Torque and Current Loop

Objectives

- After going through this lesson, the learners will be able to:
- Understand that a torque is experienced by a current loop in uniform magnetic field
- Obtain an expression for the torque experienced by a current loop placed in a uniform magnetic field and using it
- Recognise the need to describe area of the loop as a vector
- Comprehend direction of torque acting on current carrying rectangular loop in uniform magnetic field
- Orientation of a rectangular current carrying loop in a uniform magnetic field for maximum and minimum potential energy

Content Outline

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- Words you must know
- Introduction
- Behaviour of a bar magnet suspended horizontally in a uniform magnetic field
- Torque on a current carrying coil placed in a magnetic field when the plane of loop is along magnetic field B
- Calculation of torque on a rectangular current loop in a uniform magnetic field
- Torque on a current loop in a uniform magnetic field when area vector makes an angle with B current carrying coil in a magnetic field
- Solved examples

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 the 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.

Module Wise Distribution of Unit Syllabus

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

Module 4	• Force on moving charges in uniform magnetic field and uniform electric field. • Lorentz force • Cyclotron
Module 5	• Force on a current carrying conductor in uniform magnetic field • Force between two parallel current carrying conductors • Definition of ampere
Module 6	• Torque experienced by a current rectangular loop in uniform magnetic field • Direction of torque acting on current carrying rectangular loop in uniform magnetic field • Orientation of a rectangular current carrying loop in a uniform magnetic field for maximum and minimum potential energy
Module 7	• Moving coil Galvanometer- • Need for radial pole pieces to create a uniform magnetic field • Establish a relation between deflection in the galvanometer and the current • Its current sensitivity • Voltage sensitivity • Conversion to ammeter and voltmeter • Examples
Module 8	• Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. • Torque on a magnetic dipole in a uniform magnetic field. • Explanation of magnetic property of materials
Module 9	• Dia, Para and ferro-magnetic substances with examples. Electromagnets and factors affecting their strengths, permanent magnets.
Module 10	• Earth's magnetic field and magnetic elements.

Module 6

Words You Must Know

- **Coulomb's law:** The force of attraction or repulsion between two point charges is directly proportional to the product of two charges (q_1 and q_2) and inversely proportional to the square of the distance between them. It acts along the line joining them.
- **Electric current:** The time rate of flow of charge in any conductor.
- **Drift Velocity of Electrons:** The average velocity with which electrons move in conductor from the negative end of conductor to the positive end of conductor under the effect of electric field is called drift velocity. The direction of drift velocity is opposite to the direction of flow of current. The relation between current and drift velocity is given by $I = neAV_d$, where n is electron density, e charge on electrons, and A, the area of cross section of the conductor.
- **Magnetic field:** The space around a magnet within which its influence can be experienced is called magnetic field.

  Moving charges or a current sets up or creates a magnetic field in the space surrounding it.
- **Magnetic force:** The magnetic field exerts a force on a moving charge or a current in the field.
- **Magnetic force 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.
- **SI 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 experiences a force of one Newton.
- **C G S unit of magnetic field:** CGS unit of magnetic field **is gauss (G).** 1T = 10^{-4} G
- **Magnetic field lines:** It is a curve, the tangent to which at a point gives the direction of the magnetic field at that point.
- **Maxwell's cork screw rule or right hand screw rule:** It states that if the forward motion of an imaginary right handed screw is in the direction of the current through a linear conductor, then the direction of rotation of the screw gives the direction of the magnetic lines of force around the conductor.
- **Biot-Savart law:** According to Biot-Savart law, the magnetic field *dB* at *P* due to the current element *Idl* is given by

$$dB = \frac{\mu_0 Idl sin\theta}{4\pi r^2}$$

if $\theta = 0^0, sin\,\theta = 0,\ dB = 0$ The magnetic field is 0 at points on the axis of the current element.

If $\theta = 90^0, sin90^0 = 1$, $dB\ is\ maximum$. Magnetic field due to a current element is maximum in a plane passing through the element and perpendicular to its axis.

