UBC Physics 102

Lecture 16

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Outline

Electric and magnetic fields [Text: Sect. 32-1]

- **Discussion: Ampère's law**
  - Faraday's law ($\sum E_{\|} l = -\frac{d\Phi_B}{dt}$) tells us a changing B-field produces and E-field.
  - Can reverse hold? Can a changing E-field produce a B-field?
  - Maxwell recognized there must be a more general form of Ampère's law,

$$\sum B_{\|} l = \mu_0 I_{\text{encl}} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}.$$

  - So changing electric flux Φ_E produces B.

Gauss's law for magnetism [Text: Sect. 32-2]

- **Discussion: Gauss's law for magnetism**
  - Recall Gauss's law (for electricity),

$$\sum E_{\perp} A = \frac{Q}{\epsilon_0}.$$

  - Turns out there is a similar law for magnetism,

$$\sum B_{\perp} A = 0.$$

Maxwell's equations [Text: Sect. 32-3]

- **Definition:** *Maxwell's equations*
  - Maxwell recognized you only need four equations to explain *all* electricity and magnetism,

$$\sum E_\perp A = \frac{Q}{\epsilon_0}, \qquad \sum E_\parallel l = -\frac{d\Phi_B}{dt},$$
$$\sum B_\perp A = 0, \qquad \sum B_\parallel l = \mu_0 I + \mu_0\epsilon_0\frac{d\Phi_E}{dt}.$$

  - So E and B not separate but "two sides of the same coin".
  - (Even true for special relativity so more general then Newton's laws.)

Maxwell's equations, contd

- **Definition:** *Symmetry break*
  - Notice equations look almost symmetrical.
  - Difference is just due to the lack of magnetic monopoles.
  - With monopoles there would be a Q_B and I_B term in the equations to match the electric Q and I.
  - Magnetic monopoles have never been observed.
  - Dirac showed that monopoles would explain why there is a "smallest" electric charge.
  - Experiments underway to try to detect monopoles (http://mit1.fnal.gov/~schiefer/).
  - If monopoles existed could (in principle) swap all magnetism with electricity and laws of nature would be essentially unchanged.

Electromagnetic waves [Text: Sect. 32-5,6]

- **Discussion: Electromagnetic waves**
  - Consider region of empty space so that $Q = 0$ and $I = 0$.
  - Then, after some calculus, two of Maxwell's equations can be written as

$$\frac{dE}{dx} = \frac{dB}{dt},$$
$$\frac{dB}{dx} = \mu_0\epsilon_0\frac{dE}{dt}.$$

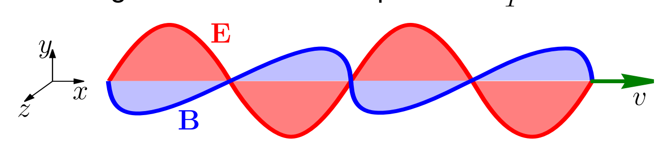
- **Interactive Quiz: PRS 16a**

Electromagnetic waves, contd

- **Discussion: Electromagnetic waves, contd**
  - Assume $\mathbf{E}$ and $\mathbf{B}$ are travelling waves, $\mathbf{E} = E_y\hat{\mathbf{j}}$ and $\mathbf{B} = B_z\hat{\mathbf{k}}$, where

$$E_y = E_0 \sin\left(\frac{x}{\lambda} - \frac{t}{T}\right),$$
$$B_z = B_0 \sin\left(\frac{x}{\lambda} - \frac{t}{T}\right).$$

  - Travelling in $+x$-direction at speed $v = \frac{\lambda}{T}$.



Electromagnetic waves, contd

- **Discussion: Electromagnetic waves, contd**
  - $\mathbf{E}$ and $\mathbf{B}$ are solutions to Maxwell's equations if the speed of the wave is

$$v = \frac{\lambda}{T} = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.00 \times 10^8 \text{ m/s}.$$

  - So waves of $\mathbf{E}$ and $\mathbf{B}$ travelling at the speed of light will continue in a straight line.
  - Now known that electromagnetic waves *are* light!

Electromagnetic waves, contd

- **Discussion: Wavelength and frequency**
  - Frequency is inverse of period, $f = \frac{1}{T}$, so speed of light, c, is

$$c = f\lambda.$$

  - λ is wavelength of light.
  - Light can be specified by either its frequency or wavelength.
- **Interactive Quiz: PRS 16b**

End

- **Practice Problems:**
  - Ch. 32: Q. 5, 7, 9, 11.
  - Ch. 32: Pr. 13, 15, 17, 35, 37, 39, 45.
- **Interactive Quiz: Feedback**
- **Tutorial Question: tut16**