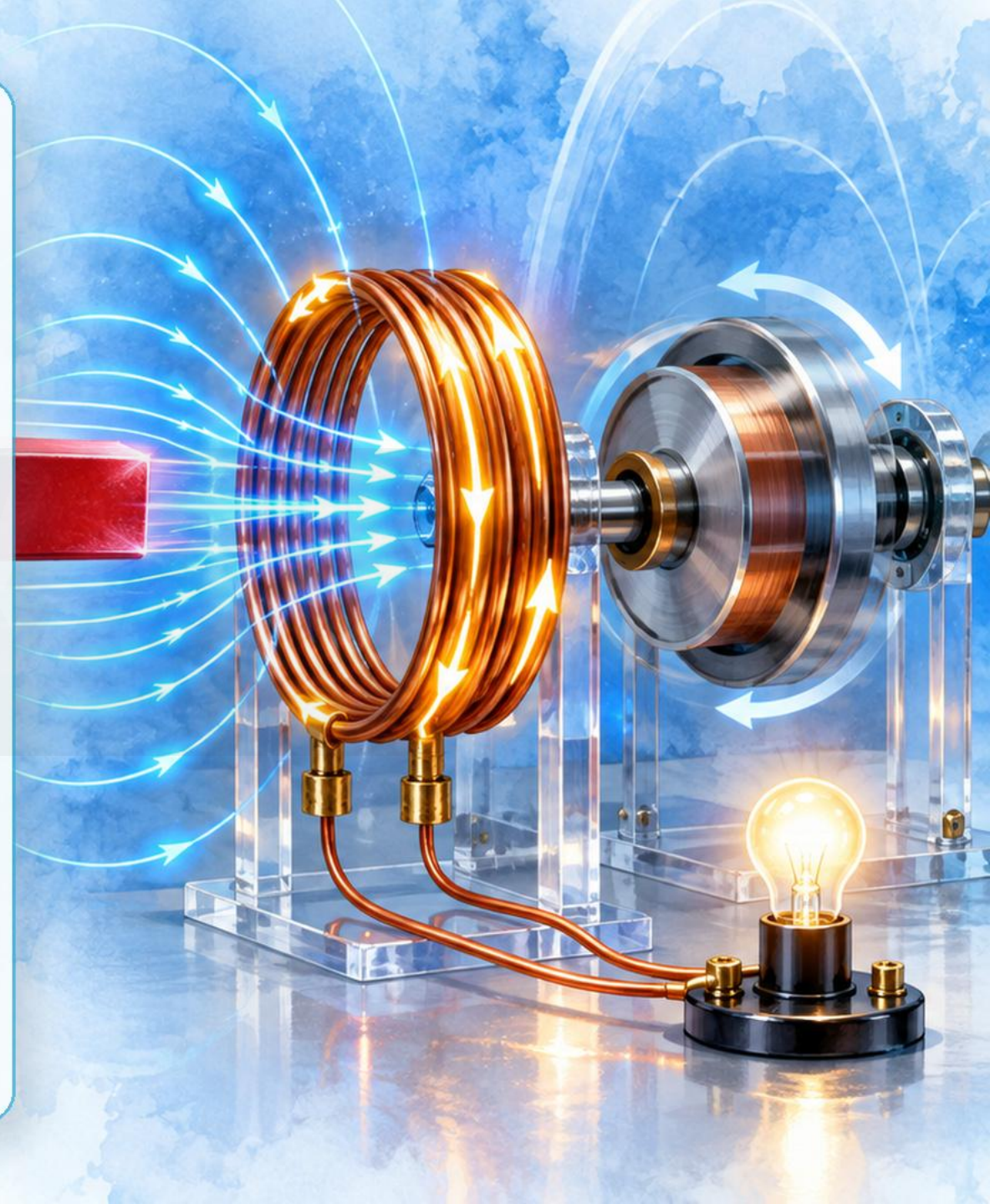


PHYSICS • CLASS 12

CHAPTER 6

Electromagnetic Induction

CHAPTER NOTES



ELECTROMAGNETIC INDUCTION

- Electromagnetic induction is the phenomenon of induced emf produced in a conductor when the magnetic flux linked with it changes.
- An induced current flows only when the conducting path is closed.