- **Right hand thumb rule or curl rule:** If a current carrying conductor is imagined to be held in the right hand such that the thumb points in the direction of the current then the tips of the fingers encircling the conductor will give the direction of the magnetic lines of force.
- **Lorentz magnetic force:** The force acting on moving charge in a magnetic field is called Lorentz magnetic force. The force depends upon the angle between the magnetic field and the direction of moving charge.
- **Maximum Force:** This force is maximum when the direction of motion of a charged particle is perpendicular to the direction of the magnetic field. When the charge particle moves along the direction of magnetic field, it does not experience any 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.
- **Force on a conductor carrying current placed in a magnetic field** is BIL where B is the strength of the magnetic field, I is the current in the conductor, L is the length of the conductor
- **Direction of force on current carrying conductor:** Direction of force acting on a current carrying conductor in magnetic field is given by the **right hand palm rule**. The force is perpendicular to both the direction of magnetic field and the direction of current.
- **Electric permittivity** ϵ is a physical quantity that describes how an electric field affects and is affected by a medium. It is determined by the ability of a material to polarise in response to an applied field and thereby to cancel partially the field inside the material.
- **Magnetic permeability** μ is the ability of a substance to acquire magnetisation in magnetic fields. It is a measure of the extent to which magnetic fields can penetrate matter.

  $\epsilon\mu = \frac{1}{v^2}$ **where v is the speed of electromagnetic radiation in the medium.**

- **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:** For a current carrying circular loop the magnetic moment is given by M = NIA, where N is number of turns, I, current flowing in the loop and A, area of loop. It is a vector quantity. Its SI unit is Am^2.

Introduction

In the previous module, we have discussed that when a current carrying conductor is placed in a magnetic field, it experiences a force. The direction of this force is perpendicular to the direction of current in the conductor.

We can now extend the analysis for force due to the magnetic field on a straight current carrying conductor to a current carrying rectangular loop.

The current carrying loop when placed in the magnetic field will thus experience a **torque**.

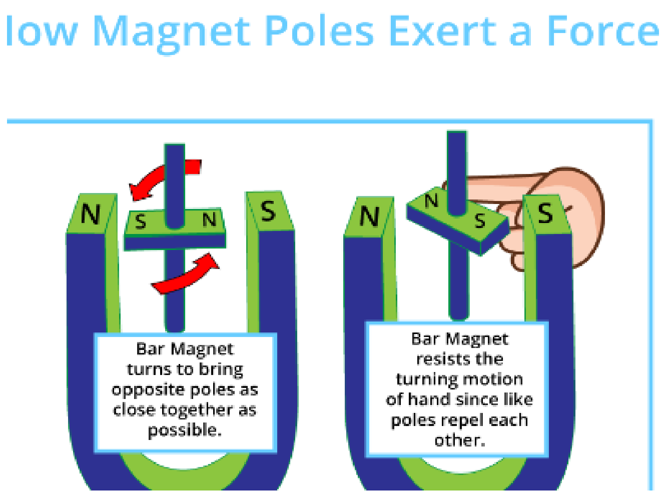
In this module, we will discuss in detail about the torque on a current carrying loop when placed in the magnetic field.

Behaviour of a Bar Magnet, Suspended Horizontally in a Uniform Magnetic Field

Uniform magnetic fields can be obtained inside a solenoid with steady current, between the poles of a horseshoe magnet.

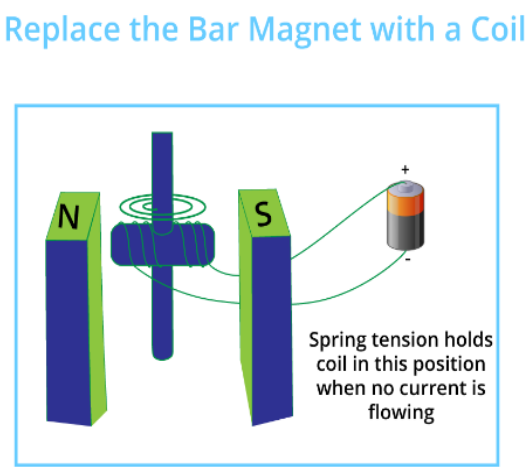
What would happen if a bar magnet is placed between the poles of a Horseshoe magnet?

