Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

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Chapter 6: Electromagnetic Induction

Chapter 6: Electromagnetic Induction

Electromagnetic induction:

Whenever the magnetic flux linked with an electric circuit changes, an emf is induced in the circuit. This phenomenon is called electromagnetic induction.

Chapter 6: Electromagnetic Induction

Faraday's Laws of Electromagnetic Induction:

- Whenever the magnetic flux linked with a circuit changes, an induced emf is produced in it.
- The induced emf lasts so long as the change in magnetic flux continues.
- The magnitude of induced emf is directly proportional to the rate of change in magnetic flux, i.e.,

$$E \propto \frac{d\varphi}{dt} \Rightarrow E = -\frac{d\varphi}{dt}$$

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Faraday's Laws of Electromagnetic Induction:

where constant of proportionality is one and negative sign indicates Lenz's law.

Here, flux = NBA cosθ, SI unit of φ = weber,

CGS unit of φ = maxwell, 1 weber = 108 maxwell,

Dimensional formula of magnetic flux

$$[\varphi] = [ML^{-2}T^{-2}A^{-2}]$$

Chapter 6: Electromagnetic Induction

Lenz's Law:

- The induced emf/ induced current direction is determined by this law.
- The direction of induced emf or current in a circuit, according to this law, is such that it opposes the source that generates it. The law of conservation of energy underpins this rule.
- When the N-pole of a bar magnet advances towards the coil, the flux associated with the loop increases, causing an emf. Induced current flows through the loop circuit since it is closed.

Chapter 6: Electromagnetic Induction

Lenz's Law:

- Because the approaching north pole is the cause of this induced current, the induced current in the loop is directed in such a way that the front face of the loop behaves like the north pole. Therefore, induced current as seen by the observer O is an anticlockwise direction.
- The cause of generated emf in the coil can also be referred to as relative motion if the loop is free to move. As a result, the relative motion between the two objects works against the cause.

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Lenz's Law:

- The loop and the incoming magnet should be in opposition. As a result, the loop will begin to move in the direction of the magnet is moving.
- It is critical to keep in mind that whenever the reason of induced the new motion is always in the direction of the emf.

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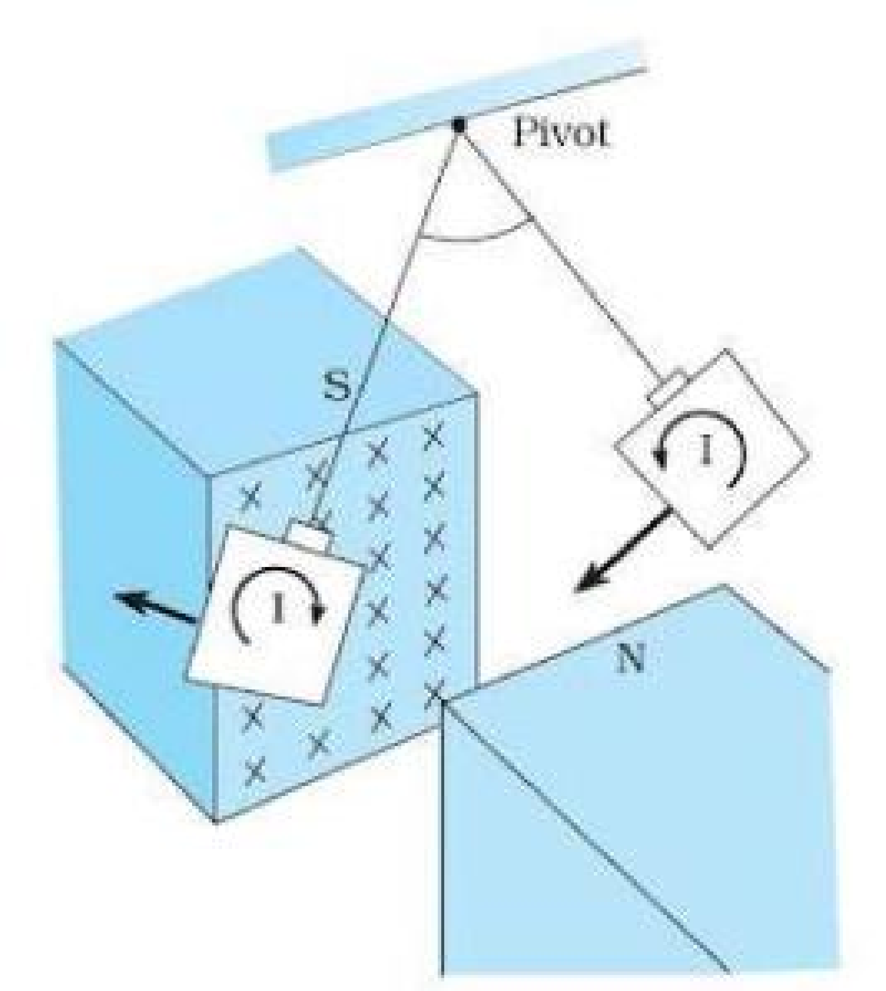
Eddy Current:



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Eddy Current:

When a changing magnetic flux is given to a large piece of conducting material, it induces circling currents known as eddy currents. Eddy currents have huge magnitudes and heat up the conductor because the bulk conductor's resistance is usually low.

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Eddy Current Applications:

Although eddy currents are generally unwelcome, they do have some helpful applications, as listed below.

- Dead-Beat Galvanometer: When a current is delivered via its coil, a deadbeat galvanometer's pointer comes to rest in the final equilibrium position instantaneously, with no oscillation around the equilibrium position. This is accomplished by winding the coil around a metallic frame, which induces significant eddy currents that give electromagnetic damping.

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Eddy Current Applications:

- When the train is running, the wheel moves in the air: When the train is stopped by electric brakes, the wheel is made to move in an electromagnet created field. Eddy currents created in the wheels as a result of the changing flux work against the cause and bring the train to a halt.

- Induction Furnace: The heat of Joule causes a metal item to melt when it is placed in a rapidly changing magnetic field.

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Eddy Current Applications:

- Speedometer: In an automobile's speedometer, a magnet is geared to the vehicle's main shaft and rotates in accordance with the vehicle's speed. Hair springs are used to secure the magnet in an aluminium cylinder. When the magnet rotates, it produces eddy currents in the drum and drags it through an angle, which indicates the speed of the vehicle on a calibrated scale.

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Eddy Current Applications:

- Energy Meter: The armature coil of an energy meter has a metallic aluminium disc that rotates between the poles of a pair of permanent horseshoe magnets. The current induced in the disc as the armature spins tend to oppose the motion of the armature coil. Deflection is proportional to the energy consumed due to this braking effect.

Chapter 6: Electromagnetic Induction

Induced Charge Flow:

When a current is induced in the circuit due to the flux change, charge flows through the circuit and the net amount of charge which flows along the circuit is given as:

$$q = \int i dt = \int \frac{1}{R}\left|\frac{d\phi}{dt}\right| dt = \frac{1}{R}\int d\phi \quad q = \frac{|\Delta\phi|}{R} \text{ and } q = N\,\frac{|\Delta\phi|}{R} \text{ for N tums}$$

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The Experiments of Faraday and Henry:

Figure shows a coil C1 connected to a galvanometer G. When the North-pole of a bar magnet is pushed towards the coil, the pointer in the galvanometer deflects, indicating the presence of electric current in the coil. The galvanometer does not show any deflection when the magnet is held stationary. When the magnet is pulled away from the coil, the galvanometer shows deflection in the opposite direction, which indicates reversal of the current's direction.

