Current loop as a magnetic dipole and its magnetic dipole moment, magnetic dipole moment of a revolving electron

CLASS-XII

SUBJECT : PHYSICS
CHAPTER NUMBER: 05
CHAPTER NAME : MAGNETISM AND MATTER

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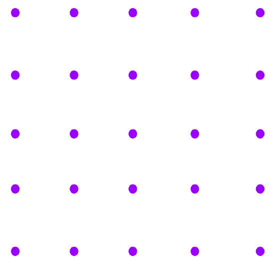
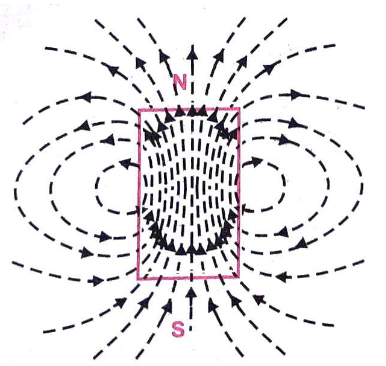
Representation of Uniform Magnetic Field:

Uniform field on the plane of the diagram

Uniform field perpendicular & into the plane of the diagram

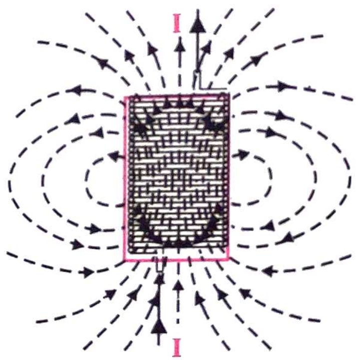


Uniform field perpendicular & emerging out of the plane of the diagram



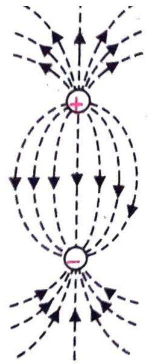
Magnetic field lines due to a bar magnet

a



Magnetic field lines due to a solenoid carrying current

b



Electric filed lines due to an electric dipole

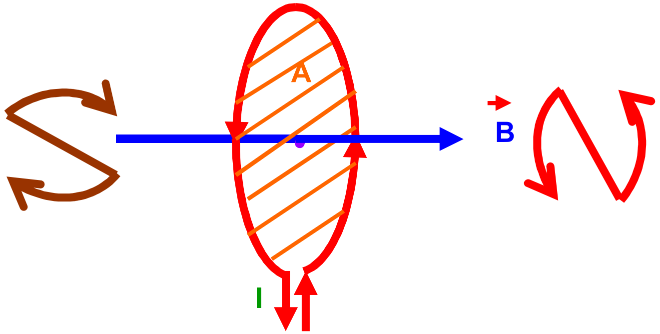
c

Magnetic Dipole & Dipole Moment

Magnetic Dipole consists of two unlike poles of equal strength and separated by a small distance.

Eg . Bar magnet , a compass needle current loop.

Current Loop as a Magnetic Dipole & Dipole Moment:



Magnetic Dipole Moment is

$$\boxed{\vec{m} = I A \hat{n}}$$

SI unit is A m^2.

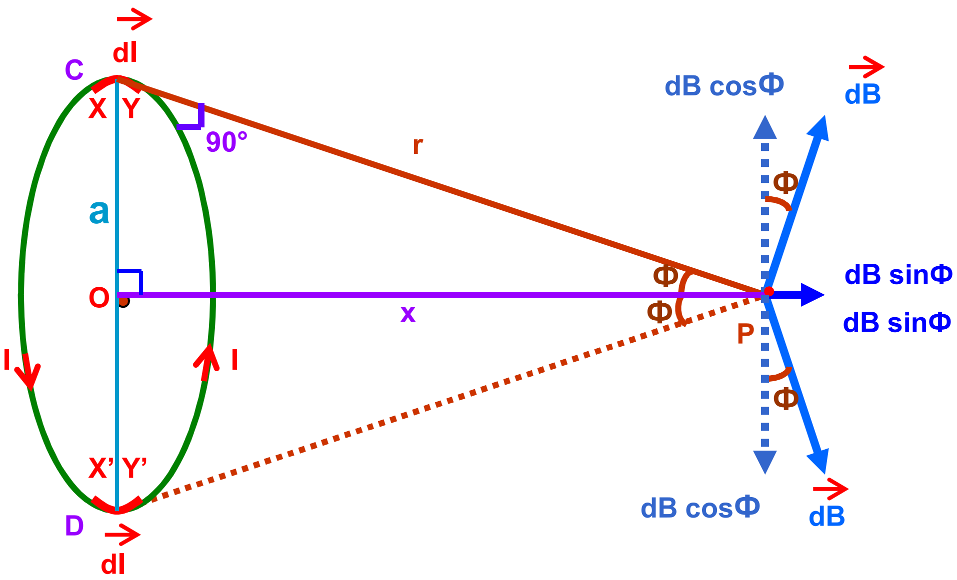
TIP:

When we look at any one side of the loop carrying current, if the current is in anti-clockwise direction then that side of the loop behaves like Magnetic North Pole and if the current is in clockwise direction then that side of the loop behaves like Magnetic South Pole.