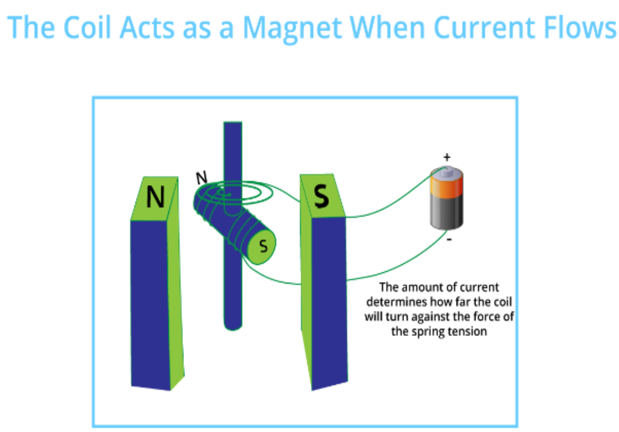
Study the two pictures and answer the following questions



- What role is played by the horseshoe magnet?
- Draw the field lines between the poles of the horse shoe magnet.
- Which property of the field lines indicates uniform magnetic field?
- The small magnet is pivoted on an axis and placed in a way to move about a vertical axis or an axis perpendicular to the field lines. Why?
- Which property of magnets causes rotation of the small magnet?
- Why do we need to push the North Pole in the diagram?
- When does the coil behave like a magnet?

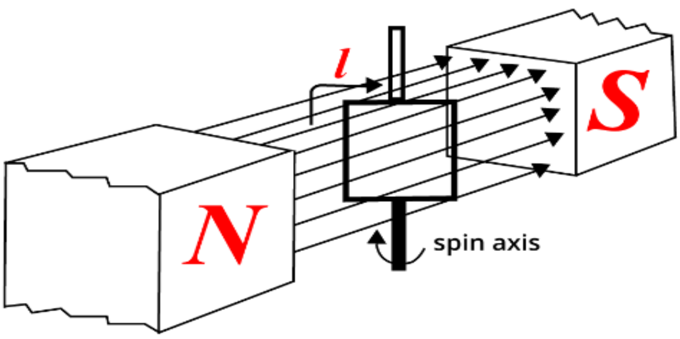
- List the factors on which the strength of the magnetic field produced in the coil depends upon.
- The coil can rotate in clockwise or anticlockwise directions. What will govern such a choice?
- What if the coil is placed such that the magnetic field produced by it makes an angle in the a) horizontal plane, b) vertical plane?



