conductor in magnetic field is given by the right hand thumb rule. The force is perpendicular to both the direction of magnetic field and the direction of current.
- **Maximum Force**: The force acting on the current carrying conductor in magnetic field is maximum when the conductor is placed perpendicular to the direction of magnetic field.
- **Torque:** It is defined as the moment of force. It is given by cross product of distance of force from axis of rotation and the force.
- **Magnetic Moment**: m = NIA., N number of turns of the coil, I is the current flowing in the coiland A is the area of the coil . in case of cylindrical windings A = $\pi r^2$ , for a rectangular winding A= l x b

- **Torque on coil**: The torque acting on the coil in magnetic field is maximum when the plane of coil is parallel to magnetic field. The coil does not experience torque when plane of coil become perpendicular to the magnetic field.

## 4. INTRODUCTION

In the previous module we have discussed that when a current carrying coil is placed in magnetic field, it experiences a torque. The magnitude of torque acting on the coil becomes maximum when its plane is parallel to magnetic field whereas the coil does not experience any torque when magnetic field is perpendicular to the plane of the coil. We can now extend the analysis for the torque acting on the coil in the magnetic field to describe the principle and working of a moving coil galvanometer.

**In this module we will discuss in detail about the working and sensitivity of galvanometer and its conversion into ammeter and voltmeter.**

## 5. MOVING COIL GALVANOMETER

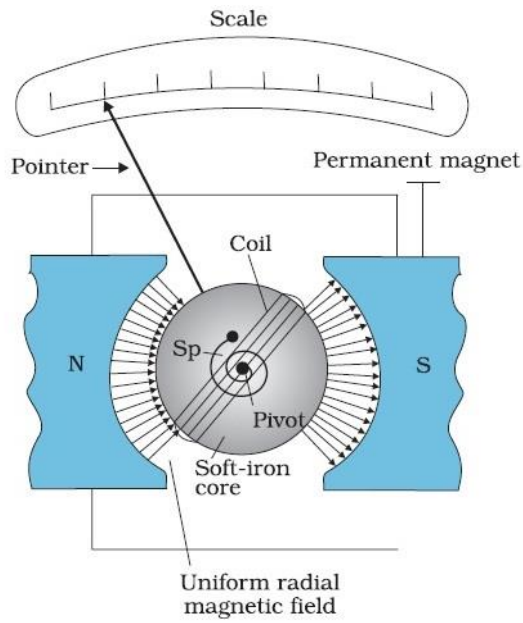
**Moving coil is a very sensitive instrument used for detection of very small current. It also gives the direction of flow of the current.**

**Principle:** It is based on the principle that when current is passed through a rectangular coil placed in a uniform magnetic field it experiences a torque which deflects the coil from its mean position.

### Theory and Working:

The galvanometer consists of a coil with many turns free to rotate about a fixed axis in a uniform radial magnetic field as shown in fig. there is a soft iron core which makes the magnetic field and also increases the strength of the magnetic field.

The coil is suspended from the torsion head with a phosphor bronze wire. The other end of the coil is attached to a hair spring. The spring exerts a very small restoring couple on the coil.




When a current flows though the coil, it experiences torque.

Let B = Intensity of magnetic field

I=current flowing through the coil

A = Area of coil

N= no of turns in the coil

Since the magnetic field is radial i.e. whatever the position of the coil be, plane of coil is always parallel to the field lines. The magnitude of the torque is given by

$$\tau = NIAB$$

This torque tends to rotate the coil in the magnetic field and produce a twist in the suspension wire and hair spring. As a result of it a restoring torque develops which tends to bring the coil back to its original position.

Let $\emptyset$ be the deflection indicated on the scale by a pointer attached to the spring and k be the restoring torque per unit twist of spring (torsional constant of the spring). Then the restoring torque is given by

Restoring torque= $K\emptyset$

In equilibrium, the restoring torque = deflecting torque

$$\mathbf{K\emptyset = NIAB}$$

$$\emptyset = \left(\frac{\mathbf{NAB}}{\mathbf{K}}\right)\mathbf{I}$$

Where $\frac{NAB}{K}$ is a constant for a given galvanometer. Thus

$\emptyset \propto \boldsymbol{I}$

**Hence the deflection produced is directly proportional to the current flowing in the coil. That is why a galvanometer has a linear scale to detect the current.**

