What is Light?

And God said, “let there be light”, and there was light.

And God said

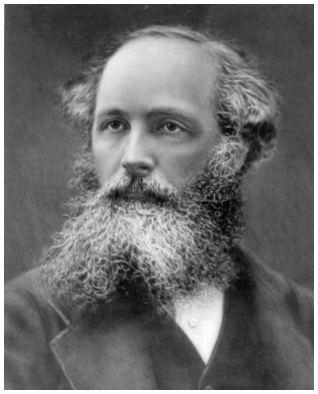
$$\oint_s \overline{E} \bullet \overline{dl} = -\int_s \frac{\partial \overline{B}}{\partial \tau} \bullet \overline{ds}$$
$$\oint_s \overline{H} \bullet \overline{dl} = \int_s \left(\overline{J}_C + \frac{\partial \overline{D}}{\partial \tau}\right) \bullet \overline{ds}$$
$$\oint_s \overline{D} \bullet \overline{ds} = \int_v \nabla \bullet \overline{D}\, dv$$
$$\oint_s \overline{B} \bullet \overline{ds} = 0$$

OR

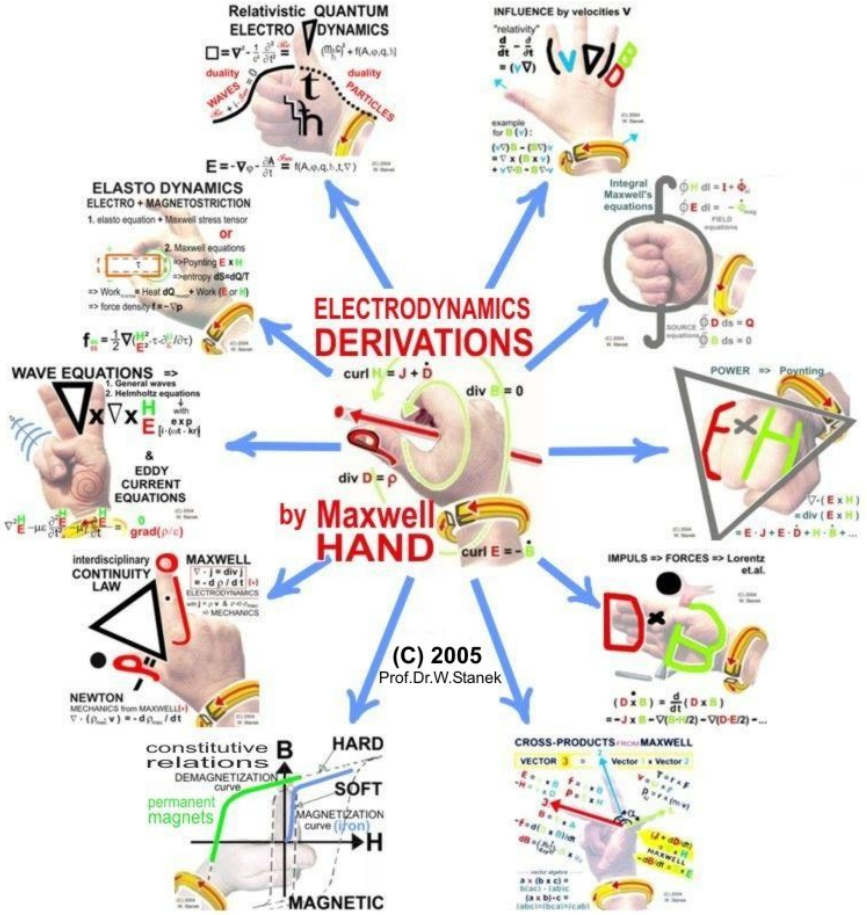
$$\nabla \times \overline{E} = -\mu \frac{\partial \overline{H}}{\partial \tau}$$
$$\nabla \times \overline{H} = \overline{J}_C + \varepsilon \frac{\partial \overline{E}}{\partial \tau}$$
$$\nabla \bullet \overline{D} = \rho_v$$
$$\nabla \bullet \overline{B} = 0$$

OR

$$\nabla \times \overline{\mathrm{E}} = -\mu \frac{\partial \overline{\mathrm{H}}}{\partial \tau}$$
$$\nabla \times \overline{\mathrm{H}} = \mathrm{J}_c + \varepsilon \frac{\partial \overline{\mathrm{E}}}{\partial \tau}$$
$$\nabla \bullet \overline{\mathrm{D}} = \rho_v$$
$$\nabla \bullet \overline{\mathrm{B}} = 0$$



