# 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**

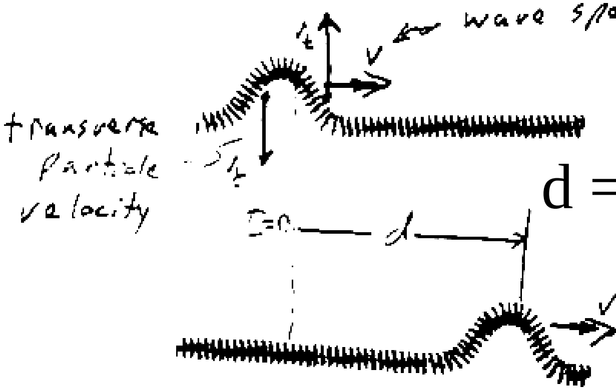
**Red shift**

$$\mathbf{u} = \frac{1}{2}\varepsilon_o \mathbf{E}^2 + \frac{1}{2\mu_o}\mathbf{B}^2$$

radio waves   μ waves   IR   ROY G BIV   X-ray   γ-ray

$$\mathbf{E} = c\mathbf{B}$$

## Transverse Wave




d = vt

waves on a string : T= tension in string; ρ = density = m/L
m= string mass
L = string length

**recall from 203**

$$v = \sqrt{\frac{T}{\rho}} \qquad \rho = \frac{m}{L}$$

sound waves gas/fluid : P= pressure; ρ = density = m/V
m= mass
V = volume

**waves in general**

$$v = \sqrt{\frac{P}{\rho}} \qquad \rho = \frac{m}{V}$$

## Longitudinal Wave

d = vt

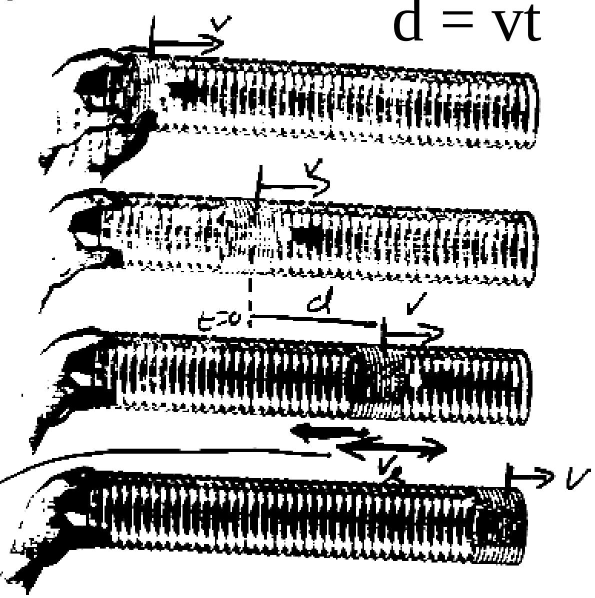
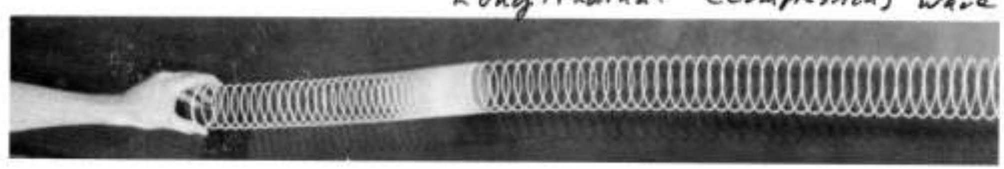