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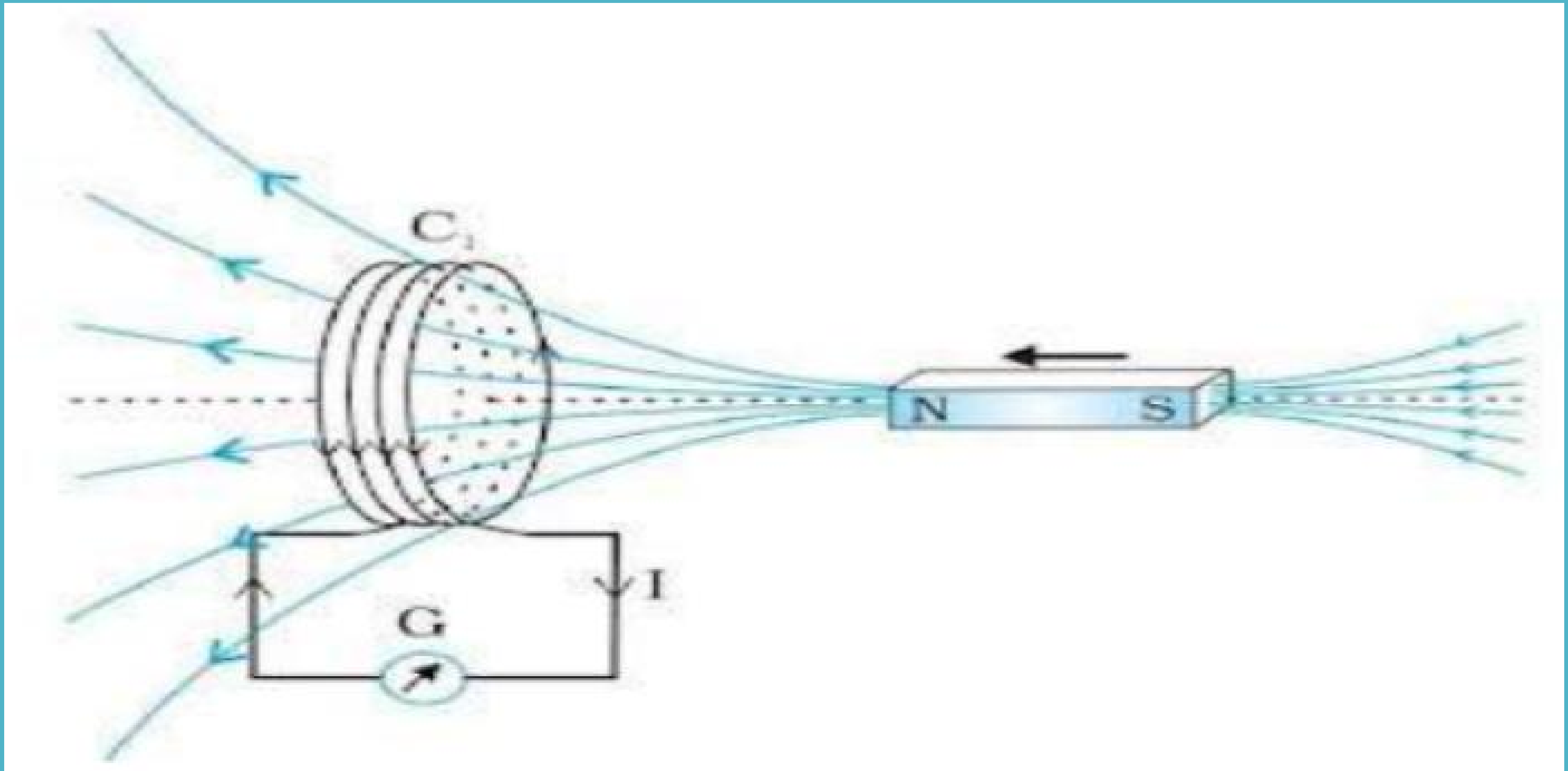
The Experiments of Faraday and Henry:



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The Experiments of Faraday and Henry:

Moreover, when the South-pole of the bar magnet is moved towards or away from the coil, the deflections in the galvanometer are opposite to that observed with the North-pole for similar movements. Further, the deflection is found to be larger when the magnet is pushed towards or pulled away from the coil faster. Instead, when the bar magnet is held fixed and the coil C1 is moved towards or away from the magnet, the same effects are observed. It shows that it is the relative motion between the magnet and the coil that is responsible for generation of electric current in the coil.

Chapter 6: Electromagnetic Induction

Fleming’s Right Hand Rule:

If we stretch the thumb, the fore finger and the central finger of right hand in such a way that all three are perpendicular to each other, if thumb represent the direction of motion, the forefinger represent tile direction of magnetic field, then centra} finger will represent the direction of induced current.