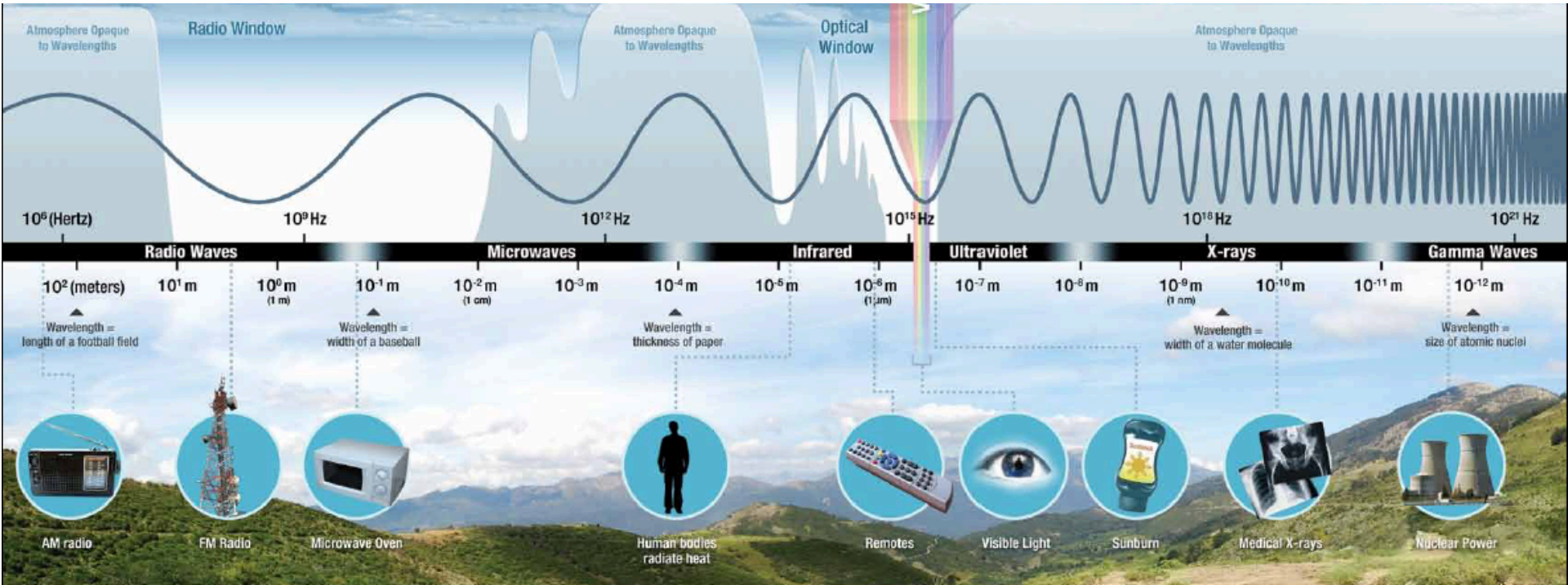
and there was light



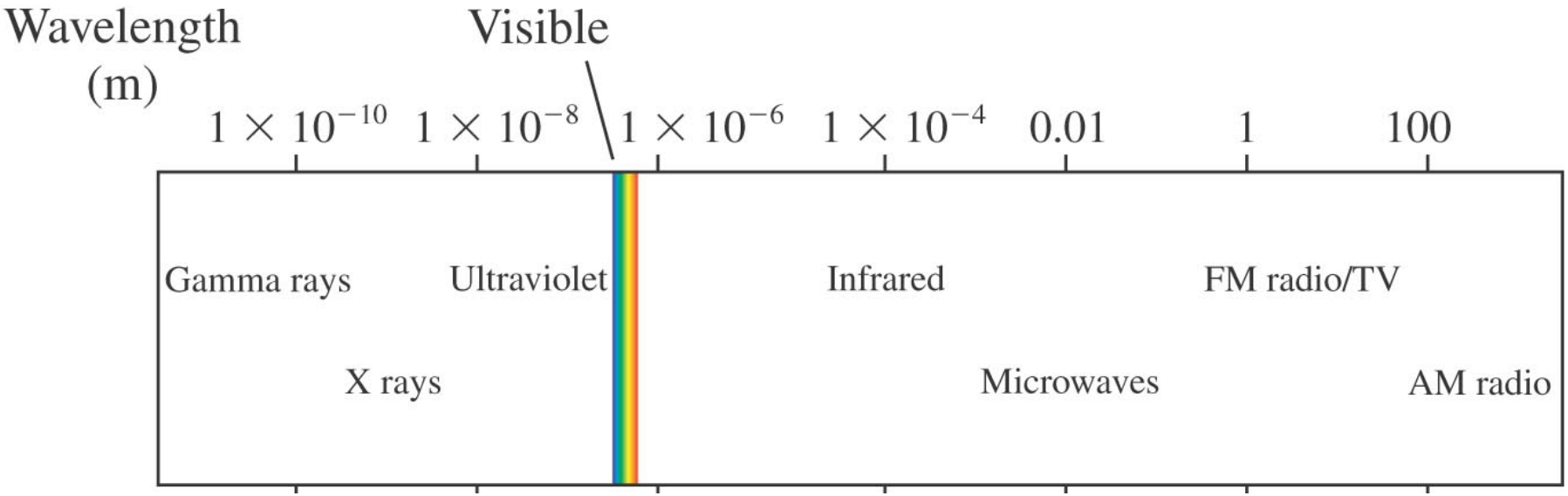
Tour of the Electromagnetic Spectrum

A 5-min video tour
http://missionscience.nasa.gov/ems/emsVideo_01intro.html

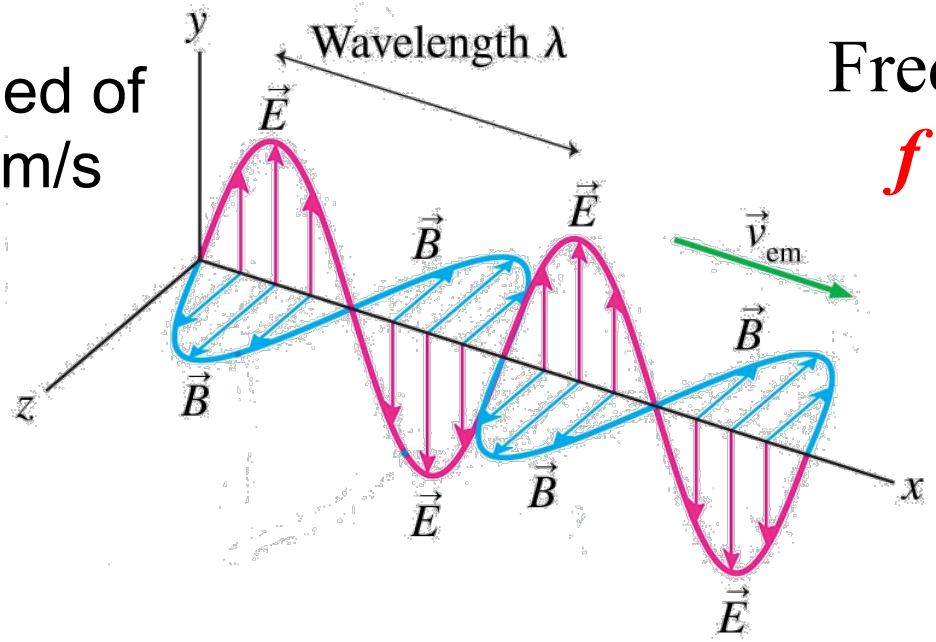
Introductions to various part of the EM spectrum
http://missionscience.nasa.gov/ems/index.html