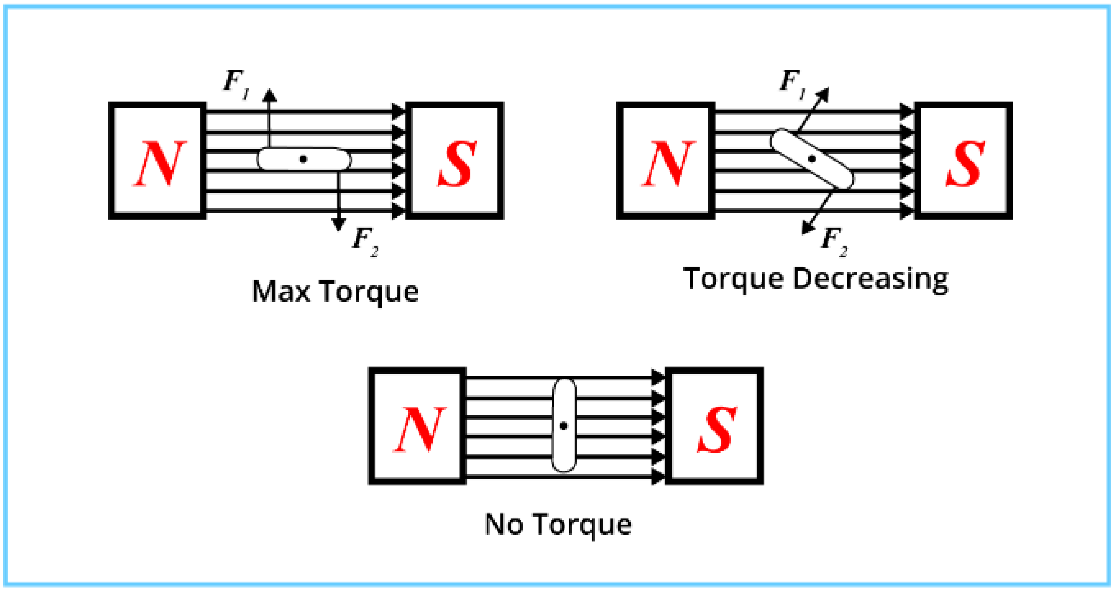


Torque on a Current Carrying Coil placed in a Magnetic field

When the plane of loop is along Magnetic field



View Looking Down on Loop From Above



Calculation of Torque on a Rectangular Current Loop in a Uniform Magnetic field

A rectangular loop carrying a steady current I and placed in a uniform magnetic field experiences a torque. It does not experience a net force.

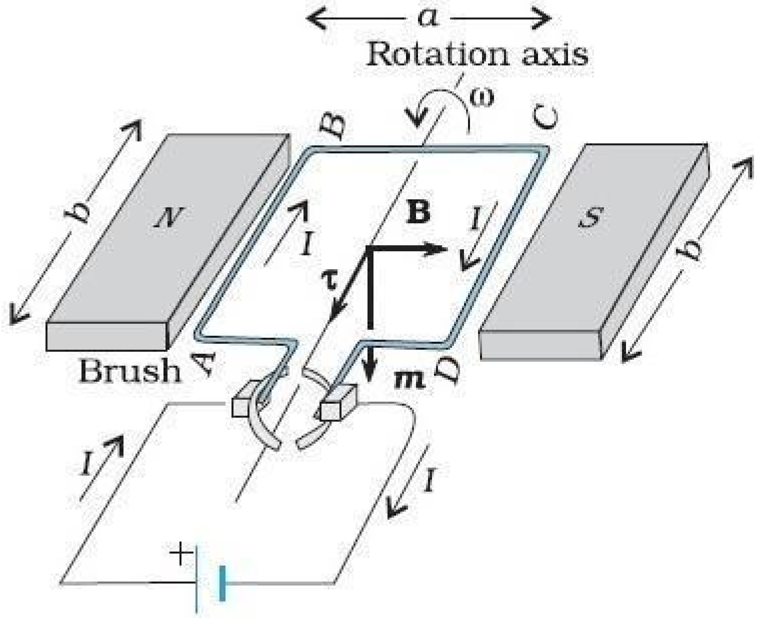
This behavior is analogous to that of an electric dipole in a uniform electric field.

Consider a rectangular coil ABCD carrying current I in a direction as shown in figure is placed in a uniform magnetic field B acting in the plane of the coil from left to right.

Here we have taken **a rectangular loop to help us** visualize the forces, due to interacting magnetic fields, on different sections of the current loop.

The diagram is a schematic one:

- The magnetic north and south poles belong to a horse shoe magnet.
- The loop has a rotation axis.
- The brush arrangement is to facilitate one complete revolution.
- Brushes connected to the ends of the wire loop allow current to flow in the loop.
- The plane of the loop is in the direction of field B.



Let b = length of rectangle and

a = breadth of rectangle

Notice:

The magnetic field is parallel to arms DA and BC so magnetic field B exerts, no force on arms DA and BC. The magnetic field is perpendicular to arms AB and CD of the loop. Therefore the magnitude of force acting on arm AB is given by

$$F_1 = IbB$$

The force F_1 is directed into the plane of the loop.

Similarly,

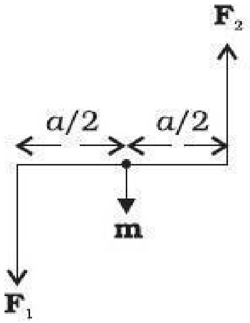
The magnitude of the force acting on the arm CD is given by

$$F_2 = IbB$$

The force F_2 is directed out of the plane of the loop.