Chapter 6: Electromagnetic Induction

Fleming's Right Hand Rule:

If R is the electrical resistance of the circuit, then induced current in the circuit is given by $I = \frac{E}{R}$

If induced current is produced in a coil rotated in uniform magnetic field, then.

where, I_o = NBA ω = peak value of induced current,

N = number of turns in the coil,

B= magnetic induction,

ω = angular velocity of rotation and

A = area of cross-section of the coil.

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Fleming’s Right Hand Rule:

Self-Induction:

The phenomena of production of induced emf in a circuit due to change in current flowing in its own, is called self-induction.

Mutual Induction:

The phenomena of production of induced emf in a circuit due to the change in magnetic flux in its neighbouring circuit, is called mutual induction.

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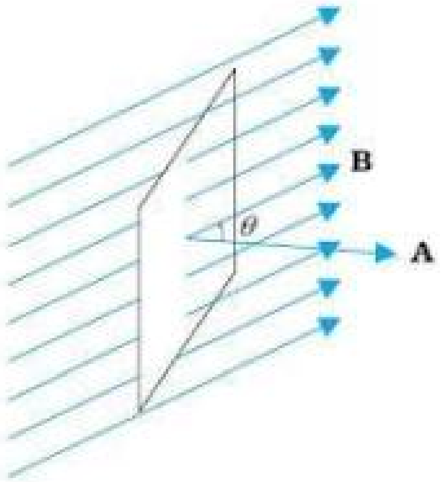
Magnetic Flux:

Like electric flux, magnetic flux is proportional to the number of magnetic field lines passing through a surface. It is denoted by ΦB. It is a scalar quantity.

Mathematically, $\emptyset B = \vec{B}\vec{A} = BA\cos\theta$



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Magnetic Flux:

SI unit of magnetic flux is weber (Wb) ($1 Wb = 1$ tesla-m^2). C.G.S. unit of magnetic flux is maxwell.
The dimensional formula of magnetic flux is $[ML^2T^{-2}A^{-1}]$.

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Motional Emf:

If a rod of length 1 moves perpendicular to a magnetic field B, with a velocity v, then induced emf produced in it given by.

$$E = B \times v \times l = Bvl$$

If a metallic rod of length 1 rotates about one of its ends in a plane perpendicular to the magnetic field, then the induced emf produced across its ends is given by.

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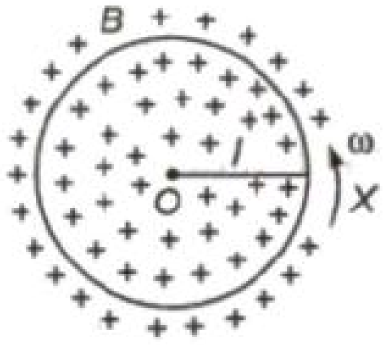
Motional Emf:



$$E = \frac{1}{2} b\omega r^2 = BAf$$

where, ω = angular velocity of rotation, f = frequency of rotation and A = πr2 = area of disc.

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Motional Emf:

The direction of induced current in any conductor can be obtained from Fleming's right hand rule.

A rectangular coil moves linearly in a field when coil moves with constant velocity in a uniform magnetic field, flux and induced emf will be zero.

A rod moves at an angle θ with the direction of magnetic field, velocity $E = - Blv \sin \theta$.

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An emf is induced:

- When a magnet is moved with respect to a coil.
- When a conductor falls freely in East-West direction.
- When an Aeroplan flies horizontally.
- When strength of current flowing in a coil is increased or decreased, induced current is developed in the coil in same or opposite direction.
- When a train moves horizontally in any direction.

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Induced Electric Field:

An electric field is induced in any region of space in which a magnetic field is changing with time.

Induced electric field and magnetic field are at right angles to each other.

Consider a particle of charge q_0 moving around the ring in a circular path. The work done by the induced electric field in one revolution is $W = q_0\varepsilon$, where ε is the induced emf.

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Induced Electric Field:

Also work done

$$W = \int \vec{F} . \vec{dl}$$

$$W = q_0 \int \vec{E} . \vec{dl}$$

$$q_0 \varepsilon = q_0 \int \vec{E} . \vec{dl}$$

$$\varepsilon = \int \vec{E} . \vec{dl}$$

By Faraday's law

$$\varepsilon = \frac{-d\emptyset B}{dt}$$

$$\therefore \int \vec{E} . \vec{dl} = \frac{-d\emptyset B}{dt}$$

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Lenz’s Law and Conservation of Energy:

Lenz's law is in accordance with law of conservation of energy. As the induced current opposes the change in flux, work has to be done against the opposition offered by induced current in changing the flux. The work done appears as electrical energy in the loop.

