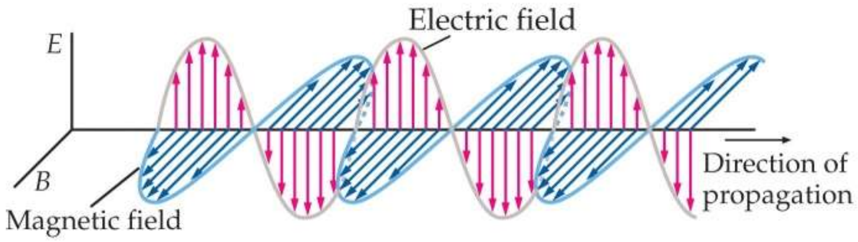
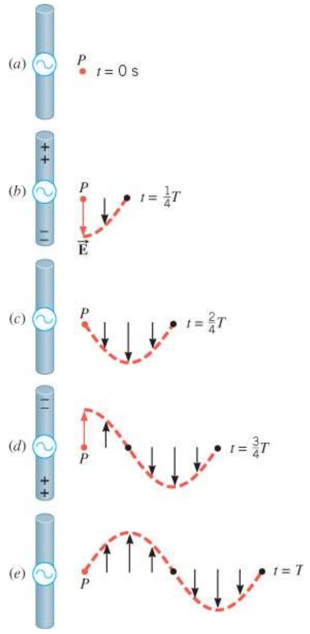


Ch 33: Electromagnetic Waves

The Electric Field of Electromagnetic Waves



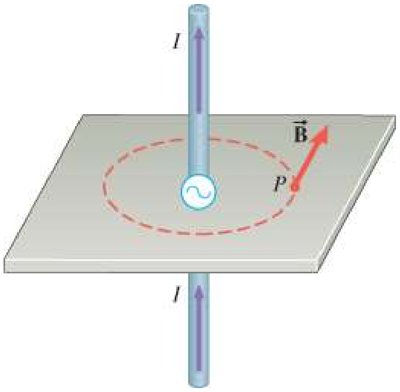
Two straight wires connected to the terminals of an AC generator can create an ***electromagnetic wave***.

Only the electric wave traveling to the right is shown here.

T = period, time for one wavelength (sec)

f = frequency, number of wavelengths per second (Hz = 1/s)

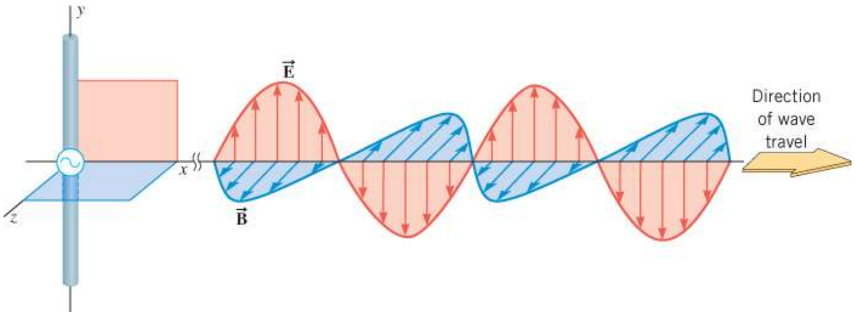
The Magnetic Field of Electromagnetic Waves



The current used to generate the electric wave creates a magnetic field.

The Nature of Electromagnetic Waves

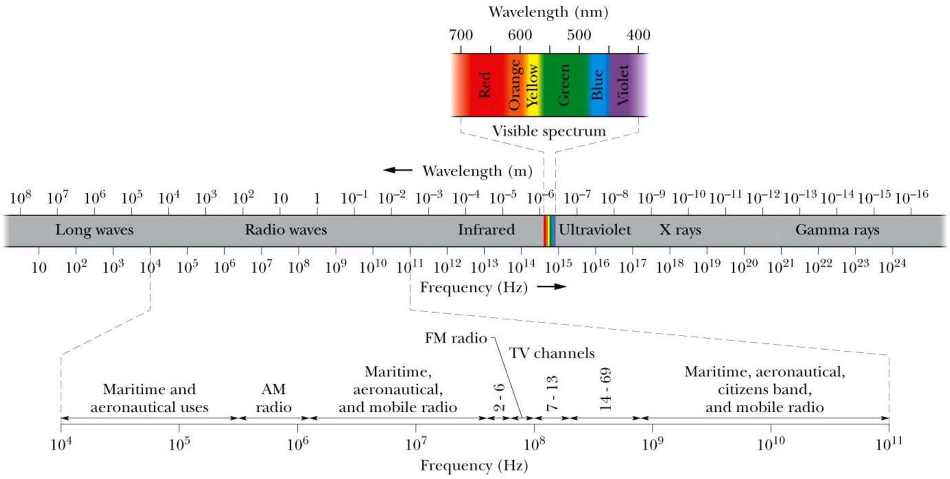
This picture shows the wave of the radiation field far from the antenna.