**USES**

The galvanometer can be used in a number of ways. It can be used:

a) **As a detector to check the presence of current flowing in the circuit.**

In experiments using Wheatstone's bridge arrangement and Potentiometer, galvanometer can be used to the position of null point (when no current flows through the galvanometer)

b) **To give the direction of current flow in a circuit**. In many circuits in the laboratory experiments with Wheatstone bridge and Meter Bridge or potentiometer you must have seen deflection in both directions about the central zero on the galvanometer scale

c) **To indicate relative strength of current in a circuit** as the deflection of the moving coil is proportional to the current passing through it a linear scale can show relative magnitude of current

## 6. NEED FOR CURVED POLE PIECES

### Radial magnetic field

We need to ensure that as the rectangular coil of the moving coil galvanometer, moves in the uniform magnetic field of the magnet, for a rectangular coil, two sides remain parallel to the field lines while its other two sides remain normal to these lines.

This cannot hold for a magnet with flat pole pieces (its field lines will be parallel to one another and perpendicular to the pole pieces).

However, it can hold if the pole pieces are given a correct curved shape. It is for this reason that we have 'concave curved pole pieces'. This ensures that the relation between the current and the deflection of the coil remains a linear relation.

As seen earlier

When a current flows through the coil, a torque acts on it. This torque is given by

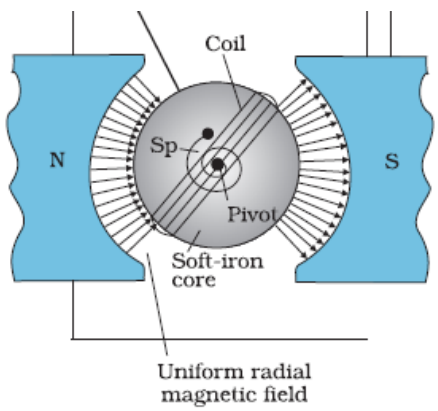
**$\tau$ = NI AB sin $\theta$**

where the symbols have their usual meaning.

Since the field is radial by design, we have taken sin $\theta = 1$ as the normal to the plane of the coil or the area vector remains perpendicular to the field B in all positions, in the above expression for the torque.

The magnetic **torque NIAB** tends to rotate the coil.

Always through the same angle for certain increase in current .See the diagram carefully




The coil is mounted on a soft iron cylinder making up the core, this helps in

a) Increasing the field B

b) Keeping the field B constant

**THINK ABOUT THESE**

**The deflection produced in the galvanometer coil is proportional to the current flowing through it.**

- **Would the galvanometer scale be linear if B is not constant**

- **Can flat pole ends produce uniform field? Would the field be uniform for coil wound on a cylindrical core?**
- **What factors will influence the deflection per scale division of the galvanometer? This is defined as figure of merit as the current which produces a deflection of one scale division in the galvanometer and is given by**

$$G = \frac{I}{\theta} = \frac{k}{NBA}$$

**K we recognise as the torsion constant of the spring or the torque required producing unit angular twist in equilibrium position. This if the property of the spring attached to produce the restoring torque against the deflection produced by the current in the coil.**

**So G will depend upon:**

- ✓ **K due to the spring**
- ✓ **N-Number of turns of the coil**
- ✓ **B-Uniform magnetic field in which the coil is placed**
- ✓ **A-Area of the coil**
- ✓ **The current I will depend upon the resistance of the coil**

## 7. SENSITIVITY OF GALVANOMETER

**A galvanometer is said to be more sensitive if it shows large deflection even when a small current is passed through it.**

Since deflection produced in galvanometer is given ***by*** $\emptyset = \left(\frac{NAB}{K}\right) I$

Thus for a given value of current I, deflection $\emptyset$ will be large, if

(i) N is large

(ii) B is large

(iii) Area A is large

(iv) Torsion constant K is small

**However N and A cannot be increased beyond limit. Otherwise size becomes large and also increases the resistance of galvanometer**.

Thus for large sensitivity B is made as large as possible and k is made as small as possible.

The value of B can be increased by using a strong horse shoe magnet and using soft iron core.

The value of K depends upon the nature of the material used for making the spring or suspension wire.

The value of K is very small for quartz or phosphor bronze.