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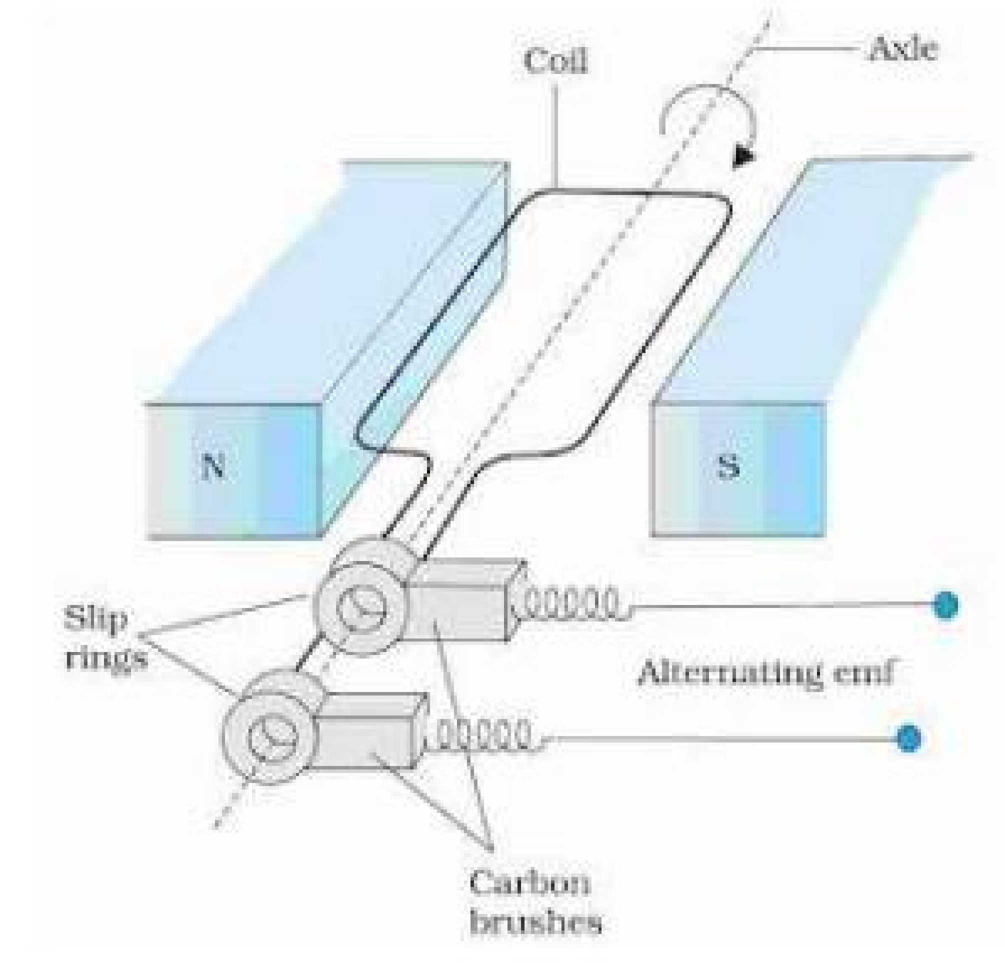
AC Generator:



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AC Generator:

It consists of a coil mounted on a rotor shaft. The axis of rotation of the coil is perpendicular to the direction of the magnetic field. The coil (called armature) is mechanically rotated in the uniform magnetic field by some external means. The rotation of the coil causes the magnetic flux through it to change, so an emf is induced in the coil. The ends of the coil are connected to an external circuit by means of slip rings and brushes.

