FREE NOTES · NCERT + JEE/NEET LEVEL

Electromagnetic Induction

Magnetic flux, Faraday aur Lenz ke laws, motional EMF, eddy currents, self aur mutual inductance, inductor ki energy aur AC generator. Diagrams aur solved numericals ke saath.

01 Faraday ke experiments
02 Magnetic flux
03 Faraday's law
04 Lenz's law
05 Motional EMF
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01 Faraday ke experiments

Oersted ne dikhaya current se magnetic field banta hai. Faraday ne ulta socha: kya magnetic field se current ban sakta hai? Haan, par sirf jab field **badal raha ho**.

- Coil ke paas magnet laao ya door le jaao: galvanometer hilta. Magnet ruka ho toh nahi.
- Magnet jitni tezi se hilao, deflection utna zyada.
- Ek coil ka current on/off karo: paas wali doosri coil me current aata (sirf on/off ke pal).

Is badalte field se paida current ko **induced current** aur EMF ko **induced EMF** kehte hain.

02 Magnetic flux

$$\Phi = \mathrm{B} \cdot \mathrm{A} = \mathrm{B}\,\mathrm{A}\cos\theta$$

θ = B aur area vector (surface ke ⊥) ke beech. Unit weber (Wb) = T·m². Scalar. N turns: total flux NΦ.

Flux teen tareekon se badal sakta: **B badlo**, **area badlo**, ya **angle badlo** (coil ghumao).

03 Faraday's law

STATEMENT

$\varepsilon = -N \, d\Phi/dt$

Induced EMF = flux ke badalne ki rate. Average: $\varepsilon = -N\Delta\Phi/\Delta t$. Minus sign = Lenz's law.

Induced current $I = \varepsilon/R$

Induced charge $Q = N\Delta\Phi/R$

Charge sirf flux ke total badlav pe depend karta, kitni tezi se badla us pe nahi.

04 Lenz's law

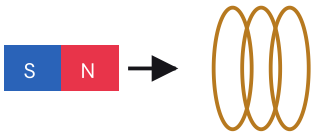
STATEMENT

Induced current ki direction aisi hoti hai ki wo us **badlav ka virodh** kare jisne use paida kiya.

- Magnet ka N pole coil ki taraf laao ⇒ coil ka saamne wala face N ban jaata (repel karta).
- N pole door le jaao ⇒ saamne wala face S (rokne ke liye kheenchta).

ENERGY CONSERVATION

Agar induced current badlav ko support karta, toh bina mehnat ke energy banti rehti, jo impossible hai. Lenz's law energy conservation ka natija hai: magnet ko dhakelne me jo work lagta, wahi bijli banti.



N face (repel)

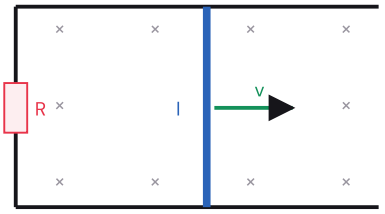
Paas aate N ko coil N ban ke rokti

05 Motional EMF

Length l ki rod velocity v se B ke ⊥ chal rahi. Rod ke andar ke charges pe Lorentz force ⇒ EMF.

$$\varepsilon = B\,l\,v$$

Circuit band ho (resistance R): I = Blv/R, rod pe ulta force F = B^2l^2v/R. Rod ko constant v se chalaane ka power = $B^2l^2v^2/R$ = heat (I^2R).



Rails pe sarakti rod, B kaagaz ke andar

06 Ghoomti rod & disc

Rod (length l) ek sire pe ω se ghoomti, B ⊥: $\varepsilon = \frac{1}{2}\,B\,\omega\,l^2$

Disc (radius R): centre aur kinare ke beech $\varepsilon = \frac{1}{2}\,B\,\omega\,R^2$

Rod ka har hissa alag speed se, average speed ωl/2 lo.

