Maxwell’s Equations
Electromagnetic Spectrum
E-M waves   Doppler Effect

\[ \lambda f = c \]

\[ \frac{\Delta f}{f} = - \frac{\Delta \lambda}{\lambda} = \pm \frac{v}{c} \]

Blue shift

Red shift

\[ u = \frac{1}{2} \varepsilon_0 E^2 + \frac{1}{2 \mu_0} B^2 \]

radio waves  \( \mu \) waves  IR  ROY G BIV  X-ray  \( \gamma \)-ray

\[ E = cB \]
recall from 203

waves on a string: \( T = \text{tension in string}; \ \rho = \text{density} = \frac{m}{L} \)
\[
\begin{align*}
v &= \sqrt{\frac{T}{\rho}} \\
\rho &= \frac{m}{L}
\end{align*}
\]

sound waves gas/fluid: \( P = \text{pressure}; \ \rho = \text{density} = \frac{m}{V} \)
\[
\begin{align*}
v &= \sqrt{\frac{P}{\rho}} \\
\rho &= \frac{m}{V}
\end{align*}
\]

waves in general

\[ d = vt \]

Figure 11.2
A longitudinal wave in a spring.

Transverse wave

6-1
**Doppler Effect**  frequency \((f)\) and wavelength \((\lambda)\) shift due to motion of source/observer.

\[
\lambda f = c \quad \frac{\lambda}{T} = c
\]

Stationary observer - time between maximum is \(T = \frac{1}{f}\)

Observer running toward wave at velocity \(v\)

Time between maximums \(T'\)

\[T'(c+v) = \lambda\]

Speed at which crests approach  Distance between crests approach

\[\lambda' = cT'\]

Apparent wave length seen by observer

\[
\frac{\lambda - \lambda'}{\lambda} = \frac{\Delta \lambda}{\lambda} = \pm \frac{v}{c} \quad \pm \text{ for } +v \text{ or } -v
\]

\[
\frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda} = \pm \frac{v}{c} \quad +
\]

Observer - wave approaching

Blue shift

\(f\) increases \(\lambda\) decreases

Observer - wave receding

Red shift

\(f\) decreases \(\lambda\) increases

“recall” from 203
Maxwell’s Equations

First and prototype for unification in physics. Present Holy Grail Theory to unify all forces String Theory? (Rutgers Active)

1.) Gauss’s Law
\[ \vec{E} \ldots Q \text{ relation} \]

2.) No magnetic monopoles

3.) Ampere’s Law
\[ I \rightarrow \vec{B} \quad \text{also:} \quad \frac{\Delta \vec{E}}{\Delta t} \rightarrow \vec{B} \]

4.) Faraday’s Law
\[ \Delta \phi \rightarrow I \]
For E & M waves:

\[
c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = \frac{1}{\sqrt{8.85(10)^{-12} \left[ \frac{C^2}{Nm^2} \right] 4\pi(10)^{-7} \left[ \frac{Jm}{A} \right]}}
\]

\[= 3(10)^8 \sqrt{\frac{C^2}{Nm^2} \frac{m}{m} \frac{m}{s} \frac{m}{s}} = 3(10)^8 \frac{1}{\sqrt{s^2/m^2}}
\]

\[c = 3(10)^8 \frac{m}{s}
\]

E & M waves - transverse

http://arana.cabrillo.edu/~jmccullough/Applets/Flash/Optics/EMWave.swf
\[ E = \text{Electric field} \]

\[ c \]

\[ \text{Speed} = c = \frac{186,000}{s} \text{mi} \]

\[ \frac{3(10)^{10}}{s} \text{cm} \]

\[ \frac{3(10)^{8}}{s} \text{m} \]

\[ \lambda = \text{wave length [repeat distance in space.]} \]

\[ \lambda f = c \]

wavelength \( \times \) frequency =speed of light

\[ \lambda f = c \]

Sit at one spot and record E-field (wave) in time as it ‘runs’ by.

\[ T = \text{period [ repeat interval in time.]} \]

\[ f = \text{frequency} \quad f = 1/T \]

Units \( 1/\text{sec} = \text{Hertz} = \text{Hz} \)

**Examples:**

Radio wave

\[ (\lambda)[f] = c = (1\text{m})[3(10)^8 \text{Hz}] = 3(10)^8 \frac{\text{m}}{s} \]

X-ray

\[ (10^{-11} \text{m})[3(10)^{19} \text{Hz}] = 3(10)^8 \frac{\text{m}}{s} \]

6-5
Electromagnetic Spectrum

ELF radio 3-30 Hz, 6000 km at 50 Hz see “Crimson Tide” movie

Energy (discuss E=hf later in course)
Energy Density of E&M Wave

\[ u = \frac{1}{2} \varepsilon_0 E^2 + \frac{1}{2 \mu_0} B^2 \]

Truly electro-magnetic wave

\[ \frac{1}{2 \mu_0} B^2 \]

MAGNETIC ENERGY DENSITY

\[ \frac{1}{2 \mu_0} B^2 \]

ELECTRIC ENERGY DENSITY

\[ \frac{1}{2} \varepsilon_0 E^2 \]

Equal energy in E & B fields!!!!!

\[ \frac{1}{2} \varepsilon_0 E^2 = \frac{1}{2 \mu_0} B^2 \]

\[ E^2 = \frac{1}{\varepsilon_0 \mu_0} B^2 = c^2 B^2 \]

From equal energy in E & B fields!!!!!

\[ E = cB \]
E&M polarization

E-field direction

Polarization direction

Polarized beam

Propagation direction

Unpolarized beam

Propagation direction

Direction of propagation

(a)

(b)