FREE NOTES · NCERT + JEE/NEET LEVEL

Electromagnetic Waves

Displacement current, Maxwell's equations, EM waves ke gun, speed, energy aur momentum, aur poora electromagnetic spectrum unke uses ke saath.

01 Displacement current
02 Maxwell's equations
03 EM wave kya hai
04 EM waves ke gun
05 Energy, intensity & momentum
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01 Displacement current

Capacitor charge ho raha hai: taar me current hai, par plates ke beech koi charge nahi beh raha. Phir bhi plates ke beech magnetic field hota hai. Maxwell ne bataya: **badalta electric field bhi current jaisa kaam karta hai**.

$$I_d = \varepsilon_0 \, d\Phi_E/dt$$

Displacement current = conduction current (charging ke time). Ampere-Maxwell law: $\oint B \cdot dl = \mu_0(I_c + I_d)$.

ISKA MATLAB

Badalta B ⇒ E (Faraday). Badalta E ⇒ B (Maxwell). Dono ek doosre ko banate hue aage badhte: yahi **EM wave** hai.

02 Maxwell's equations

Equation	Naam	Matlab
$\oint E \cdot dA = Q/\varepsilon_0$	Gauss (electricity)	Charge field banata
$\oint B \cdot dA = 0$	Gauss (magnetism)	Monopole nahi
$\oint E \cdot dl = -d\Phi_B/dt$	Faraday	Badalta B ⇒ E
$\oint B \cdot dl = \mu_0 I + \mu_0\varepsilon_0 \, d\Phi_E/dt$	Ampere-Maxwell	Current ya badalta E ⇒ B

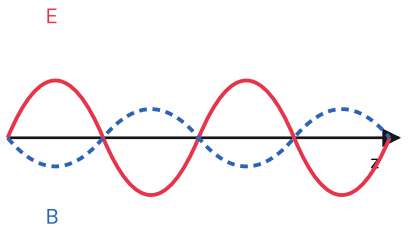
03 EM wave kya hai

Accelerated (ya oscillating) charge EM waves paida karta hai. Ruka charge sirf E deta, constant speed wala charge E aur B deta, par wave sirf accelerated charge se.

$$E_x = E_0 \sin(kz - \omega t)$$

$$B_y = B_0 \sin(kz - \omega t)$$

E, B aur wave ki direction teeno ek doosre ke ⊥. E aur B same phase me. Direction = E × B.



E aur B ⊥, dono wave ki direction (z) ke ⊥

04 EM waves ke gun

- **Transverse** waves.
- **Medium ki zaroorat nahi**, vacuum me sabse tez.
- Vacuum me speed $c = 1/\sqrt{(\mu_0 \varepsilon_0)} = 3 \times 10^8\ m/s$, sab frequencies ke liye same.
- Medium me $v = 1/\sqrt{(\mu \varepsilon)} = c/n$, n = refractive index = $\sqrt{(\mu_r \varepsilon_r)}$.
- $E_0/B_0 = c$ (E bada dikhta par energy dono me barabar).
- Charge ke bina hote, isliye electric ya magnetic field me nahi mudte.

05 Energy, intensity & momentum

Energy density $u = \frac{1}{2}\varepsilon_0 E^2 + B^2/(2\mu_0)$; dono hisse barabar

Average $u = \frac{1}{2}\,\varepsilon_0\,E_0^2$

$$\text{Intensity } I = u_{avg} \times c = \frac{1}{2}\,\varepsilon_0\,E_0^2\,c$$

Momentum $p = U/c$

Radiation pressure: poora absorb ⇒ I/c, poora reflect ⇒ 2I/c. Isliye sunlight ka halka sa dhakka hota hai (comet ki poonch Sun se door).

06 Electromagnetic spectrum

Wave	Wavelength (approx.)	Kaise banti	Use
Radio	> 0.1 m	Antenna me oscillating current	Radio, TV, mobile
Microwave	0.1 m – 1 mm	Klystron, magnetron	Radar, microwave oven, satellite
Infrared	1 mm – 700 nm	Garam cheezein, molecules ka hilna	Remote, night vision, physiotherapy, "heat waves"
Visible	700 – 400 nm	Atom me electrons ka jump	Dekhna (laal sabse lamba, baingani chhota)
Ultraviolet	400 – 1 nm	Sun, bahut garam cheezein	Paani saaf karna, LASIK; ozone isse bachaati
X-rays	1 nm – 10^{-3} nm	Fast electrons metal pe takrayein	Haddi ki photo, cancer treatment
Gamma rays	< 10^{-3} nm	Nucleus (radioactivity)	Cancer treatment, food sterilise

ORDER YAAD KARNE KI TRICK

Wavelength ghatte order me: **R**adio, **M**icro, **I**nfra, **V**isible, **U**V, **X**, **G**amma, yaani **R–M–I–V–U–X–G**. Frequency aur energy isi order me badhti.