Since, F_1 and F_2 are equal and opposite to each other, the net force on the loop is zero.

However these two forces produce torque on the loop which tends to rotate it anti clockwise. The magnitude of the torque is given by:



$$\tau = F_1 \frac{a}{2} + F_2 \frac{a}{2}$$

$= IbB\frac{a}{2} + IbB\frac{a}{2}$

$= I(ab)B$

$= I\ A\ B$

$= mB$

Where

A = ab is the area of the rectangular loop and

$m = IA$ is the magnetic moment of the loop

Meaning of Magnetic Moment

The magnetic moment is the magnetic strength and orientation of a magnet or other object that produces a magnetic field.

Examples of objects that have magnetic moments include: loops of electric current (such as electromagnets), permanent magnets, elementary particles (such as electrons), various molecules, and many astronomical objects (such as many planets, some moons, stars, etc).

More precisely, the term magnetic moment normally refers to a system's magnetic dipole moment the component of the magnetic moment that can be represented by an equivalent magnetic dipole: a magnetic north and south pole separated by a very small distance.

If the loop has N closely wound turns, the torque is given as:

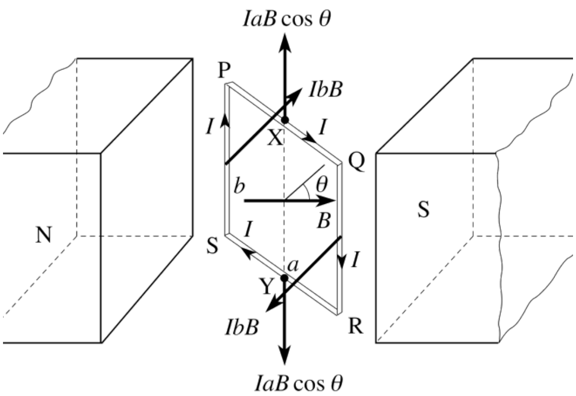
$\tau = NIAB$

$= mB$

Where, m = NIA

Torque on a Current Carrying Coil in a Magnetic Field When Area Vector (The Normal to the Loop) Makes an angle θ With Magnetic Field

Consider a rectangular loop PQRS carrying current *I* is placed in uniform magnetic field B such that the normal to plane makes an angle θ with the magnetic field as shown in figure.



The magnitude of force on the arm PQ is given by:

$F_1 = IaBSin(90 - \theta) = IaBcos\theta$

The force F_1 is directed upward in the plane of the loop.

The magnitude of force on the arm RS is given by

$F_2 = IaBSin(90 + \theta) = IaBcos\theta$

The force F_2 is directed downward in the plane of the loop.

The forces on the arms PQ and RS are equal, opposite and act along the axis of rotation of the loop. Thus they cancel each other resulting in no force or torque on the loop.

Now the magnitude of force on arm PS is given

$F_3 = IbBsin90^0 = IbB$

The force F_3 is directed into the plane of the loop.

Similarly the magnitude of force on arm QR is given

$F_4 = IbBsin90^0 = IbB$

The force F_4 is directed out of the plane of the loop.

Since, F_3 and F_4 are equal and opposite to each other, the net force on the loop is zero.

However,

These two forces are not collinear and thus produce torque on the loop which tends to rotate it anti clockwise.

Since the torque is given by the product of force and its perpendicular distance from the axis of rotation. The magnitude of the torque acting on the loop is given by

$$\tau = F_3 \frac{a}{2} sin\theta + F_4 \frac{a}{2} sin\theta$$

$$= IbB \frac{a}{2} sin\theta + IbB \frac{a}{2} sin\theta$$

$$= I(ab)B\, sin\theta$$

$$= IABsin\theta$$

$$= mBsin\theta$$

As θ tends to become 0, the perpendicular distance between the forces of the couple also approaches zero.

This makes the forces collinear and the net force and torque zero.

The torques can be expressed as a vector product of the magnetic moment of the coil and the magnetic field.