Remember the EM Spectrum



In a vacuum, speed of light is $c = 3 \times 10^8$ m/s



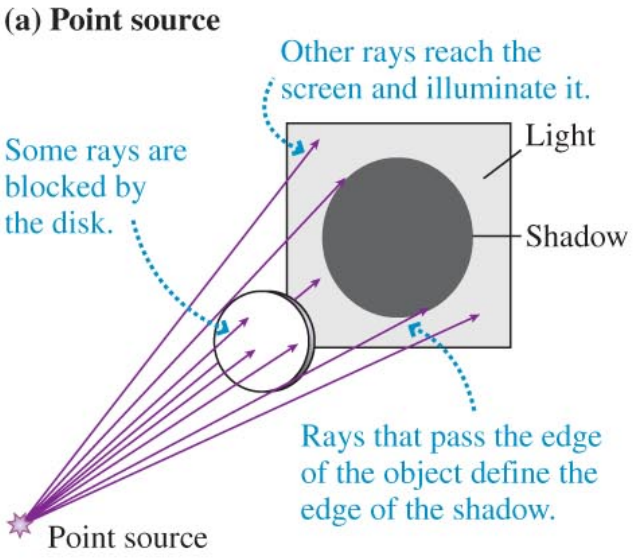
Frequency,

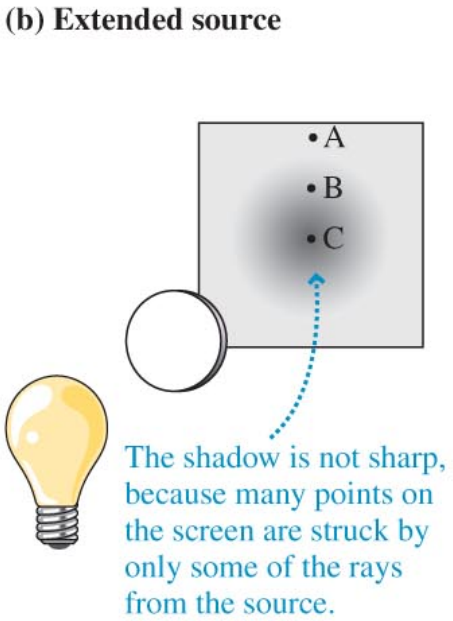
$f = c/\lambda$

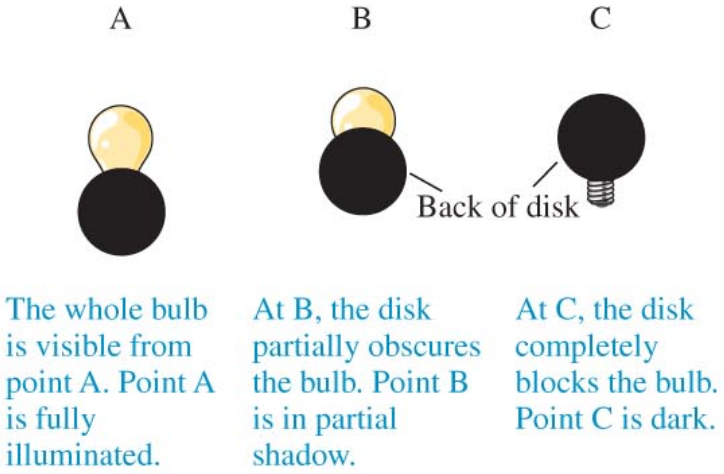
What is light?

- Light is a form of **electromagnetic energy** – detected through its effects, e.g. heating of illuminated objects, conversion of light to current, mechanical pressure ("Maxwell force") etc.
- Light energy is conveyed through particles: "photons"
  –ballistic behavior, e.g. shadows
- Light energy is conveyed through waves
  –wave behavior, e.g. interference, diffraction
- Quantum mechanics reconciles the two points of view, through the "wave-particle duality" assertion