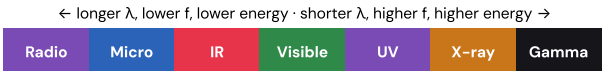
GREENHOUSE EFFECT

Earth garam hoke infrared chhodti, CO_2 jaisi gases use rok leti ⇒ Earth garam rehti.

07 JEE Extra + Tricks

JEE LEVEL

- c = $1/\sqrt{(\mu_o \varepsilon_o)}$; $E_o = cB_o$; E, B aur chalne ki disha aapas me perpendicular (E × B se disha).
- Displacement current $I_d = \varepsilon_o \, d\Phi_E/dt$ (charge hote capacitor ke andar Ampère law sahi).
- Average energy density $u = \frac{1}{2}\varepsilon_o E_o^2$ (E aur B me barabar); intensity I = u·c.
- Radiation pressure: poora absorb I/c, poora reflect 2I/c.



Visible: 400 nm (violet) to 700 nm (red)
Trick: "Ram's Mother Is Visiting Uncle X-ray Gamma"

Electromagnetic spectrum

08 Solved numericals

Q1. EM wave me $E_o = 60$ V/m. B_o?
$B_o = E_o/c = 60/(3 \times 10^8) = 2 \times 10^{-7}$ T. **Ans: 2×10^{-7} T**

Q2. 30 MHz radio wave ka wavelength?
$\lambda = c/f = 3 \times 10^8/3 \times 10^7 = 10$ m. **Ans: 10 m**

Q3. Capacitor ki plates ka area 0.01 m², E 10^{12} V/m·s ki rate se badal raha. Displacement current? ($\varepsilon_o = 8.85 \times 10^{-12}$)
$I_d = \varepsilon_o A\, dE/dt = 8.85 \times 10^{-12} \times 0.01 \times 10^{12} = 0.0885$ A. **Ans: ≈ 88.5 mA**

Q4. Glass ($\varepsilon_r = 2.25$, $\mu_r = 1$) me light ki speed?
$n = \sqrt{2.25} = 1.5 \Rightarrow v = 2 \times 10^8$ m/s. **Ans: 2×10^8 m/s**

09 Common mistakes

- E aur B ko 90° phase difference me maan lena. Wo same phase me hain, sirf directions ⊥.
- Uniform speed wale charge se EM wave maan lena (accelerated chahiye).
- Vacuum me alag frequencies ki alag speed maan lena.
- Spectrum ka order galat (UV aur X-ray, IR aur microwave mix).

10 Formula sheet

Displacement current	$I_d = \varepsilon_0\, d\Phi_E/dt$
Speed	$c = 1/\sqrt{(\mu_0\varepsilon_0)}$, $v = c/n$
Field ratio	$E_0/B_0 = c$
Wave relation	$c = f\lambda$
Intensity	$I = \frac{1}{2}\varepsilon_0 E_0^2 c$
Momentum	$p = U/c$
Radiation pressure	I/c (absorb), $2I/c$ (reflect)

11 Practice questions

1. Kaun si EM wave sabse zyada energy wali?
2. TV remote me kaun si wave?
3. Ozone layer kis wave ko rokti?
4. $B_o = 10^{-8}$ T. E_o?

ANSWERS

1) Gamma rays · 2) Infrared · 3) Ultraviolet · 4) 3 V/m

12 Quick revision: exam se pehle 5 minute

BASICS

- $I_d = \varepsilon_o \, d\Phi_E/dt$.
- Accelerated charge ⇒ EM wave.
- Transverse, medium nahi chahiye.

NUMBERS

- $c = 1/\sqrt{(\mu_o \varepsilon_o)} = 3 \times 10^8$.
- $E_o = cB_o$; same phase.
- $I = \frac{1}{2}\varepsilon_o E_o^2 c$.

SPECTRUM

- Radio > micro > IR > visible > UV > X > γ (λ).
- Energy ulte order me.

USES

- Microwave: radar, oven.
- IR: remote, heat.
- X-ray: haddi; γ: cancer.

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