**That is why, in sensitive galvanometer quartz or phosphor bronze strip is used as a suspension wire and spring**

**(i) CURRENT SENSITIVITY:**

The current sensitivity of a galvanometer is defined as the deflection produced in the galvanometer per unit current flowing through it. It is given by

$$I_s = \frac{\emptyset}{I}$$

$$I_s = \frac{NAB}{K}$$

Unit of current sensitivity is rad/A or div/A

**(ii) VOLTAGE SENSITIVITY:**

Voltage sensitivity of a galvanometer is defined as the deflection produced in the galvanometer per unit voltage applied to it. It is given by

$$V_s = \frac{\emptyset}{V} = \frac{\emptyset}{IR}$$

Where R is resistance of galvanometer

$$V_s = \frac{NBA}{KR}$$

The increasing of current sensitivity may not necessarily increase the voltage sensitivity. If we increase current sensitivity by increasing number of turn N, voltage sensitivity will not change. This is because the resistance of the galvanometer coil will change in the same ratio as length of wire changes by changing the number of turns N

**EXAMPLE**

**A galvanometer needs 50 m V for a full scale deflection of 50 divisions. Find its voltage sensitivity. What must be its resistance if its current sensitivity is 1 division /micro amperes?**

**SOLUTION**

$$\text{Voltage sensitivity} = \frac{\theta}{V} = \frac{50\ div}{50\times10^{-3}} = 10^3\ div\ V^{-1}$$

Resistance of the galvanometer

$$= \frac{current\ sensitivity}{voltage\ sensitivity} = \frac{1 div\ \mu A^{-1}}{10^3 div\ V^{-1}} = \frac{10^6 div A^{-1}}{10^3 div\ V^{-1}} = \mathbf{10^3 ohms}$$

**EXAMPLE**

**To increase the current sensitivity of a moving coil galvanometer by 50%, its resistance is increased so that the new resistance becomes twice its initial resistance. By what factor does its voltage sensitivity change?**

**SOLUTION**

Current sensitivity $I_s = \frac{\theta}{I}$

Voltage sensitivity $Vs = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{I_s}{R}$

New current sensitivity, $I_s' = I_s + 50/100\ I_s = 3/2\ I_s$

New voltage sensitivity, $V_s'$= New current sensitivity $I_s'/2R = 3/2 I_s/2R = ¾\ V_s = 0.75\ V_s$

Voltage sensitivity decreases by 25 %.

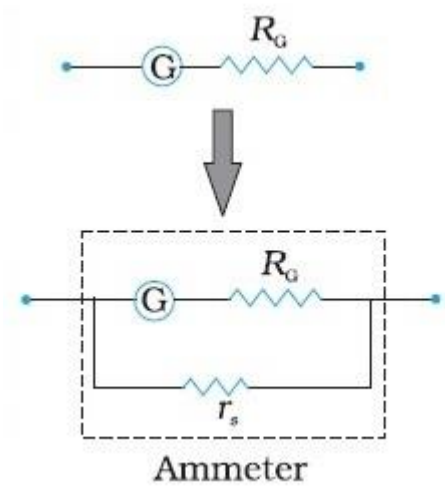
## 8. CONVERSION OF GALVANOMETER INTO AMMETER

The galvanometer cannot as such be used as an ammeter to measure the value of current in a given circuit. **This is for two reasons**:

(a) **Galvanometer is a very sensitive instrument; it gives a full scale deflection for very small current**

**(b) For measuring currents the galvanometer has to be connected in series, and as it has large resistance, this will change the value of the current in the circuit**.

The galvanometer can be converted into ammeter by connecting a small resistance called shunt in parallel with it.




Let $R_G$ = resistance of galvanometer

$r_s$ = shunt resistance

I = current flowing through the circuit

Let $I_g$ be the current flowing through galvanometer for the full scale deflection. The remaining current ($I - I_g$) flows through the shunt.

$$I_g R_G = (I - I_g) r_s$$

This gives the expression for shunt resistance required as

$$\mathbf{r_s = \frac{I_g R_G}{(I - I_g)}}$$

The equivalent resistance of ammeter is given by

$$R = \frac{R_G r_S}{R_G + r_S}$$

If $R_G >> r_s$

Then

$$R \cong r_s.$$

**Thus an ammeter is a low resistance instrument capable of measuring current in circuits with steady current.**

## 9. CONVERSION OF GALVANOMETER INTO VOLTMETER

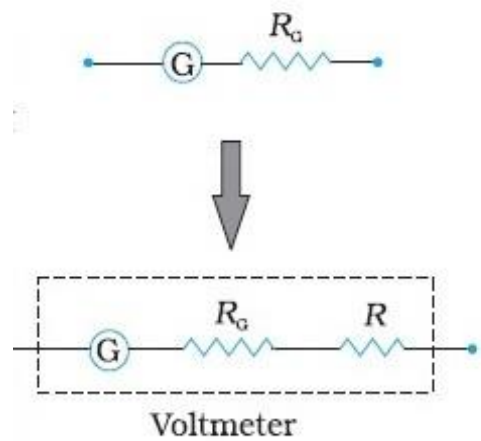
Voltmeter is used for measuring voltage across a given section of the circuit. For this it must be connected in parallel with that section of the. Further it must draw a very small current.