07 Eddy currents

Bade metal ke tukde me badalte flux se andar gol-gol currents (bhanwar jaise) bante hain: **eddy currents**. Ye garmi paida karte aur motion ka virodh karte.

FAYDE

- Train ke electromagnetic brakes.
- Galvanometer ki sui jaldi rukti (damping).
- Induction furnace, induction cooktop.
- Speedometer.

NUKSAAN AUR BACHAAV

Transformer/motor core me energy loss aur garmi. Bachaav: core ko patli **laminated** (insulated) sheets se banana, taaki current ka raasta tukdon me toot jaaye.

08 Self inductance

Coil ka apna current badle toh uska apna flux badalta ⇒ khud me EMF jo badlav ka virodh karta (back EMF). Ye current ki "inertia" hai.

$$N\Phi = L\,I$$

$$\varepsilon = -\,L\,dI/dt$$

Lamba solenoid: $L = \mu_0\, n^2\, A\, l = \mu_0 N^2 A/l$

Unit henry (H). Iron core (μ_r) daalo ⇒ L μ_r guna.

INDUCTOR ME STORED ENERGY

$$U = \tfrac{1}{2}\,L\,I^2$$

Magnetic field me store. Energy density = $B^2/(2\mu_0)$. Mass ki KE $\tfrac{1}{2}mv^2$ jaisa: L ↔ m, I ↔ v.

Switch kholne pe current achanak 0 hone ki koshish ⇒ bahut bada back EMF ⇒ **spark** dikhta hai.

09 Mutual inductance

Ek coil ka current badle toh paas wali doosri coil me EMF.

$$N_2\Phi_2 = M\,I_1,\ \varepsilon_2 = -\,M\,dI_1/dt$$

Do coaxial solenoids: $M = \mu_0\, n_1\, n_2\, A\, l$

$$M = k\,\sqrt{(L_1 L_2)},\ 0 \le k \le 1 \text{ (coupling)}$$

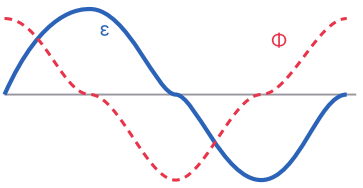
$M_{12} = M_{21}$. Coils paas aur same axis pe ⇒ M zyada. Transformer isi pe chalta.

10 AC generator

Coil (N turns, area A) magnetic field me ω se ghumao. Angle θ = ωt badalta ⇒ flux $NBA\cos\omega t$ badalta ⇒ EMF.

$$\varepsilon = N\,B\,A\,\omega\sin\omega t = \varepsilon_0\sin\omega t$$

Peak EMF ε_0 = NBAω. Jab coil ka plane B ke parallel (flux 0), tab EMF **max**. Jab plane ⊥ (flux max), EMF 0.



Flux max ⇒ EMF 0, aur ulta (π/2 ka fark)

Mechanical energy (turbine, paani, bhaap) → electrical energy. India me f = 50 Hz.

11 JEE Extra + Tricks

JEE LEVEL

- Motional emf: rod $\varepsilon = Bvl$; ek sire pe ghoomti rod $\varepsilon = \frac{1}{2}B\omega l^2$; disc $\frac{1}{2}B\omega R^2$.
- Solenoid ka self-inductance $L = \mu_0 n^2 Al$; energy $\frac{1}{2}LI^2$; energy density $B^2/2\mu_0$.
- LR circuit: badhna $I = I_0(1 - e^{-t/\tau})$, ghatna $I = I_0 e^{-t/\tau}$, $\tau = L/R$. t = 0 pe inductor open circuit; steady state me seedha taar.
- Coaxial solenoids ka $M = \mu_0 n_1 n_2 Al$; $M \le \sqrt{(L_1 L_2)}$.
- Lenz ka law = energy conservation: induced current badlav ka virodh (tambe ki tube me girta magnet dheere girta).