The speed of an electromagnetic wave in a vacuum is:

$$c = 3.00 \times 10^{8}\ \mathrm{m/s}$$

The Electromagnetic Spectrum

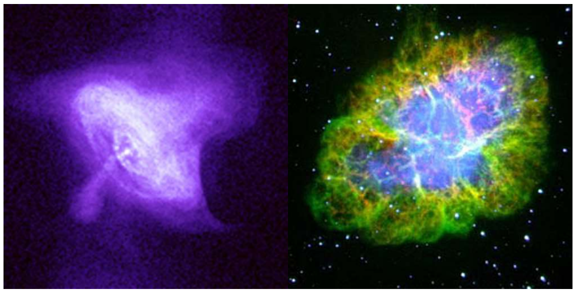


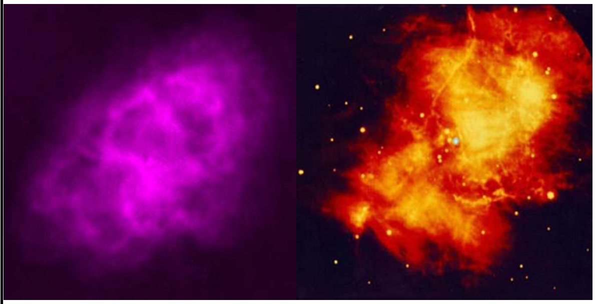
$$\boxed{c = \lambda f}$$

The Crab Nebula

Remnants of a star that underwent a supernova explosion in 1054 AD. It's located 6300 light-years from earth.

X-ray and Visible Spectrums →





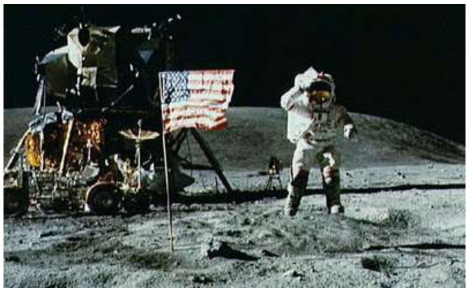
←Radio and Infrared Spectrums

E&M Waves are Fast but Space is HUGE!

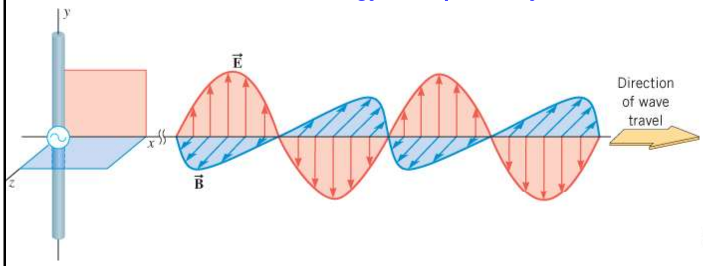
Neil Armstrong was the first human to walk on the moon. The earth to moon distance is 3.85 x 10^8m.

a) How long did it take his words: “One small step for man, one giant step for human kind.” to reach the earth?

b) How long would it had taken if one of the Mars Rovers had sent those words instead? (Mars to earth = 5.6 x 10^{10} m)

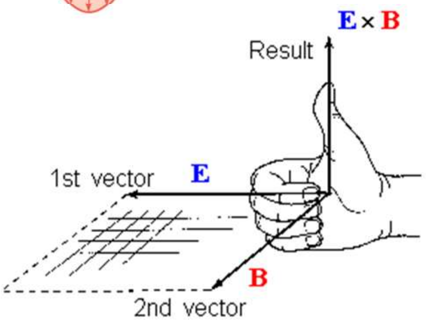


Direction of E&M Waves and Energy Transported by Wave



The Poynting Vector: The rate per unit area at which energy is transported via an electromagnetic wave.

$$\vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B}$$



The direction of the Poynting vector $\vec{S}$ of an electromagnetic wave at any point gives the wave’s direction of travel and the direction of energy transport at that point.

Average Energy Transported

The time-averaged rate per unit area at which energy is transported is S_{avg}, which is called the intensity *I* of the wave:

$$I = \frac{1}{c\mu_0} E_{\text{rms}}^2.$$

← $E_{rms} = E_m/\sqrt{2}$

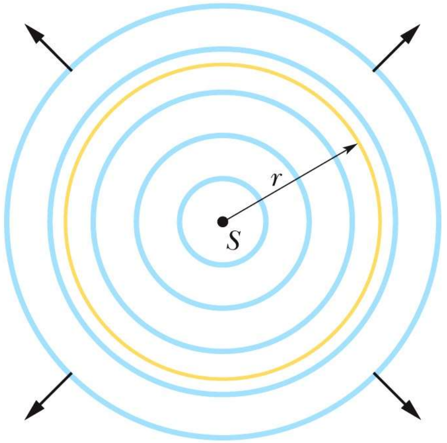
Energy carried by E&M waves are shared equally by the electric and magnetic fields.

