PHY-112
Principles of Physics-II
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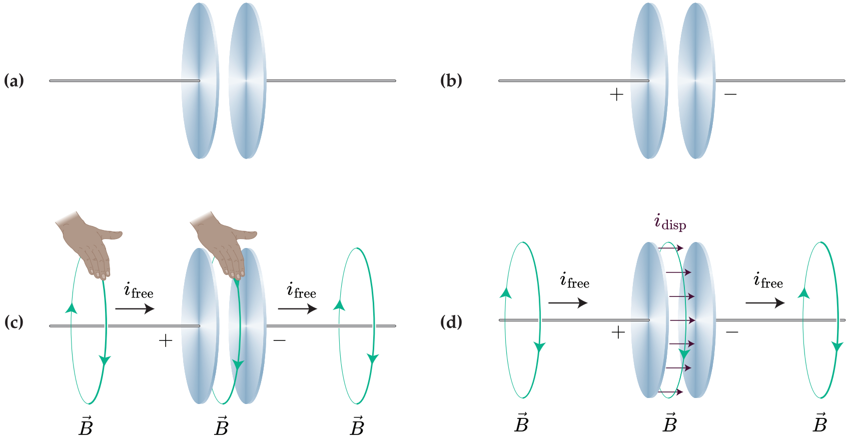
Spring-24 | Class-22

What's ailing Ampère's Law?

Faraday had discovered the significance of a changing Φ_B. It induced an electric field to oppose the change in flux. But no one had considered a changing Φ_E. Turns out, this change in electric flux can create a magnetic field without producing any *real* current.

Maxwell was the first to notice this. He hypothesized that this *invisible* current that the changing Φ_E creates was the **missing** piece of Ampère's law, so he modified Ampère's law to include both sources of magnetic fields.

Fixing Ampère's Law: The Displacement Current



$$i_{\text{disp}} = \frac{dq}{dt} = \epsilon_0 \frac{d(EA)}{dt} = \epsilon_0 \frac{d\Phi_E}{dt}.$$

With this Maxwell correction, Ampère's Law states:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i_{\text{free}} + \mu_0 i_{\text{disp}}$$

The first half claims that **Electric Currents create a magnetic field**. The second half claims that **a Magnetic field can also be created by a changing Electric field.**

Electricity and Magnetism can be summarized in four equations for the fields, called Maxwell's equations, and one equation for *Electromagnetic Force* that tells us how charges respond to fields.

- **Gauss's Law for Electricity**: Electric Charges create Electric fields.
- **Gauss's Law for Magnetism**: There are no isolated Magnetic monopoles.
- **Faraday's Law**: Electric fields can also be created by changing Magnetic fields.
- **Ampère-Maxwell Law**: Magnetic fields can be created either by currents or by changing Electric fields.

Gauss's Law for $\vec{E}$-Fields

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho_{\text{enc}}}{\varepsilon_0} \qquad \text{(Differential Form)}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\varepsilon_0} \qquad \text{(Integral Form)}$$

Gauss's Law for $\vec{B}$-Fields

$$\vec{\nabla} \cdot \vec{B} = 0 \qquad \text{(Differential Form)}$$

$$\oint \vec{B} \cdot d\vec{A} = 0 \qquad \text{(Integral Form)}$$

Faraday's Law of Electromagnetic Induction

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \text{(Differential Form)}$$

$$\oint \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{A} \qquad \text{(Integral Form)}$$

Ampère-Maxwell Law

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t} \qquad \text{(Differential Form)}$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{free}} + \mu_0 \epsilon_0 \oint \vec{E} \cdot d\vec{A} \qquad \text{(Integral Form)}$$

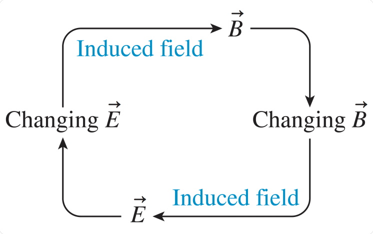
The Electromagnetic Force: Lorentz Force

An electric charge moving through an Electromagnetic force will respond to the field by this force equation