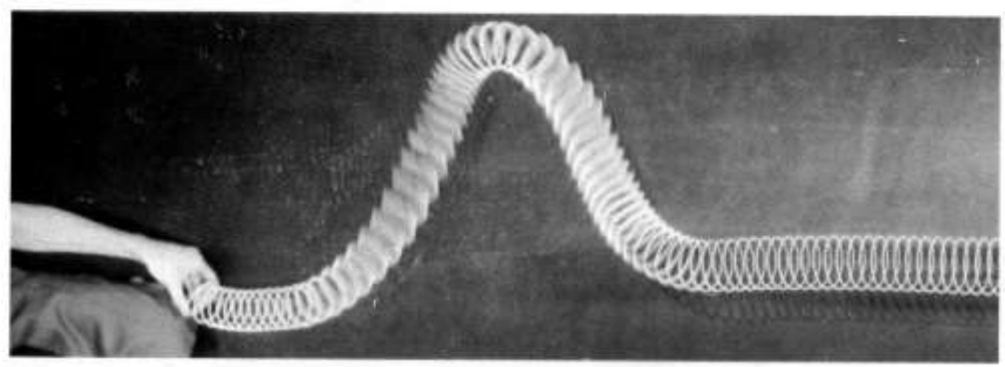

**Figure 11.2**
A longitudinal wave in a spring.

longitudinal particle motion/velocity

Longitudinal (compression) wave



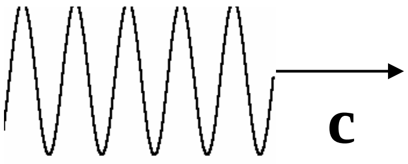
eg. sound



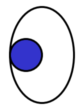
Transverse wave

eg. - waves on string
- E&M Radiation

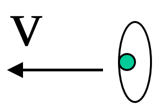
**Doppler Effect** frequency ( f ) and wavelength ( $\lambda$ ) shift due to motion of source/observer.




$$\lambda f = c \qquad \frac{\lambda}{T} = c$$



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




Observer running toward wave at velocity v

Time between maximums T'

**"recall" from 203**

$$T'(c+v) = \lambda$$

Speed at which crests approach

Distance between crests

$$\lambda' = cT'$$

Apparent wave length seen by observer

$$\frac{\lambda-\lambda'}{\lambda} = \frac{\Delta\lambda}{\lambda} = \pm\frac{v}{c} \qquad \pm \text{ for } +v \text{ or } -v$$

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

**+** → **Observer - wave approaching** (**f increases**, **$\lambda$ decreases**) **Blue shift**

**-** → **Observer - wave receding** (**f decreases**, **$\lambda$ increases**) **Red shift**

# Maxwell's Equations

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

Light & Optics

Radio waves

E & M waves

Electricity & Magnetism

unified in Maxwell's Equations

**1.) Gauss's Law**

$\vec{E}$.....Q relation

**2.) No magnetic monopoles**

**3.) Ampere's Law**

$$\mathrm{I} \rightarrow \vec{B} \quad \text{also:} \frac{\Delta \vec{\mathrm{E}}}{\Delta \mathrm{t}} \rightarrow \vec{B}$$

**4.) Faraday's Law** $\Delta \phi \rightarrow I$

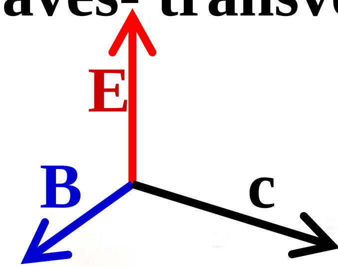
## For E & M waves:

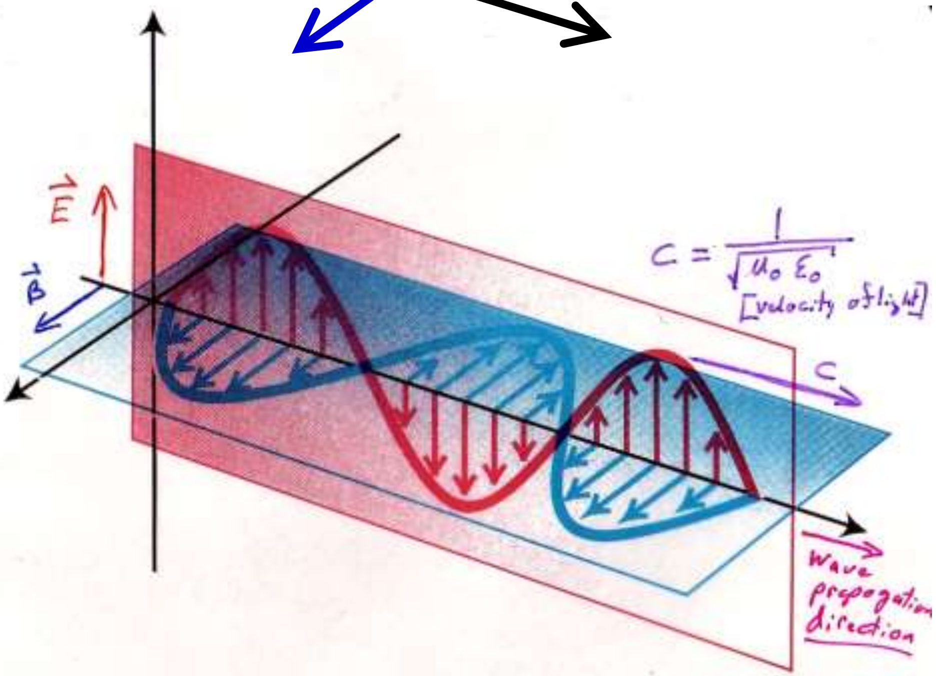
$$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = \frac{1}{\sqrt{8.85(10)^{-12}[\frac{C^2}{Nm^2}]\,4\pi(10)^{-7}[\frac{Jm}{A}]}}$$

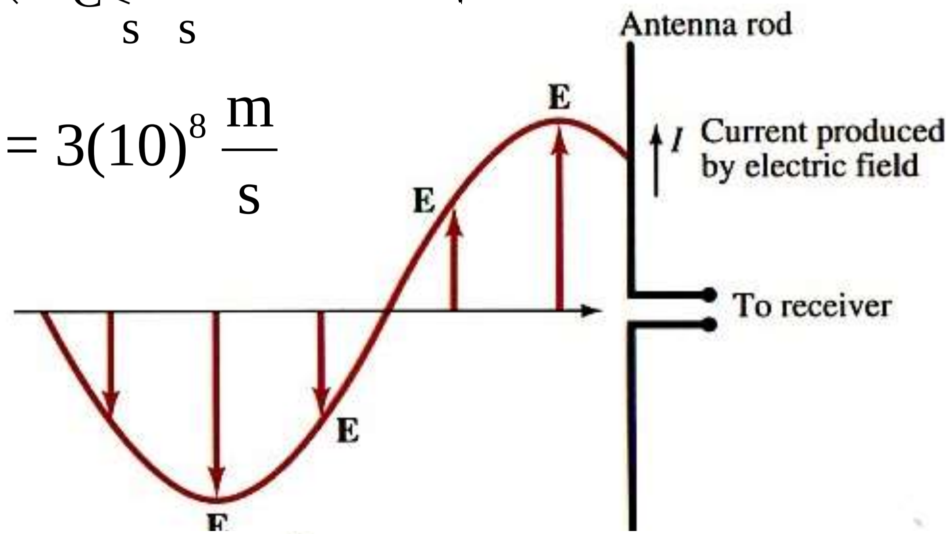
$$=3(10)^8\frac{1}{\sqrt{\frac{C^2}{Nm^2}\frac{N}{C\frac{m}{s}}\frac{m}{\frac{C}{s}}}} = 3(10)^8\frac{1}{\sqrt{\frac{s^2}{m^2}}}$$