THE CENTRAL CAUSAL CHAIN

Change in any of these quantities

- Magnetic field $\vec{B}$
- Area A
- Orientation θ

Change in magnetic flux Φ_B

Induced emf $\mathcal{E}$

Induced current I (in closed circuit)

KEY RELATION

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

For uniform B over area A at angle θ :

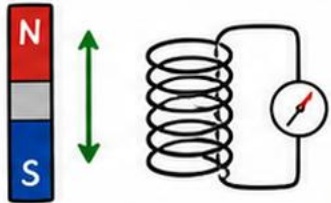
$$\Phi_B = BA \cos \theta$$

UNITS

Φ_B : weber (Wb)
 $\mathcal{E}$: volt (V)
 I : ampere (A)

① FARADAY-HENRY EXPERIMENTS

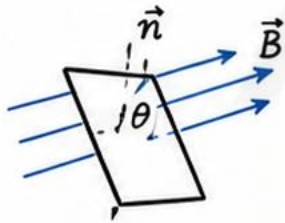
Changing magnetic flux through a coil induces an emf; no change, no emf.



- Move magnet in/out $\rightarrow$ meter deflects.
- Keep magnet still $\rightarrow$ no deflection.

② MAGNETIC FLUX

Flux through a surface is the measure of magnetic field lines passing through it.



$$\Phi_B = BA \cos \theta$$

(uniform B over area A)

Maximum Φ_B at $\theta = 0^\circ$
 Zero Φ_B at $\theta = 90^\circ$

③ FARADAY'S LAW

The induced emf is equal to the negative rate of change of magnetic flux linkage.

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$

For N turns, Φ_B is flux per turn.

Average emf over Δt :

$$\mathcal{E}_{\text{avg}} = -N \frac{\Delta \Phi_B}{\Delta t}$$

Unit check:

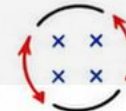
$$[\mathcal{E}] = N \frac{[\text{Wb}]}{[\text{s}]} = \text{V}$$

④ LENZ'S LAW

The induced emf (and current) has a direction such that its effect opposes the change in magnetic flux that produces it.

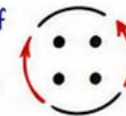
EXAMPLES

Flux into page increasing



Induced B out of page (counteracts increase)

Flux out of page decreasing



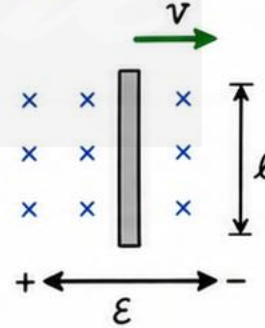
Induced B out of page (counteracts decrease)

Thumb rule for loop:

Thumb $\rightarrow$ induced B ; fingers $\rightarrow I$.

⑤ MOTIONAL EMF

A conductor of length ℓ moving with speed v in magnetic field B experiences an emf.

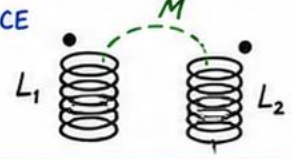


$$\mathcal{E} = B\ell v \sin \theta$$

θ = angle between $\vec{v}$ and $\vec{B}$.

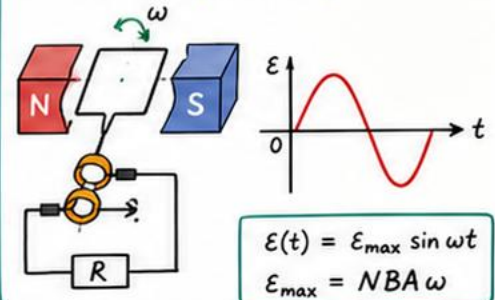
⑥ INDUCTANCE AND AC GENERATOR

INDUCTANCE



$$\mathcal{E}_1 = -L_1 \frac{dI_1}{dt} - M \frac{dI_2}{dt}$$

AC GENERATOR (SLIP RINGS)



$$\mathcal{E}(t) = \mathcal{E}_{\text{max}} \sin \omega t$$

$$\mathcal{E}_{\text{max}} = NBA\omega$$



ENERGY MESSAGE: Generators convert mechanical energy into electrical energy by electromagnetic induction. Work done to rotate or move parts $\rightarrow$ changing flux $\rightarrow$ emf $\rightarrow$ current $\rightarrow$ electrical energy.