Current loop as a magnetic dipole

1) At a point on the axial line:

$$B = \frac{\mu_0 I a^2}{2(a^2 + x^2)^{3/2}}$$

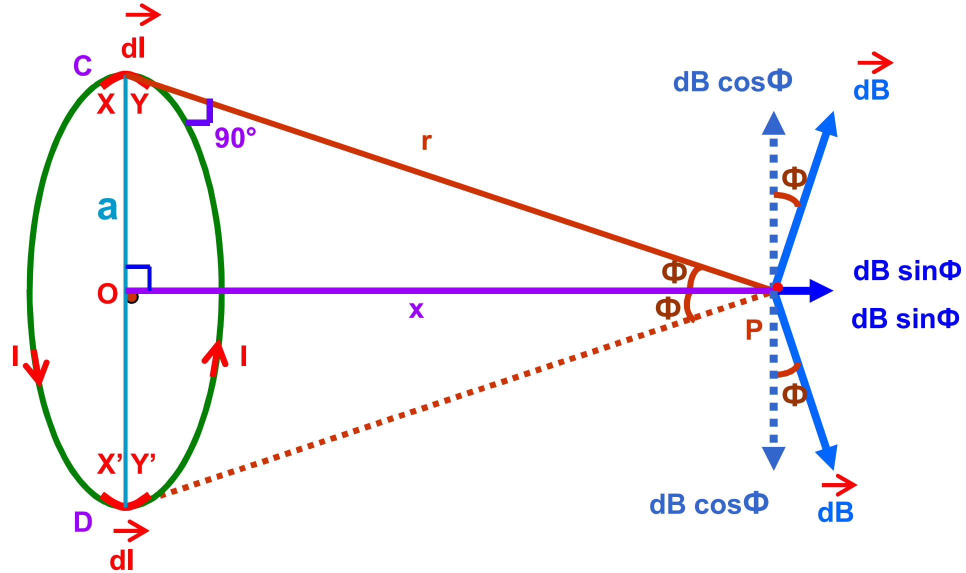


Current loop as a magnetic dipole

i) If the observation point is far away from the coil, then a << x. So, a^2 can be neglected in comparison with x^2.

$$\therefore \quad \boxed{B = \frac{\mu_0 I a^2}{2 x^3}}$$

$$B = \frac{\mu_0}{4\pi} \frac{2NIA}{x^3}$$



We define the magnetic moment of the current loop as,

$$\vec{m} = I\vec{A}$$

where the direction of the area vector $\vec{A}$ is given by the right-hand thumb rule and is directed along the positive x-axis in fig.

So in vector form $\boxed{\vec{B} = \frac{\mu_0}{4\pi} \frac{2N\vec{m}}{x^3}}$

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Current loop as a magnetic dipole

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{2N\vec{m}}{x^3}$$

The expression is very similar to an expression obtained earlier for the electric field of a dipole. The similarity may be seen if we substitute,

$$\mu_0 \rightarrow 1/\varepsilon_0$$

$$\mathbf{m} \rightarrow \mathbf{p}_e \text{ (electrostatic dipole)}$$

$$\mathbf{B} \rightarrow \mathbf{E} \text{ (electrostatic field)}$$

We then obtain,

$$\mathbf{E} = \frac{2\mathbf{p}_e}{4\pi\varepsilon_0 x^3}$$

which is precisely the field for an electric dipole at a point on its axis.

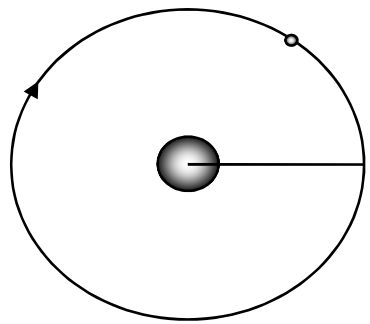
The results obtained above can be shown to apply to any planar loop: a planar current loop is equivalent to a magnetic dipole of dipole moment **m = I A**, which is the analogue of electric dipole moment **p.**

Note,

A fundamental difference : an electric dipole is built up of two elementary units, the charges (or electric monopoles).
In magnetism, a magnetic dipole (or a current loop) is the most elementary element.
The equivalent of electric charges, i.e., magnetic monopoles, are not known to exist

Magnetic Dipole Moment of Revolving Electron

The electron of charge (–e) performs uniform circular motion around a stationary heavy nucleus of charge +Ze.