12 Solved numericals

Q1. 100 turns ki coil me flux 0.05 Wb se 0.01 Wb tak 0.2 s me. EMF?
$\varepsilon = 100 \times 0.04/0.2 = 20$ V. **Ans: 20 V**

Q2. 50 cm rod 4 m/s se 0.5 T field ke ⊥. EMF? Circuit R = 2 Ω, current?
$\varepsilon = 0.5 \times 0.5 \times 4 = 1$ V. I = 0.5 A. **Ans: 1 V, 0.5 A**

Q3. 1 m rod ek sire pe 10 rad/s se 0.2 T field me ghoom rahi. EMF?
$\varepsilon = \frac{1}{2} \times 0.2 \times 10 \times 1 = 1$ V. **Ans: 1 V**

Q4. Coil L = 0.2 H, current 0.1 s me 5 A se 0. Induced EMF?
$\varepsilon = L\,\Delta I/\Delta t = 0.2 \times 50 = 10$ V. **Ans: 10 V**

Q5. 2 H inductor me 3 A. Stored energy?
$U = \frac{1}{2} \times 2 \times 9 = 9$ J. **Ans: 9 J**

Q6. Generator: 100 turns, A = 0.1 m², B = 0.01 T, 50 Hz. Peak EMF?
$\omega = 100\pi$. $\varepsilon_0 = 100 \times 0.01 \times 0.1 \times 100\pi = 10\pi \approx 31.4$ V. **Ans: ≈ 31.4 V**

13 Common mistakes

- Constant flux pe bhi EMF maan lena. Sirf **badalte** flux pe.
- Lenz's law me direction ulta lena: induced current badlav ka **virodh** karta.
- Generator me "flux max to EMF max" likhna (ulta hai).
- Ghoomti rod me Blv lagana (½Bωl² sahi).
- L ke formula me n (per metre) aur N (total) mix karna.

14 Formula sheet

Flux	$\Phi = BA\cos\theta$
Faraday	$\varepsilon = -N\,d\Phi/dt$
Induced charge	$Q = N\Delta\Phi/R$
Motional EMF	$\varepsilon = Blv$
Rotating rod	$\varepsilon = \frac{1}{2}B\omega l^2$
Self inductance	$\varepsilon = -L\,dI/dt,\ L = \mu_0 n^2 Al$
Mutual inductance	$\varepsilon = -M\,dI/dt,\ M = \mu_0 n_1 n_2 Al$
Energy	$U = \frac{1}{2}LI^2,\ u = B^2/2\mu_0$
AC generator	$\varepsilon = NBA\omega\sin\omega t$

15 Practice questions

1. Solenoid ke turns 2 guna (length same). L?
2. Generator ki speed 2 guna. Peak EMF?
3. Magnet ko coil me tez ya dheere daalo: induced charge me fark?
4. Transformer core laminated kyun?

ANSWERS

1) 4 guna ($L \propto N^2$) · 2) 2 guna · 3) Koi fark nahi ($Q = N\Delta\Phi/R$) · 4) Eddy current loss kam karne ke liye

16 Quick revision: exam se pehle 5 minute

LAWS

- $\varepsilon = -N\, d\Phi/dt$.
- Lenz: badlav ka virodh (energy conservation).
- $Q = N\Delta\Phi/R$ (speed pe nahi).

MOTIONAL

- Rod: Blv.
- Ghoomti rod/disc: $\frac{1}{2}B\omega l^2$.
- Eddy current: laminated core se kam.

INDUCTANCE

- $\varepsilon = -L\, dI/dt$; $L = \mu_0 n^2 Al$.
- $U = \frac{1}{2}LI^2$.
- $M = k\sqrt{(L_1 L_2)}$.

GENERATOR

- $\varepsilon_0 = NBA\omega$.
- Flux max ⇒ EMF 0.

Doubt hai? padhaiadda.netlify.app pe AI Doubt Solver se poocho, ya is chapter ka mock test do.