FARADAY EXPERIMENT – MAGNET & COIL

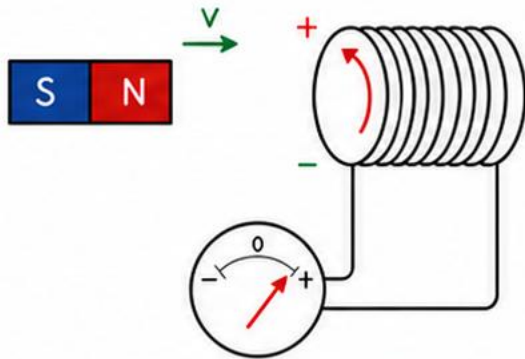
Faraday showed that a changing magnetic flux through a coil induces an emf and a current.

In the experiment below, a coil is connected to a centre-zero galvanometer.

A bar magnet is moved along the axis of the coil with its NORTH pole facing the coil.

The arrows inside the coil show the induced current as seen by the observer at the magnet side.

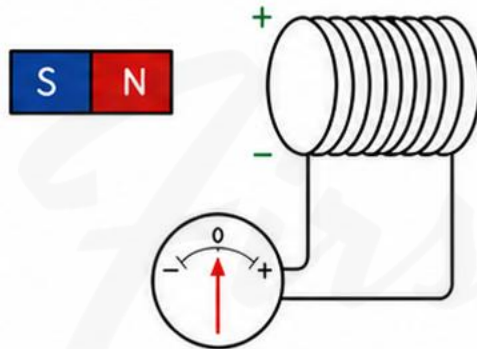
1) N POLE APPROACHING COIL



Deflects to RIGHT (+)

Induced current:
COUNTERCLOCKWISE
(as seen from magnet side)

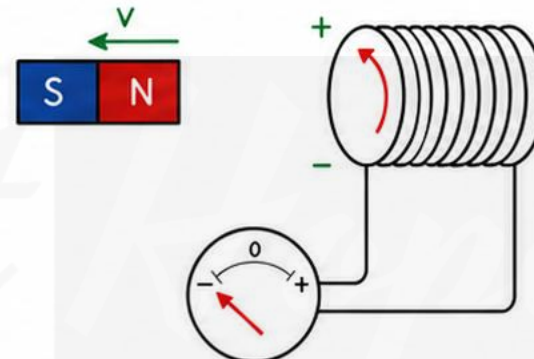
2) MAGNET STATIONARY



No deflection (0)

No induced current

3) N POLE RECEDING FROM COIL



Deflects to LEFT (-)

Induced current:
CLOCKWISE
(as seen from magnet side)

KEY SUMMARY

- A current is induced in the coil only when the magnetic flux through the coil changes.
- Approaching N pole (flux into coil increases) → current is counterclockwise; galvanometer deflects right (+).
- Receding N pole (flux into coil decreases) → current is clockwise; galvanometer deflects left (-).
- Reversing the magnet (N ↔ S) reverses every indicated direction.
- Greater speed of relative motion → larger change of flux → larger deflection.
- Moving the coil instead of the magnet gives the same result: relative magnet-coil motion is what matters.

MATHEMATICAL STATEMENT

Induced emf: $\mathcal{E} = -N \frac{d\Phi_B}{dt}$ (Faraday's law)

Induced current: $I = \frac{\mathcal{E}}{R}$ (R = total circuit resistance)

Direction: given by Lenz's law.
It opposes the change in flux.

REVERSING THE MAGNET

If we reverse the magnet so that the S pole faces the coil, then in every case the deflection and the current direction are reversed.

Approaching (S pole) → deflects LEFT (-)

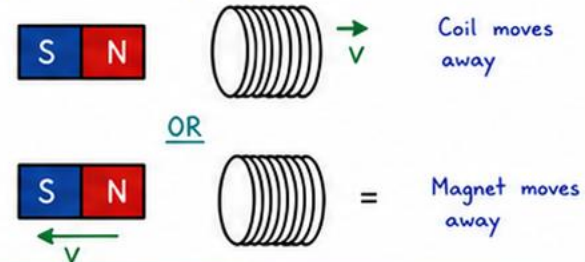
Receding (S pole) → deflects RIGHT (+)

FASTER MOTION, LARGER DEFLECTION

The greater the speed of relative motion, the faster the change of flux and the larger the emf and current. Therefore, the galvanometer shows a larger deflection.

RELATIVE MOTION MATTERS

It is the relative motion between the magnet and the coil that matters. Moving the coil instead of the magnet produces exactly the same effect.