Shadows

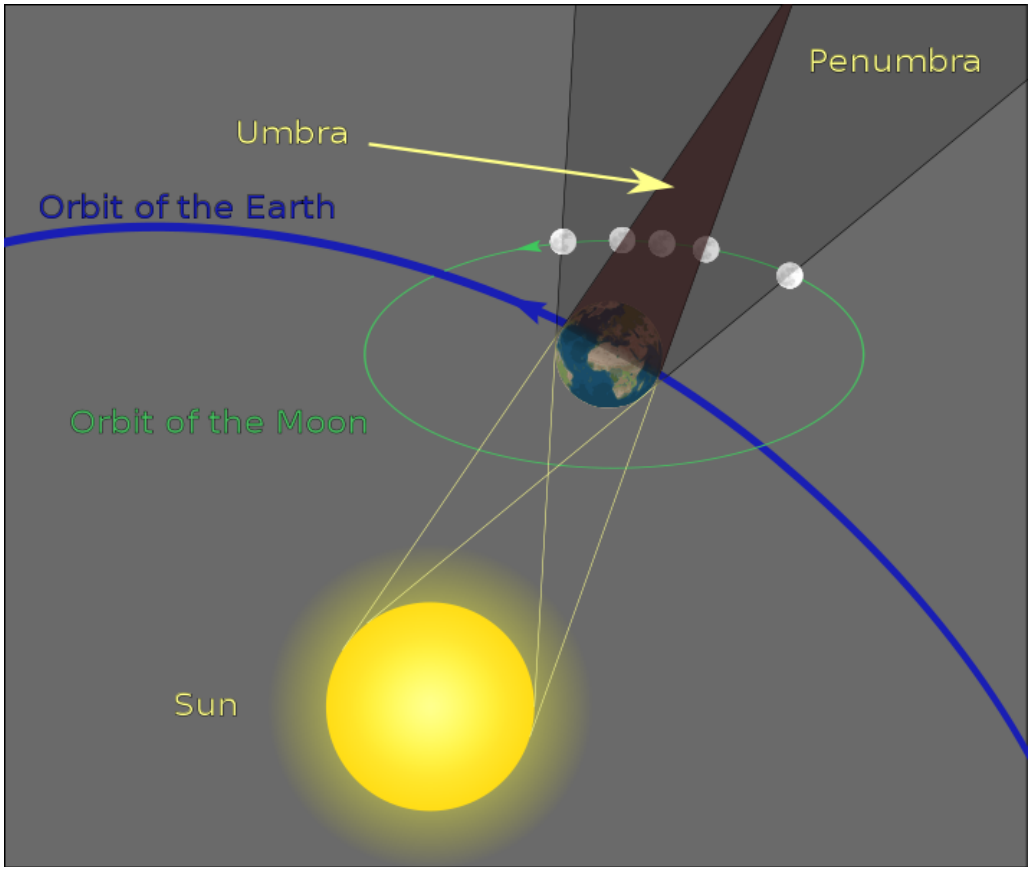






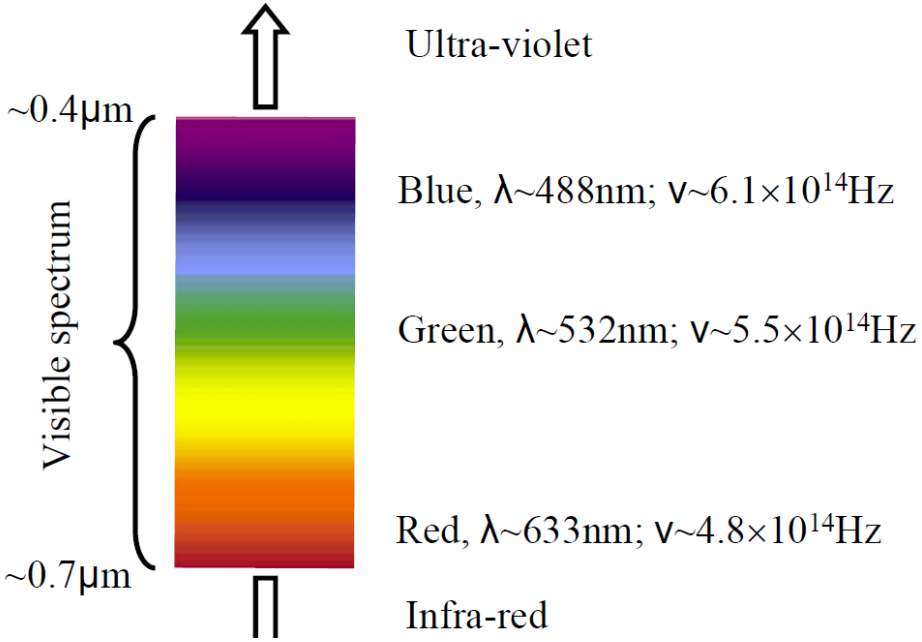
During a solar eclipse, the sun – a small but extended source – casts a shadow of the moon on the earth. The moon's shadow had a dark center surrounded by a region of increasing brightness as shown in (b).

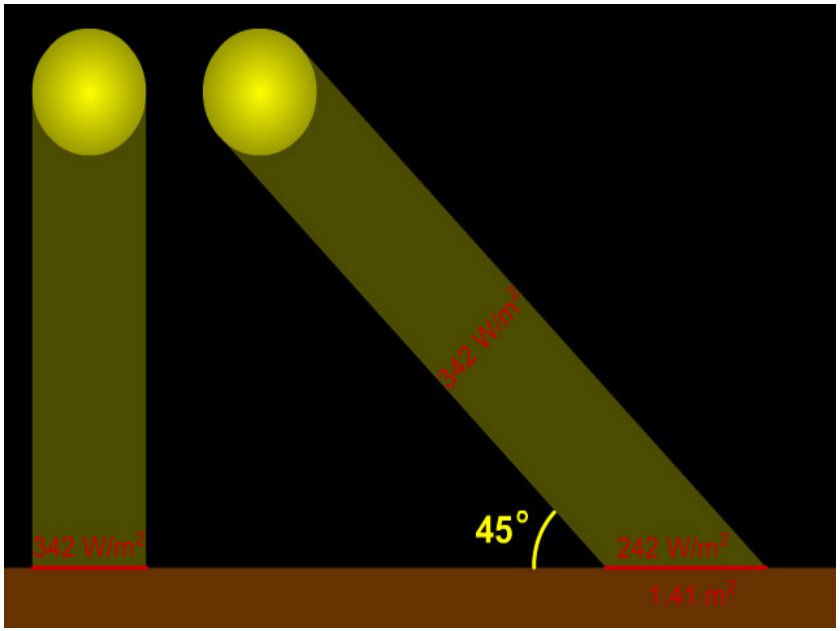
‘Shadows’ and ‘Eclipse’



Shadows (Babylon 5)

What is Light?

