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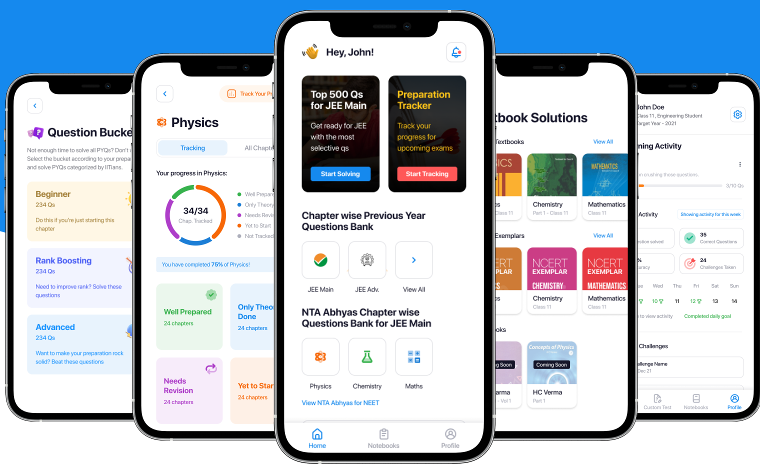

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ELECTROMAGNETIC WAVES

Maxwell's Equations

(a) $\oint \vec{E}.d\vec{s} = \dfrac{q}{\epsilon_0}$ (Gauss's theorem in electrostatics)

(b) $\oint \vec{B}.d\vec{s} = 0$ (Gauss's law in magnetism)

(c) $\oint \vec{E}..d\vec{s} = -\dfrac{d}{dt}\int \vec{B}.d\vec{s}$ (Faraday's law of electromagnetic induction)

Important Features of Electromagnetic waves

- E.M. waves are transverse waves in which there are sinusoidal variations of electric and magnetic fields. These two fields exist at right angles to each other as well as at right angles to the direction of wave propagation.
- Both these fields vary with time and space and have the same frequency of variation.
- These waves can travel through vacuum also, hence these waves are non-mechanical.
- Velocity of electromagnetic wave in free space (vaccum) is constant and given by

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = \frac{1}{\sqrt{4\pi \times 10^{-7} \times 8.854 \times 10^{-12}}} = 3 \times 10^8 \, ms^{-1}$$

- Direction of wave propagative is given by the direction of $\vec{E} \times \vec{B}$.
- Examples of electromagnetic waves are radio waves, microwaves, infrared rays, light waves, ultraviolet rays, X-rays and $\gamma -$rays.
- The amplitudes of electric and magnetic fields in free space, in electromagnetic waves are related by $E_0 = cB_0$

Energy Density of Electromagnetic Eave

- The average energy density of electric field is, $U_E = \frac{1}{2}\epsilon_0 E^2 = \frac{1}{2}\epsilon_0 \left(E_0/\sqrt{2}\right)^2 = \frac{1}{4}\epsilon_0 E_0^2$
- The average density of magnetic field is, $U_B = \dfrac{B^2}{2\mu_0} = \dfrac{\left(B_0/\sqrt{2}\right)^2}{2\mu_0} = \dfrac{B_0^2}{4\mu_0}$
- In EM waves the average energy density due to either field are equal i.e. $U_E = U_B$

Momentum of Electromagnetic wave

- The electromagnetic wave has linear momentum associated with it. The linear momentum p carried by the portion of wave having energy U is given by $p = \dfrac{U}{c}$. As per plank, $p = \dfrac{hv}{c} = \dfrac{h}{\lambda}$

Production of Electromagnetic Waves

- An electromagnetic wave is emitted when an electron orbiting in higher stationary orbit of an atom jumps to one of the lower stationary orbits of that atom.
- Accelerated charge (e.g. LC oscillator) produces EM waves.
- Some electromagnetic waves (i.e. X-rays) are also produced when fast moving electrons are suddenly stopped by a metal surface having high atomic number.

Electromagnetic Spectrum

The major components spectrum with their wavelength λ ranges in incrasing order are

1. Gamma rays $[\lambda = 6 \times 10^{-19}\, m \, to 10^{-11} m]$

2. X-rays $[\lambda = 6\times10^{-19}\,\text{m to } 3\times10^{-8}\,\text{m}]$
3. Ultraviolet $[\lambda = 6\times10^{-10}\,\text{m to } 4\times10^{-7}\,\text{m}]$
4. Visible light $[\lambda = 4\times10^{-7}\,\text{m to } 8\times10^{-7}\,\text{m}]$
5. Infra red $[\lambda = 8\times10^{-7}\,\text{m to } 3\times10^{-5}\,\text{m}]$
6. Heat radiations $[\lambda = 8\times10^{-5}\,\text{m to } 10^{-1}\,\text{m}]$
7. Micro waves $[\lambda = 10^{-3}\,\text{m to } 0.03\,\text{m}]$
8. Ultra high frequency $[\lambda = 10^{-1}\,\text{m to } 1\,\text{m}]$
9. Very high ratio frequency $[\lambda = 1\,\text{m to } 10\,\text{m}]$
10. Radio frequencies $[\lambda = 10\,\text{m to } 10^{4}\,\text{m}]$

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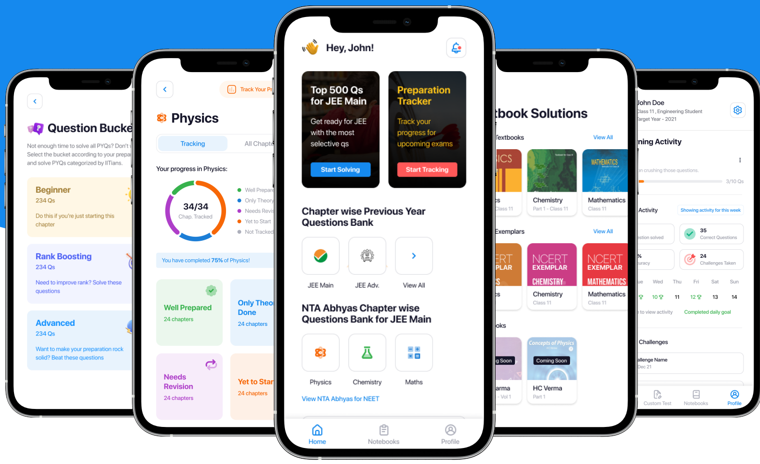

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