A galvanometer can be converted into voltmeter by connecting a large resistance R in series with it as shown in figure.

If $I_g$ be the current flowing in the circuit for which voltmeter gives full scale deflection. Then the voltage measured by the instrument is given by

$$V = I_g ( R_G + R)$$

**Here the resistance of the voltmeter is $R_G$ + R, which is very large**




## 10. PROBLEMS FOR PRACTICE

i) A galvanometer having a resistance of 8 Ω is shunted by a wire of resistance 2 Ω. If the total current is 1 A. find the part of the current passing through the shunt.

**Solution**: $(I - I_g)S = I_g\, G \;\Rightarrow\; I_g = 0.2A \;\Rightarrow\; I_s = 0.8A$

ii) A galvanometer having a coil of resistance of 60 Ω shows full scale deflection when a current of 1.0 A passes through it. Find the value of shunt required to convert it into an ammeter to read currents upto 5.0 A.

**Answer:** Shunt resistance S = 15 Ω

iii)The resistance of an ammeter is 13 Ω and its scale is graduated for a current up to 100 A. After an additional shunt has connected to this ammeter, it becomes possible to measure currents up to 750 A by this meter. Find the value of shunt resistance.

Answer: Shunt S = 2Ω

iv) A galvanometer of 50 ohm resistance has 25 divisions. A current of 4 X $10^{-4}$ A gives a deflection of 1 division. Find the resistance to be connected to convert this galvanometer into a voltmeter having a range of 25V.

**Answer** : Resistance, R = 2450 Ω

v)A galvanometer with a coil resistance of 100 Ω shows full scale deflection for 3 mA current. Calculate the value of the resistance required to convert it into an ammeter of the range 0-6 A.

**Answer**: 0.05 Ω

vi) Calculate the value of the resistance needed to convert a galvanometer of resistance 200 Ω, which gives a full scale deflection for a current of 5mA to a voltmeter of 250V range.

**Answer**: 4800 Ω

vii)_A galvanometer of resistance 100 Ω gives full scale deflection for 20 mV. Find the resistance to be attached, so that it gives full deflection of 5 V

**Answer:** R = 24.9 X $10^3$ Ω in series

viii) State the principle of moving coil galvanometer.

**Answer:** When a current carrying loop or coil is placed in the uniform magnetic field, it experiences a deflecting torque.

ix)What is the nature of the magnetic field in a moving coil galvanometer?

**Answer**: Uniform radial magnetic field.

x)What is the advantage of radial magnetic field inside galvanometer?

Answer: whatever be the position of coil in magnetic field, plane of coil is always parallel to magnetic field. Thus the torque acting on the coil is always maximum and remains the same.

xi)State two factors on which the sensitivity of a moving coil galvanometer depends?

**Answer**: (i) torsional constant of the suspension wire

(ii) Area of the coil

(iii) Magnetic field

xii) State two properties of the material of the wire used for restoring spring in a moving coil galvanometer.

**Answer:** It should be non-brittle conductor and its restoring torque per unit twist should be small.

xiv)Why a voltmeter is always connected in parallel with a circuit element across which voltage is to be measured?

**Answer:** So that it may not change the resistance of the circuit and hence voltage across it.

xv)An ammeter and a milliammeter are converted from the same galvanometer. Out of the two, which should have higher resistance?

**Answer:** Milliammeter has higher resistance because it has shunt of higher resistance as compared to that of an ammeter.

xvi)Galvanometer as such cannot be used to measure current flowing in the circuit. Why?

**Answer:** (a) it is a very sensitive instrument and shows very large deflection for small amount of current (b) it has very high resistance and can affect the value of current in the circuit.

## 11. SUMMARY

In this module we have learnt

- Principle and working of the galvanometer.
- Magnetic field inside galvanometer is radial. As a result of this we can show that the deflection produced in the galvanometer is directly proportional to the current flowing in the coil.

- Factors on which sensitivity of galvanometer can depend.
- Conversion of galvanometer into ammeter and voltmeter.