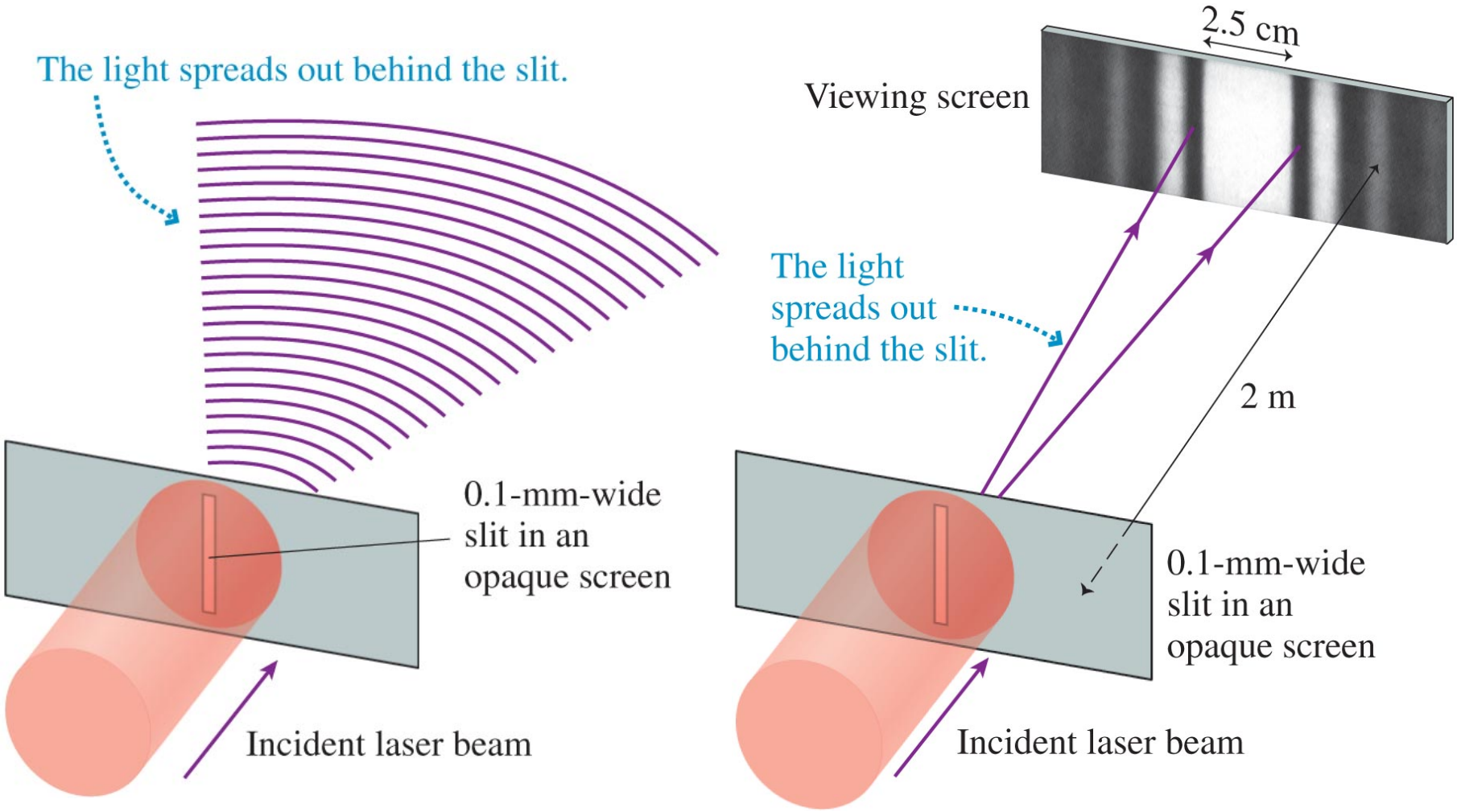




When the Sun is directly overhead, its rays strike Earth perpendicular to the ground and so deliver the maximum amount of energy. When the Sun is lower in the sky, a sunbeam strikes the ground at an angle (in the example above, 45°) and so its energy is "spread out" over a larger area... thus "diluting" its energy. In this example, the energy is spread over an area of 1.41 square meters (instead of 1 