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

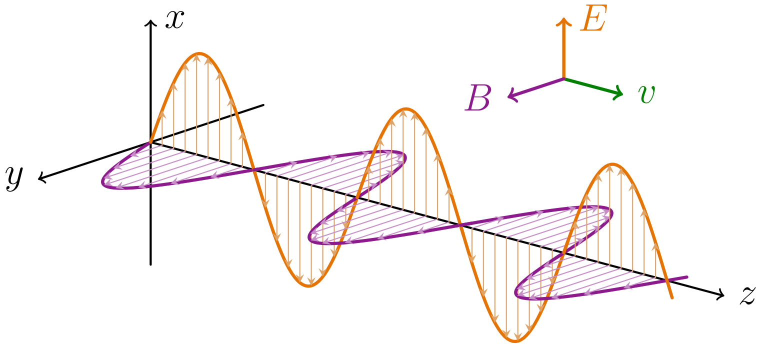
Maxwell's equations for the fields, together with the Lorentz force law to tell us how matter responds to the fields, form *the complete theory of electromagnetism.*

Faraday discovered that a changing magnetic field creates an induced electric field, and **Maxwell**'s postulated displacement current says that a changing electric field creates an induced magnetic field.



This is the basis for an **Electromagnetic wave**, with changing $\vec{E}$ and $\vec{B}$ fields, where both fields are **perpendicular to each other** and also to the direction of their propagation.

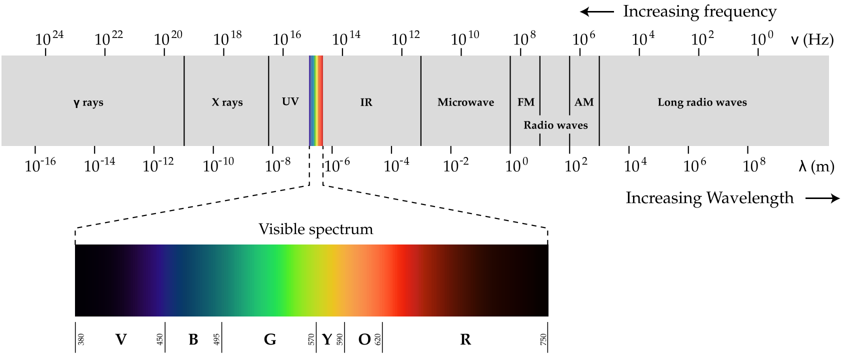
How do Electromagnetic Waves propagate?



Properties of Electromagnetic Waves

- Maxwell's equations predict the existence of sinusoidal electromagnetic waves that travel through empty space independent of any charges or currents
- The waves are transverse waves, with $\vec{E}$ and $\vec{B}$ perpendicular to the direction of propagation
- The field strengths are related by $E = vB$ at every point on the wave
- $\vec{E}$ and $\vec{B}$ are perpendicular to each other in a manner such that $\vec{E} \times \vec{B}$ is in the direction of propagation
- All electromagnetic waves, regardless of frequency or wavelength, travel in vacuum at speed $v = \dfrac{1}{\sqrt{\mu_0 \epsilon_0}} = c$, the speed of light

Light is an Electromagnetic Wave!



The End!

About the Final Exam!

Marks Distribution

Full-Marks: 35

Duration: 1 hour 40 minutes

There will be **4 Questions**.

Of them, 1 is **mandatory** (15 marks) for all.

You may choose **any 2 from the other 3**.

10 marks each makes 20.

What to Expect?

A detailed chapter-wise topic list will be posted on the Slack Workspace. The following general pattern will be adopted:

- One mandatory question from Electric Current & Circuit
- One question from Magnetic Field Sources and Forces
- One question from Induction and Lenz's Law
- One question from Ampère's law, Maxwell's equations and Electromagnet

Note: The last three are subject to change and may be mixed and merged

How to prepare?

Following the steps below in order shall help You get a good standing in the final exam:

- Read up on all the **class notes** and **lecture notes**/**lecture slides** on the selected topics
- Attempt all the **Testing Concepts** problems from the slides
- Attempt the **Quiz** and **Assignment** questions
- Attempt the selected **Exercise problems** from *Resnick-Halliday*
- Practice writing down the formulas with correct labelling and draw accurate vector diagrams, such as for Magnetic Field vectors, forces, magnetic dipole moments, etc.
- Refrain from applying brute memorized formulas without showing how you applied the Physics principles the question asks of You

Good luck!
Godspeed, Spring 2024.