A more straight forward way of thinking of the wave intensity, I, is the average of S (the Poynting vector) over one or more cycles:

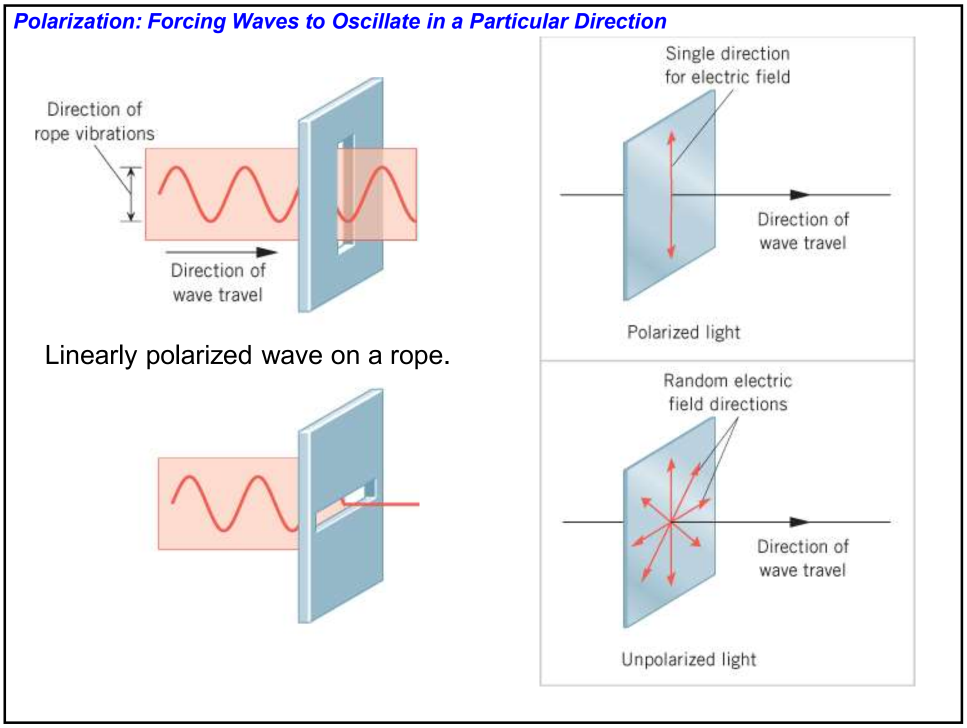
$$I = S_{avg} = \frac{E_{max}B_{max}}{2\mu_o} = \frac{E_{max}^2}{2\mu_o c} = \frac{c\,B_{max}^2}{2\mu_o}$$

Intensity at Some Point in Space from Wave source

The energy emitted by light source *S* must pass through the sphere of radius *r*.