square meter when the Sun is directly overhead), so the energy per unit area is reduced from 342 W/m2 to 242 W/m2 (342 ÷ 1.41 = 242).
Credit: Artwork by Randy Russell.

http://www.windows2universe.org/earth/climate/sun_radiation_at_earth.html

Light waves also spread out behind a very narrow slit



Will come back to the single slit case in a bit

Wave Nature of Light

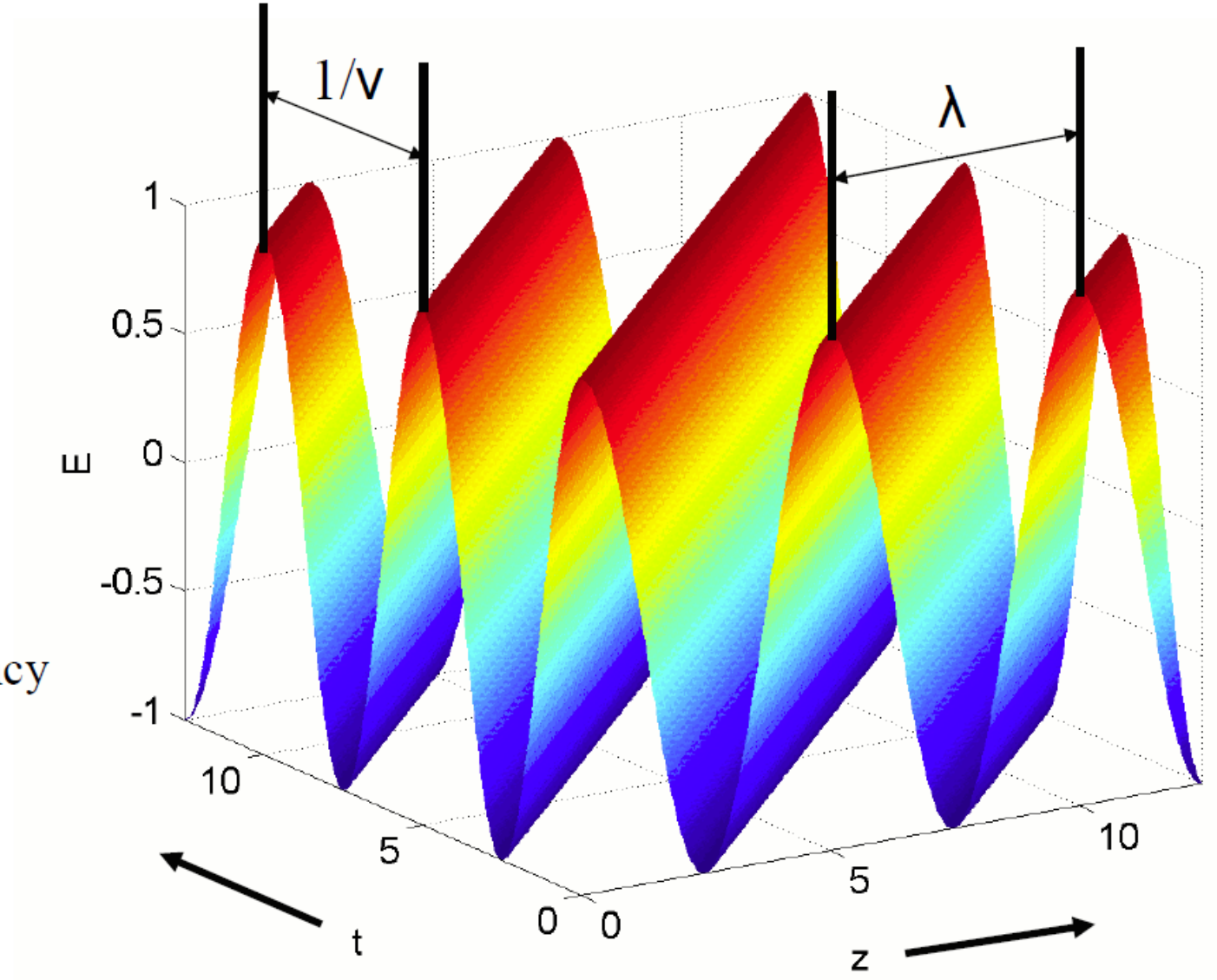
λ: **wavelength**
(spatial period)