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AC Generator:

When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector B and the area vector A of the coil at any instant t is θ = ωt. As a result, the effective area of the coil exposed to the magnetic field lines changes with time, and the flux at any time to is.

$$\phi_B = BA\cos\theta$$

$$\phi_B = BA\cos\theta$$

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AC Generator:

From Faraday's law, the induced emf for the rotating coil of N turns is, then,

$$\varepsilon = -N\frac{d\phi_B}{dt}$$

$$\varepsilon = -NBA\frac{d}{dt}(\cos\omega t)$$

Thus, the instantaneous value of the emf is,

$$\varepsilon = NBA\omega \sin\omega t$$

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AC Generator:

If we denote NBAω as ε0,

$$\varepsilon = \varepsilon_0 \sin \omega t$$

The direction of the current changes periodically and therefore the current is called alternating current (ac).

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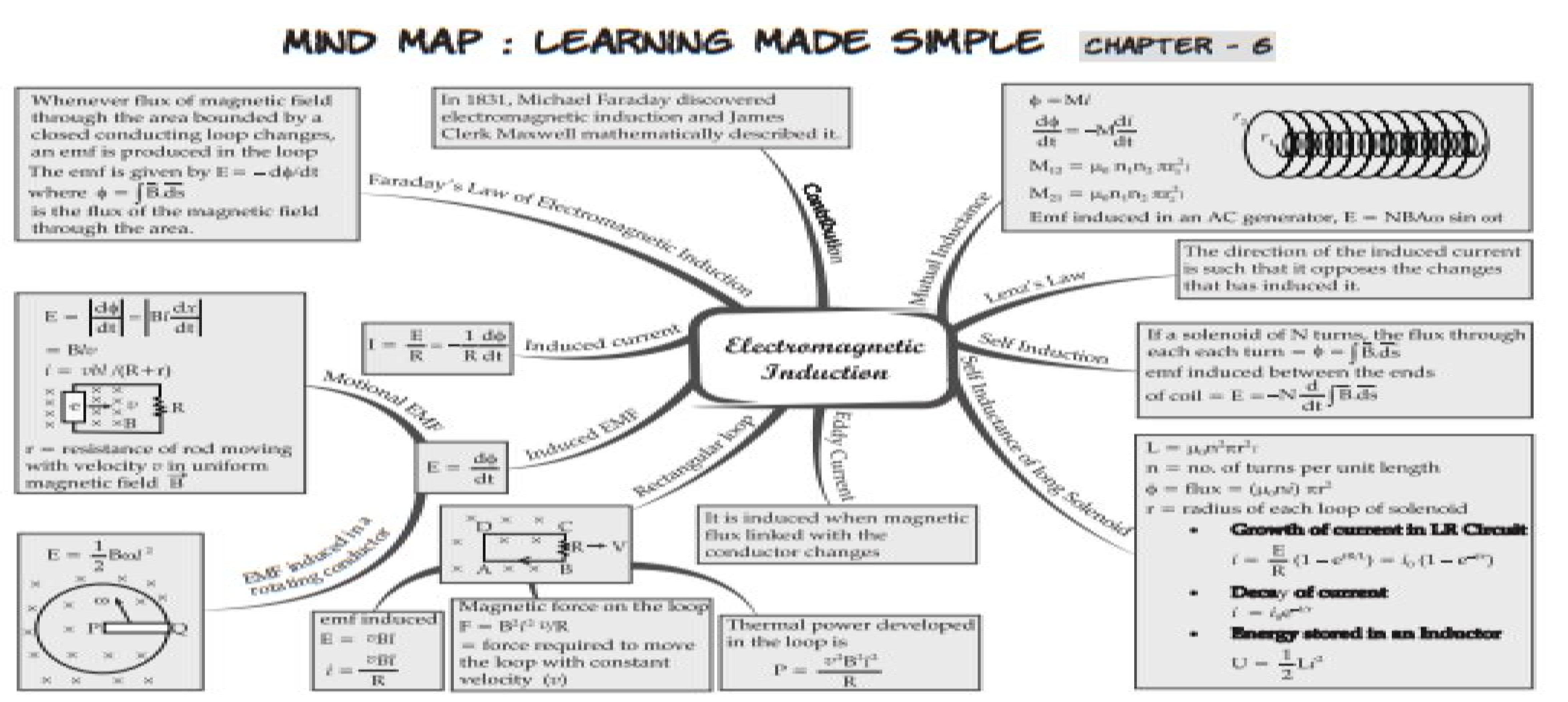

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