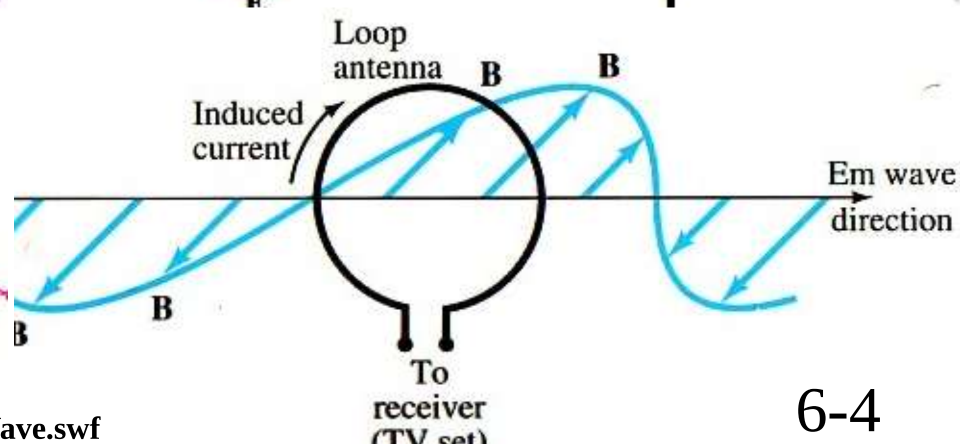
$$c = 3(10)^8\frac{m}{s}$$

**E & M waves- transverse**

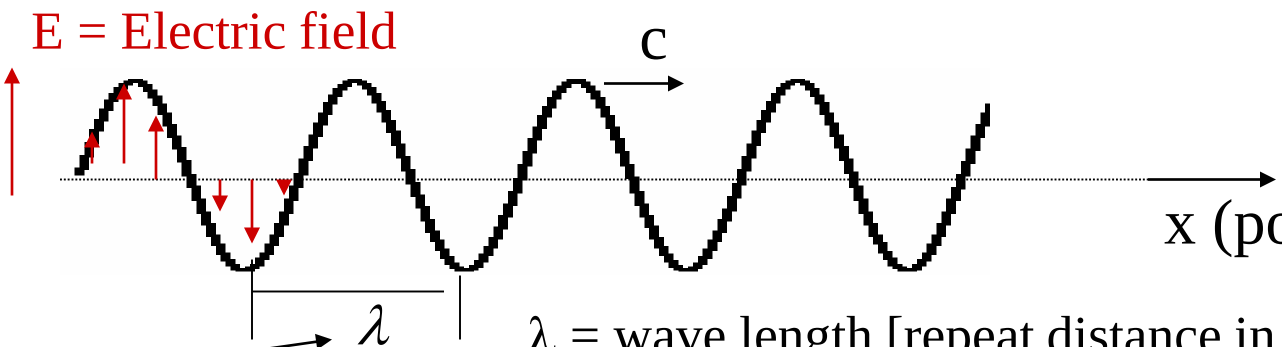



http://arana.cabrillo.edu/~jmccullough/Applets/Flash/Optics/EMWave.swf




Speed = c = $186{,}000 \frac{mi}{s}$

$3(10)^{10} \frac{cm}{s}$

$3(10)^{8} \frac{m}{s}$

$\lambda$ = wave length [repeat distance in space.]