We define the ***magnetic moment*** of the current loop as, m = I A

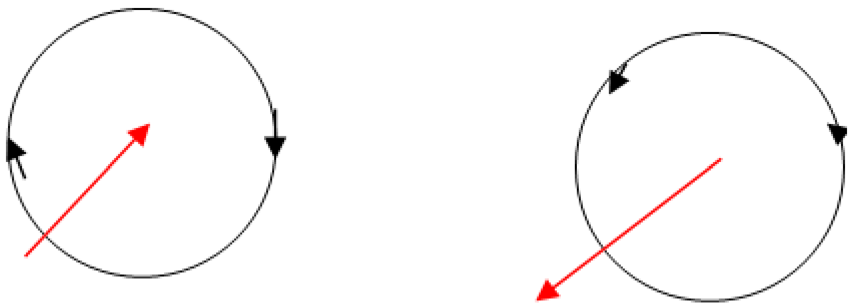
The magnetic moment m is directed into the plane of the loop.

Here m = IA,

the direction associated with m is perpendicular to the plane of the loop.

Using our previous knowledge of direction of magnetic field at the centre of the coil

- m is perpendicular to the plane of the coil it is emerging from the loop if the current in it is anticlockwise and
  into the plane of the coil if the current in the loop is clockwise.



The red arrow points towards the direction of 'm' where the direction of the area vector A is given by the right-hand thumb rule and is directed into the plane of the loop.

When $\theta = 0°$, that is when normal to the plane of loop and magnetic field are parallel to each other, torque acting on the loop becomes zero. In this case m and B are parallel.

This indicates a state of equilibrium as there is no net force and torque on the loop.

The result has been derived from a rectangular loop but it is a general result valid for any shape.

You will also now understand the importance of:

- Area of the loop
- Keeping magnetic field B constant

In vector form, the torque can be expressed as a cross product of the magnetic moment of the loop and the magnetic field.

Thus

$\tau = m \times B$

This is analogous to the electrostatic case (Electric dipole of dipole moment 'p' in an electric field E).

T = p × E

As is clear from above that the dimensions of the magnetic moment are $[A][L^2]$ and its unit is Am^2.

We see that the torque τ vanishes when m is either parallel or anti parallel to the magnetic field B.

This indicates a state of equilibrium as there is no torque on the coil (this also applies to any object with a magnetic moment m).

When m and B are parallel the equilibrium is a stable one. Any small rotation of the coil produces a torque which brings it back to its original position. When they are anti-parallel, the equilibrium is unstable as any rotation produces a torque which increases with the amount of rotation.

The presence of this torque is also the reason why a small magnet or any magnetic dipole aligns itself with the external magnetic field, remember

If the loop has *N* closely wound turns, the expression for torque, still holds, with m = N I A

Example

A 100 turn closely wound circular coil of radius 10 cm carries a current of 3.2 A.

a. What is the field at the centre of the coil?
b. What is the magnetic moment of this coil?

   The coil is placed in a vertical plane and is free to rotate about a horizontal axis which coincides with its diameter. A uniform magnetic field of 2T in the horizontal direction exists such that initially the axis of the coil is in the direction of the field. The coil rotates through an angle of 90º under the influence of the magnetic field.

c. What are the magnitudes of the torques on the coil in the initial and final position?
d. What is the angular speed acquired by the coil when it has rotated by 90º? The moment of inertia of the coil 0.1 kg $m.^2$

Solution

a. $B = \frac{\mu_0 NI}{2R}$

N=100, I = 3.2 A and R = 0.1 m

$$B = \frac{4\pi\times10^{-7}\times10^{2}\times3.2}{2\times10^{-1}} = \frac{4\times10^{-5}\times10}{2\times10^{-1}} \qquad \text{(Using } \pi \times 3.2 = 10\text{)}$$

$= 2 \times 10^{-3}$ T

The direction is given by the right-hand thumb rule.

b. The magnetic moment is given by

$m = NIA = NI \pi r^2 = 100 \times 3.2 \times 3.14 \times 10^{-2} = 10 \ Am^2$

c. torque = m × B = m B sin θ

Initially θ = 0°, hence the torque will be 0.