$k=2\pi/\lambda$
wavenumber

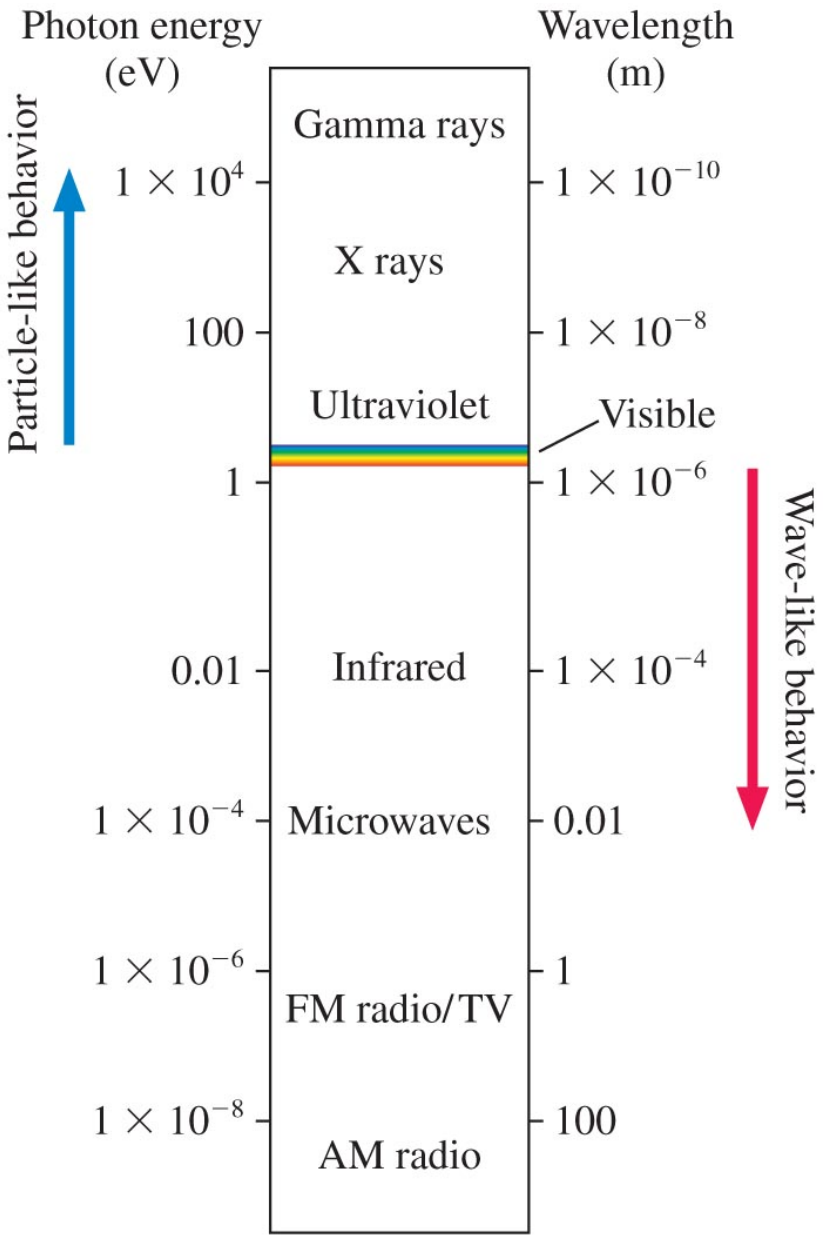
ν: temporal
frequency

$\omega=2\pi\nu$
angular frequency

E: electric
field



The Electromagnetic Spectrum

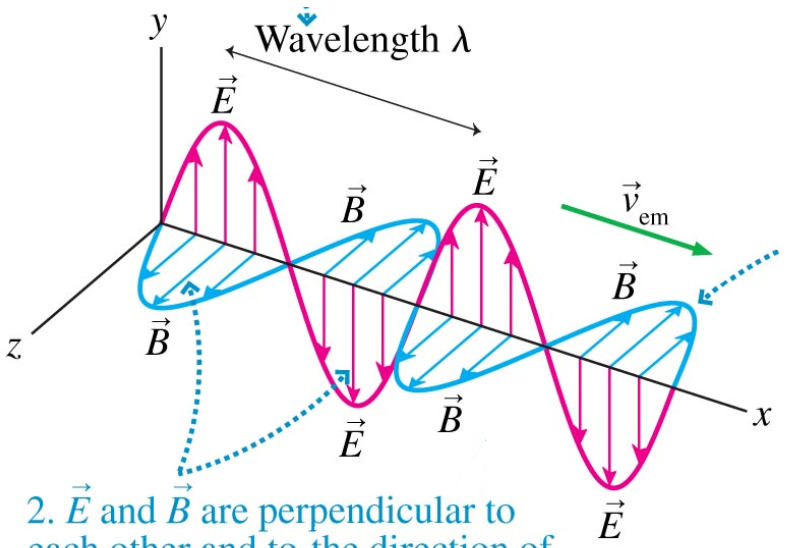


Maxwell's theory

- Maxwell showed that E and B fields could sustain themselves (free from charges or currents) if they took the form of an electromagnetic (EM) wave.
- Maxwell's theory predicted that an EM wave would travel with speed:

$$v_{em} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