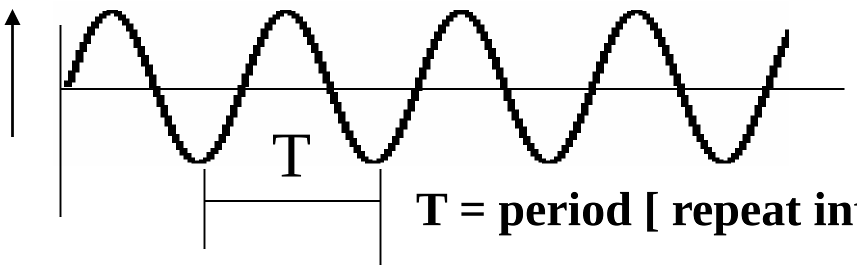
units: m, nm, or Å = Angstroms

$$\lambda f = c$$

**wavelength x frequency**

**=speed of light**

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




**T = period [ repeat interval in time.]**

f = frequency  f=1/T

Units 1/sec = Hertz= Hz

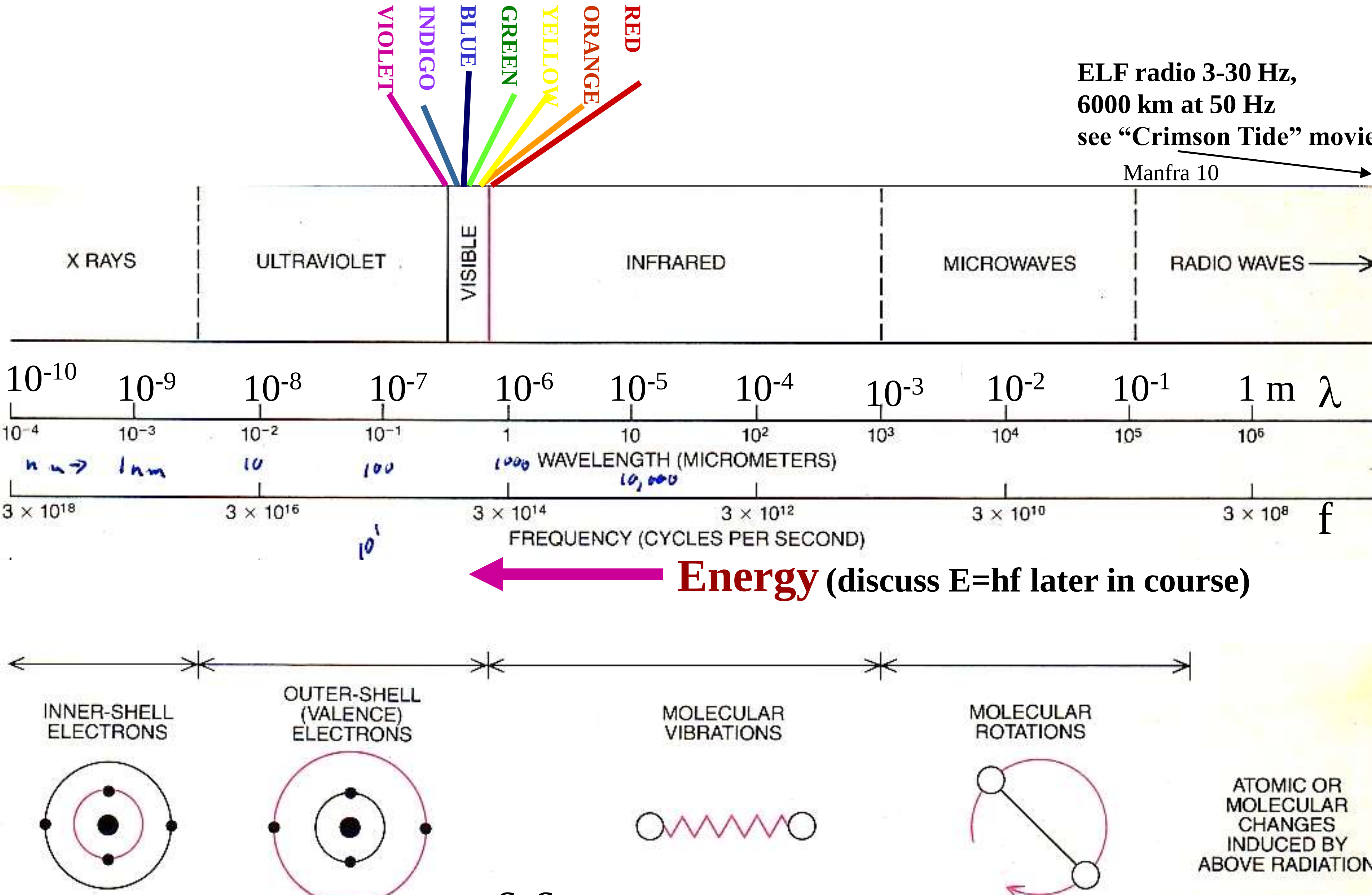
<u>**Examples:**</u> Radio wave

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

X-ray

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

# Electromagnetic Spectrum



# Energy Density of E&M Wave

$$\mathbf{u = \frac{1}{2}\varepsilon_o E^2 + \frac{1}{2\mu_o} B^2}$$

Truly electro-magnetic wave

**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!!!!!

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

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

$$\mathbf{E = cB}$$

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

# E&M polarization