Finally θ = 90°, thus torque = m b = 10 × 2 = 20 Nm

d. From Newton's second law, ma = F or Iα =T

$$I\frac{d\omega}{dt} = mBsin\,\theta$$

$$as: \ \frac{d\omega}{dt} = \frac{d\omega}{d\theta}.\frac{d\theta}{dt} = \frac{d\omega}{d\theta}.\,\omega$$

Using this, $I\omega\, d\omega = mB\, sin\theta\, d\theta$

Integrating from $\theta = 0\ to\ \theta = \pi/2$

$$I\int_0^{\omega_f} \omega d\omega = mB\int_0^{\pi/2} sin\theta d\theta$$

$$I\frac{\omega_f^2}{2} = \ -\left|mBcos\,\theta\right|_0^{\pi/2} = mB$$

$$\omega_f = \left(\frac{2mB}{I}\right)^{1/2} = \left(\frac{2\times20}{10^{-1}}\right) = 20\ s^{-1}$$

Example

A current-carrying circular loop lies on a smooth horizontal plane. Can a uniform magnetic field be set up in such a manner that the loop turns around itself (i.e., turns about the vertical axis).

Solution

No, because that would require τ to be in the vertical direction. But τ = *I* A × B, and since A of the horizontal loop is in the vertical direction, τ would be in the plane of the loop for any B.

Example

A current-carrying circular loop is located in a uniform external magnetic field. If the loop is free to turn, what is its orientation of stable equilibrium? Show that in this orientation the flux of the total field (external field + field produced by the loop) is maximum.

Solution

Orientation of stable equilibrium is one where the area vector A of the loop is in the direction of the external magnetic field. In this orientation, the magnetic field produced by the loop is in the same direction as the external field, both normal to the plane of the loop, thus giving rise to maximum flux of the total field.

Example

A loop of irregular shape carrying current is located in an external magnetic field. If the wire is flexible, why does it change to a circular shape?

Solution

It assumes circular shape with its plane normal to the field to maximize flux, since for a given perimeter, a circle encloses greater area than any other shape.

Solved Example

Example

- What is the magnetic moment associated with a coil of 1 turn, area of loop 10^{-4} m^2, carrying a current of 2A?

Solution: $m = NIA = 1 \times 2 \times 10^{-4} = 2 \times 10^{-4}$ Am^2

- The maximum torque acting on a coil of effective area 0.04 m^2 is 4×10^{-8} Nm when the current in it is 100 μA. find the magnetic field (induction) in which it is kept

Solution

Maximum torque acting on the coil is given by $\tau = IAB$.

Using this $B = 10^{-2} T$

- A loop of area 0.02 m^2 and carrying a current of 10 ampere is held parallel to a magnetic field of intensity of 0.2T. Find the torque acting on the loop?

Solution

$\tau = IAB = 4 \times 10^{-2}\ Nm$

- A wire of length 4m carrying a current of 11A is bent into a circular loop. Find its magnetic moment?

  Solution

Here, circumference of loop $2\pi r = 4$

Magnetic moment $m = I\pi r^2 = 14 Am^2$

- A square coil of 10 cm consists of 20 turns and carries a current of 12A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30^0 with the direction of a uniform horizontal magnetic field of magnitude 0.80T. What is the magnitude of the torque experienced by the coil?

Hint: $\tau = NIAB\, sin30^0 = 0.96\, Nm$

- A square coil of 10cm has 20 turns and carries a current of 12A. The coil is suspended vertically. The normal to the plane of the coil makes an angle of 60^0 with the direction of a uniform horizontal magnetic field. If the torque experienced by the coil is 0.96 Nm, find the magnitude of the magnetic field?

Hint: using $\tau = NIABsin30^0$, B = 0.8T

- A circular coil of 100 turns radius 10 cm carries a current of 5A. It is suspended vertically in a uniform magnetic field of 0.5T, the field lines making an angle of 60^0 with the plane of the coil. Calculate the magnitude of the torque that must be applied on it to prevent it from turning.

Hint: Magnitude of the required = magnitude of the deflecting torque due to magnetic field.