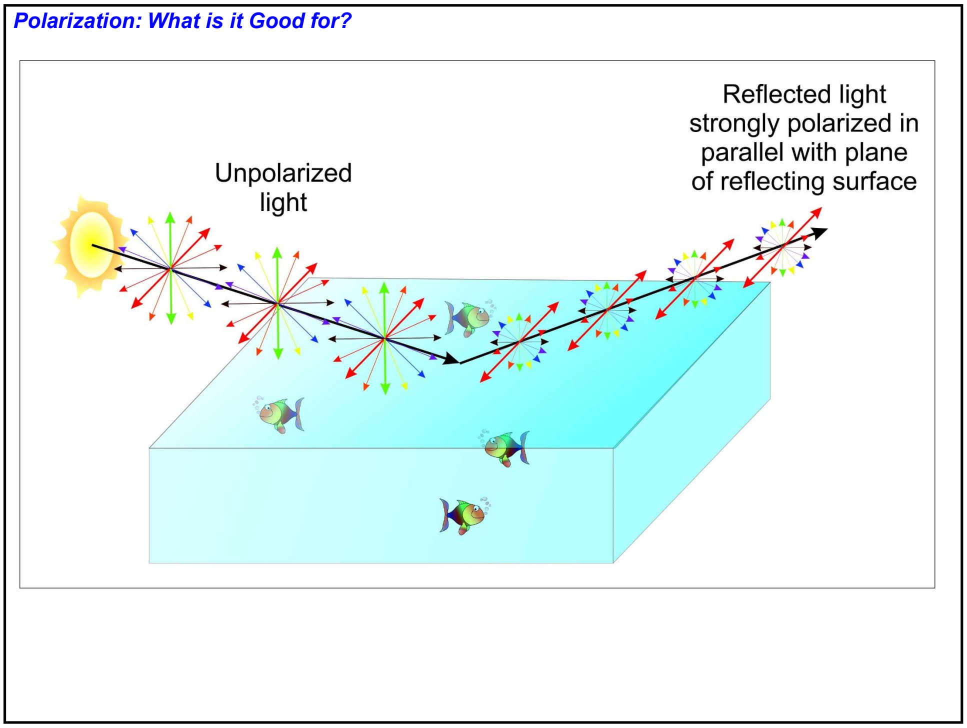


$$I = \frac{\text{power}}{\text{area}} = \frac{P_s}{4\pi r^2},$$



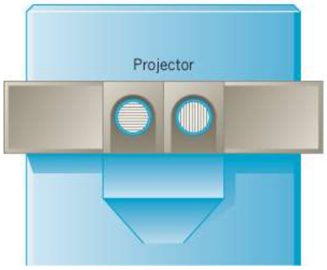
Polarization: Forcing Waves to Oscillate in a Particular Direction

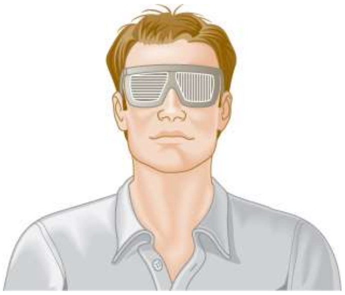
Linearly polarized wave on a rope.



Polarization: What is it Good for?

Polarization: What is it Good for?

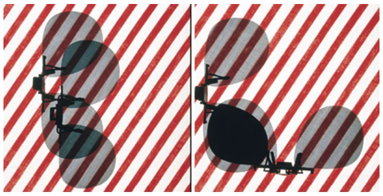




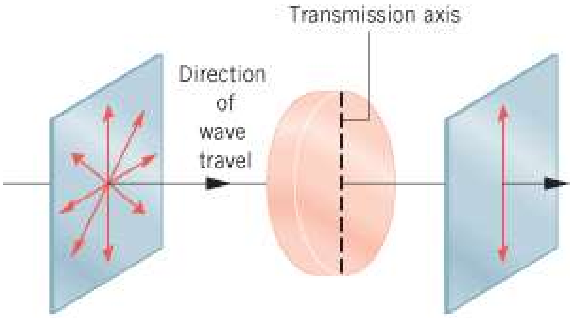
Crossed Polarization = 3D Movies!

1. Record the movie using a camera that provides images from two different.
2. Show the movie through projector that has apertures spaced roughly at the distance between our eyes.
3. Make sure the polarization of the two apertures are crossed, i.e. at 90 degrees from each other.
4. Give movie viewer glasses with corresponding crossed polarization.

Polarization: The Math Behind It



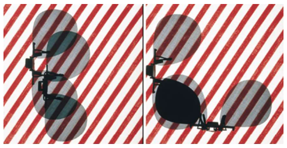
When Polaroid sunglasses are crossed, the intensity of the transmitted light is reduced to zero. Why?



If the original light is **initially unpolarized**, the transmitted intensity I is half the original intensity I_0:

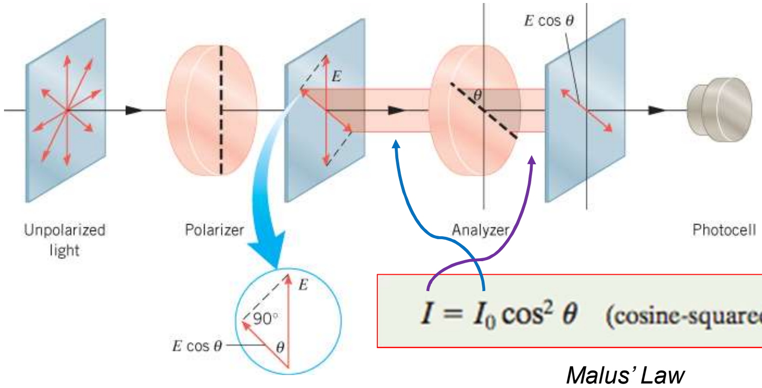
$$I = \tfrac{1}{2} I_0 \quad \text{(one-half rule).}$$

Polarization: The Math Behind It



When Polaroid sunglasses are crossed, the intensity of the transmitted light is reduced to zero. Why?

If the original light is **initially polarized**, the transmitted intensity depends on the angle Θ between the polarized light (axis of first polarizer) and the axis of the second polarizer (analyzer):



$$I = I_0 \cos^2 \theta \quad \text{(cosine-squared rule).}$$

Malus' Law

Polarization Example

What value of θ should be used so the average intensity of the polarized light reaching the photocell is one-tenth the average intensity of the unpolarized light?