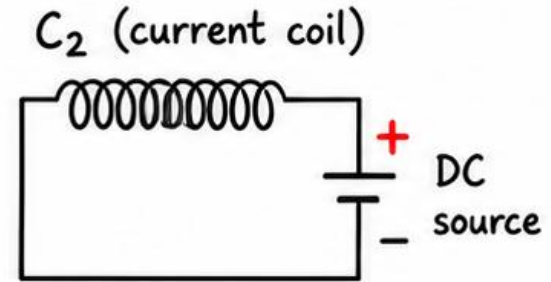
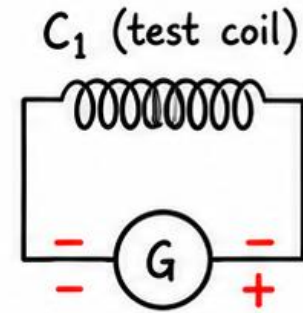
CONVENTIONS USED

- Arrow inside coil shows conventional current as seen from the magnet side.
- Dot (•) = magnetic field out of the page (towards you).
- Cross (x) = magnetic field into the page (away from you).

FARADAY EXPERIMENTS — COILS & SWITCHING

A. MOTION OF COILS (WITH STEADY CURRENT IN C_2)

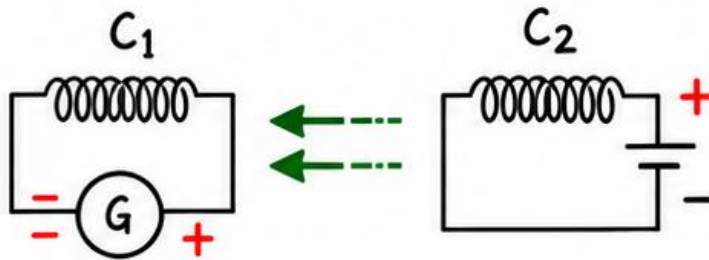
A test coil C_1 connected to a galvanometer G is placed near a current-carrying coil C_2 (connected to a DC source). Moving C_2 towards or away from C_1 changes the magnetic flux through C_1 and produces a momentary current. Opposite motions give opposite deflections. If the coils are stationary and the current in C_2 is steady, the flux is constant and no current is induced.



Take right deflection as positive.

① C_2 APPROACHES C_1

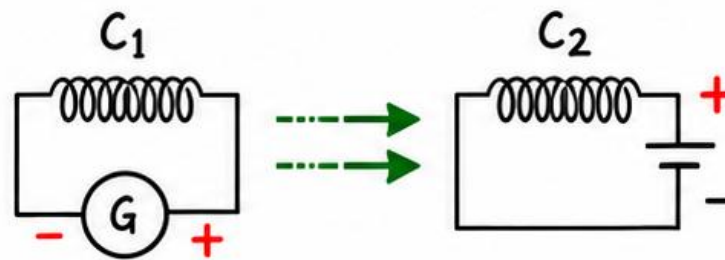
Flux through C_1 increases.



Induced current: momentary.
Gives **RIGHT** deflection (+).

② C_2 RECEDES FROM C_1

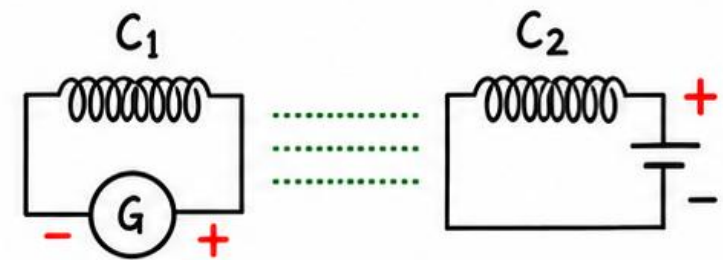
Flux through C_1 decreases.



Induced current: momentary.
Gives **LEFT** deflection (-).

③ COILS STATIONARY

Flux through C_1 constant.



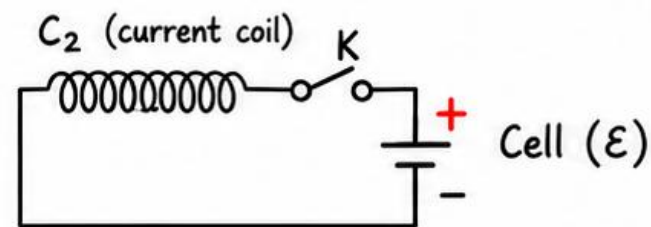
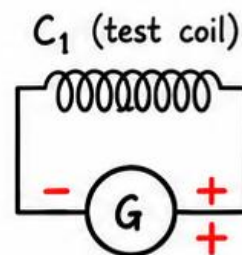
Induced current: zero.
Galvanometer shows **NO** deflection (zero).