Magnetic Dipole Moment of Revolving Electron

The electron of charge (–e) performs uniform circular motion around a stationary heavy nucleus of charge +Ze. This constitutes a current I, given by

$$I = \frac{e}{T} \text{---(1)}$$

If T is the time period of revolution, r be the orbital radius, and v the orbital speed of the electron then,

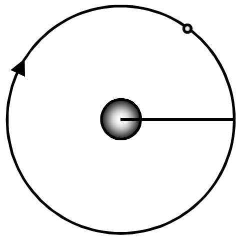
$$v = \frac{2\pi r}{T} \text{---(2)}$$

So eq.(1) becomes

$$I = e\frac{v}{2\pi r} \text{---eq.(3)}$$

There will be a magnetic moment, associated with this circulating current given by,

$$\mu = I\pi r^2$$
$$= e\frac{v}{2\pi r}\pi r^2$$
$$= \frac{evr}{2}$$
$$= \frac{emvr}{2m}$$
$$= \frac{el}{2m} \quad \text{---eq.(4)}$$



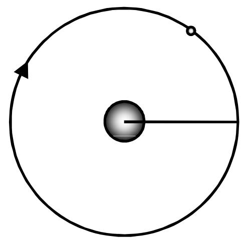
Magnetic Dipole Moment of Revolving Electron

Bohr hypothesised that the angular momentum assumes a discrete set of values, namely,

$$l = \frac{nh}{2\pi} \text{---eq.(5)}$$

where n is a natural number, n = 1, 2, 3, ... and h is Planck's constant. named after Max Planck constant) with a value $h = 6.626 \times 10^{-34} Js$.

So,



$$\mu = \frac{e}{2m}\frac{nh}{2\pi}$$

$$= n\frac{eh}{4\pi m}$$

$$= n\mu_B \text{ ---eq.(6)}$$

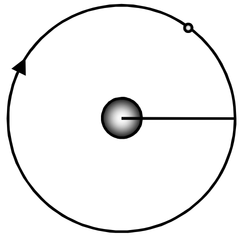
where,

$$\mu_B = \frac{eh}{4\pi m} \text{ ---eq.(7)}$$

is called Bohr magneton and its value is $\mu_B = 9.27 \times 10^{-24} A \cdot m^2$

Magnetic Dipole Moment of Revolving Electron

In fig.(2) the negatively charged electron is moving clockwise, leading to an anticlockwise current. From the right-hand rule, the magnetic moment is perpendicular to the plane of the paper and outward. The angular momentum of the electron w.r.t. the nucleus is perpendicular to the plane of the paper and inward. So in vector form



$$\vec{\boldsymbol{\mu}} = -\frac{e\vec{l}}{2m} \text{---eq.(8)}$$

The ratio

$$\frac{\mu}{l} = \frac{e}{2m} \text{---eq.(9)}$$

is called the gyromagnetic ratio and is a constant. Its value is 8.8×10^{10} C/kg for an electron.

Numerical

Question: A circular coil of N turns and diameter d carries a current I. It is unwound and rewound to make another coil of diameter 2d, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil.

Numerical

11. The length of wire will be same in two cases as the same coil in unwound and rewound.

Length of wire of coil 1 = Length of wire of coil 2

$$N_1 \times \pi d_1 = N_2 \times \pi d_2$$

$$N_1 \times \pi d = N_2 \times \pi \times 2d$$

$$N_2 = \frac{N_1}{2} \qquad \text{[where, } N_1 = N\text{]}$$

$$\Rightarrow \quad N_2 : N_1 = 1 : 2$$

$$\Rightarrow \quad N_1 : N_2 = 2:1$$ **(1)**

Magnetic moment, $M = NIA$

$$\therefore \quad \frac{M_1}{M_2} = \frac{N_1 I A_1}{N_2 I A_2} = \frac{N_1 \pi d^2}{N_2 \pi (2d)^2}$$

$$\frac{M_1}{M_2} = \left(\frac{N_1}{N_2}\right) \times \frac{1}{4}$$

$$= 2 \times \frac{1}{4} = \frac{1}{2}$$

$$\frac{M_1}{M_2} = \frac{1}{2}$$

$$\Rightarrow \quad M_1 : M_2 = 1 : 2$$ **(1)**

Numerical

Question: An electron of mass m, revolves around a nucleus of charge +Ze. Show that it behaves like a tiny magnetic dipole. Hence, prove that the magnetic moment associated with it is expressed as $\mu = -\frac{e}{2m_e}L$, where L is the orbital angular momentum of the electron. Give the significance of negative sign.

MCQ Questions

1. A current loop in magnetic field
(a)Experiences a torque whether the field is uniform or non -uniform in all orientations.
(b)Can be in equilibrium in one orientation
(c)Can be in equilibrium in two orientations, both the equilibrium states are unstable.
(d)Can be in equilibrium in two orientations, one stable while the other is unstable.

2. Assertion: Magnetic moment of helium atom is zero.
Reason: All the electron are paired in helium atom orbitals.

MCQ Questions

1. A current loop in magnetic field
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(d)Can be in equilibrium in two orientations, one stable while the other is unstable.
Answer: (d) Can be in equilibrium in two orientations, one stable while the other is unstable

2. Assertion: Magnetic moment of helium atom is zero.
Reason: All the electron are paired in helium atom orbitals.
Answer: A
Solution:
Helium atom has paired electrons so their electron spin are opposite to each other and hence its net magnetic moment is zero.

THANKING YOU

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