Using $\tau = NIAB\, sin30^0$ = 3.925 Nm

- A coil of radius 2 cm and 10 turns is suspended in a uniform horizontal magnetic field 100 T makes an angle of 30^0 with the normal to the coil. Find the torque acting on the when a current of 10 A passes through the coil.

Hints: $\tau = NIAB\, sin30^0 = 4\pi\, Nm$

- A circular coil of 20 turns and radius 10 cm is placed in a uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5.0A, what is the (a) total torque on the coil (b) total force on the coil?

Hints: (a) zero, $\theta = 0$ (b) zero

- A solenoid of 0.4m length with 500 turns carries a current of 3A. A coil of 10 turns and of radius 0.01m carries a current of 0.4A. Find the torque required to hold the coil with its axis at right angles of that of solenoid in the middle of it.

Hints:Magnetic field inside solenoid B = $\mu_0 nI$ and $\tau = NIAB\, sin90^0 = 6\pi^2 \times 10^{-7} Nm$

- Two wires of equal lengths are bent in the form of two loops. One of the loops is square shaped, whereas the other loop is circular. These are suspended in a uniform magnetic field and the same current is passed through them. Which loop will experience greater torque? Give reasons.

Hint: Circular coil will experience greater torque because it has greater area.

- What is the SI unit of magnetic moment?

Hint: A m^2

- Show that the current carrying loop behaves as a magnetic dipole.

Solution

The face of the loop in which current is flowing in clockwise direction magnetic field lines enter into the plane and thus behaves as a south magnetic pole. While the face of the loop in which current is flowing in anticlockwise direction magnetic field lines directed out of the plane of loop and thus behaves as a magnetic north pole. Thus the current carrying loop behaves as a magnetic dipole.

- Write the factors on the magnetic moment of the current carrying loop depending.

Solution

Magnetic moment of current carrying loop depends on

- number of turns of loop (N)
- Current flowing in the loop (I)
- Area of loop (A)

- If the radius of circular loops carrying current is doubled. What happens to its magnetic moment?

Hint: If the radius is doubled the magnetic moment becomes four times its initial value.

- A current carrying loop free to turn is placed in a uniform magnetic field. What will be its orientation to the magnetic field in the equilibrium state?

Hint: for equilibrium the coil should be oriented normal to the magnetic field so that torque acting on it is zero.

- A circular coil of radius r carrying current I is unwound and rewound into another coil with radius r/2 carrying the same current. Find the ratio of magnetic moment of the coils in the two cases?

Hint: M_1: M_2 = 2:1

- A 100 turn closely-wound circular coil of radius 10 cm carries a current of 3.2A. What is the magnetic moment of the coil?

Hint: $M = NI\pi r^2 = 10.06Am^2$

Summary

In this module we have learnt:

- In a uniform magnetic field the net magnetic force on the current loop is zero but the torque varies from zero to maximum value.
- When a current carrying loop is placed in a magnetic field it experiences torque.
- The magnitude of the torque also depends upon the current flowing through the loop and the area of the loop.
- T=NIBA sinθ, the torque on a planar current loop depends on current strength of magnetic field and area of loop. it is independent of shape of loop
- Area vector is the area of the loop its direction is given by the right-hand thumb, the curling fingers in the direction of current and the thumb gives the field due to the current also the direction of magnetic dipole **m**.
- For a planar current loop of a given perimeter suspended in a magnetic field, the torque is maximum when the loop is circular in shape. This is because for a given perimeter a circle has maximum area.
- When the plane of the coil is parallel to the magnetic field, the torque acting on the coil is maximum. As the area vector is perpendicular to B and $\theta = 90^0$.
- When the plane of the coil is perpendicular to the magnetic field, the coil does not experience any torque. In this orientation the forces become collinear and the perpendicular distance between forces approaches to zero. $\theta = 0^0$ the equilibrium state of the coil in the magnetic field.

- The expression T = m × B for the torque on a current loop in a magnetic field is analogous to the expression t = p × E.

  For the torque on an electric dipole in an electric field this video also indicates that a current loop is a magnetic dipole:

  https://www.youtube.com/watch?v=MosMfPI1MNA