→ **CONCLUSION (A):** Induction in C_1 occurs only when the magnetic flux through it **changes** due to motion of C_2 . Mere presence of magnetic field (with steady current and no motion) produces **no current**.

FARADAY EXPERIMENTS – COILS & SWITCHING

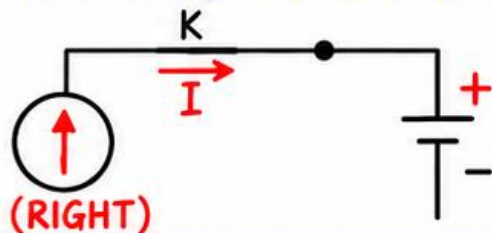
B. SWITCHING CURRENT IN C_2 (COILS STATIONARY)

Both coils are fixed in position. C_2 is connected to a cell and key K. Closing or opening the key changes the current in C_2 , hence the magnetic field and flux through C_1 , producing momentary currents in C_1 . When the key is held closed, the current and flux are steady and no current is induced.



① KEY CLOSED (K CLOSED)

Current in C_2 rises from 0 to I .



Field $\uparrow \Rightarrow$ Flux through $C_1 \uparrow$
(Change is increasing)

Induced current: momentary.

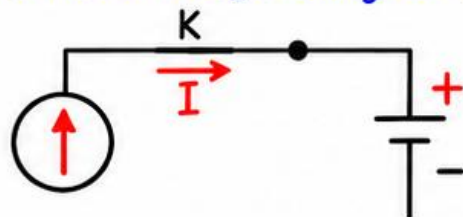
Deflection: **RIGHT (+)**.

$$\mathcal{E}_{\text{ind}} = -N_1 \frac{d\Phi_B}{dt} < 0$$

(since $\frac{d\Phi_B}{dt} > 0$)

② KEY HELD CLOSED

Current in C_2 steady at I .



Field steady $\Rightarrow$ Flux constant
(Change is zero)

Induced current: zero.

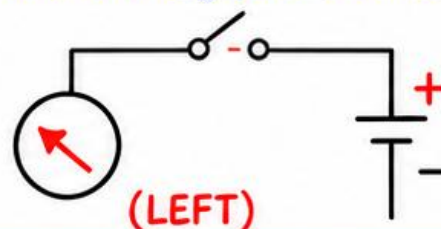
Deflection: **ZERO (none)**.

$$\mathcal{E}_{\text{ind}} = -N_1 \frac{d\Phi_B}{dt} = 0$$

(since $\frac{d\Phi_B}{dt} = 0$)

③ KEY OPENED (K OPENED)

Current in C_2 falls from I to 0.



Field $\downarrow \Rightarrow$ Flux through $C_1 \downarrow$
(Change is decreasing)

Induced current: momentary.

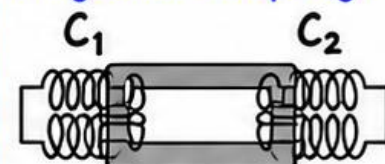
Deflection: **LEFT (-)**.

$$\mathcal{E}_{\text{ind}} = -N_1 \frac{d\Phi_B}{dt} > 0$$

(since $\frac{d\Phi_B}{dt} < 0$)

EFFECT OF SOFT-IRON CORE

Placing a soft-iron core inside both coils greatly increases magnetic coupling.



- $\Rightarrow$ Larger flux Φ_B for the same current.
- $\Rightarrow$ Greater change in flux for the same switching.
- $\Rightarrow$ Larger induced emf and a greater galvanometer deflection.

$\Rightarrow$ **CONCLUSION (B):** Induced current in C_1 appears only when the flux through it changes due to a change in current in C_2 (on closing or opening the key). Steady current $\Rightarrow$ steady flux $\Rightarrow$ no induced current. The experiment proves: It is **CHANGE OF FLUX**, not mere presence of magnetic field, that produces induction.

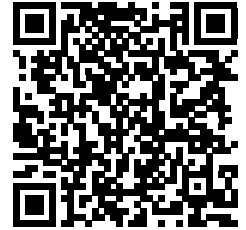


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