$$v_{em} = c = \text{ speed of light}$$



2. $\vec{E}$ and $\vec{B}$ are perpendicular to each other and to the direction of travel. Thus an electromagnetic wave is a transverse wave.

Light is an electromagnetic wave!

Animation http://www.walter-fendt.de/ph14e/emwave.htm

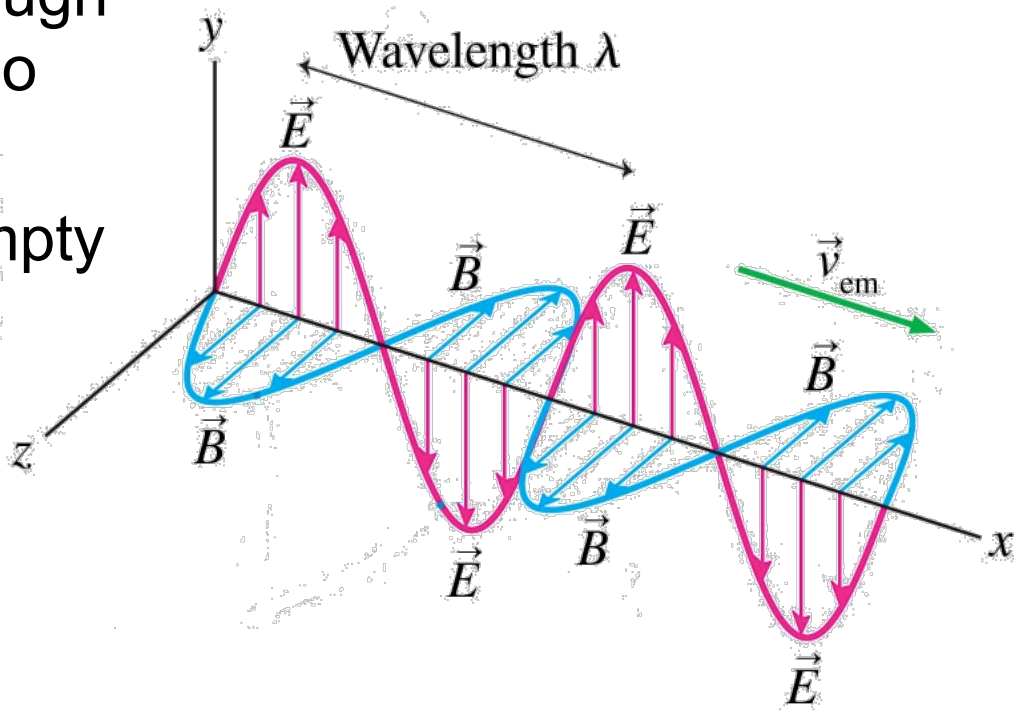
Electromagnetic (EM) Waves

- EM waves can travel through empty space (vacuum); no medium is necessary!
- The speed of light **c** in empty space is

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

= 299,792,458 m/s

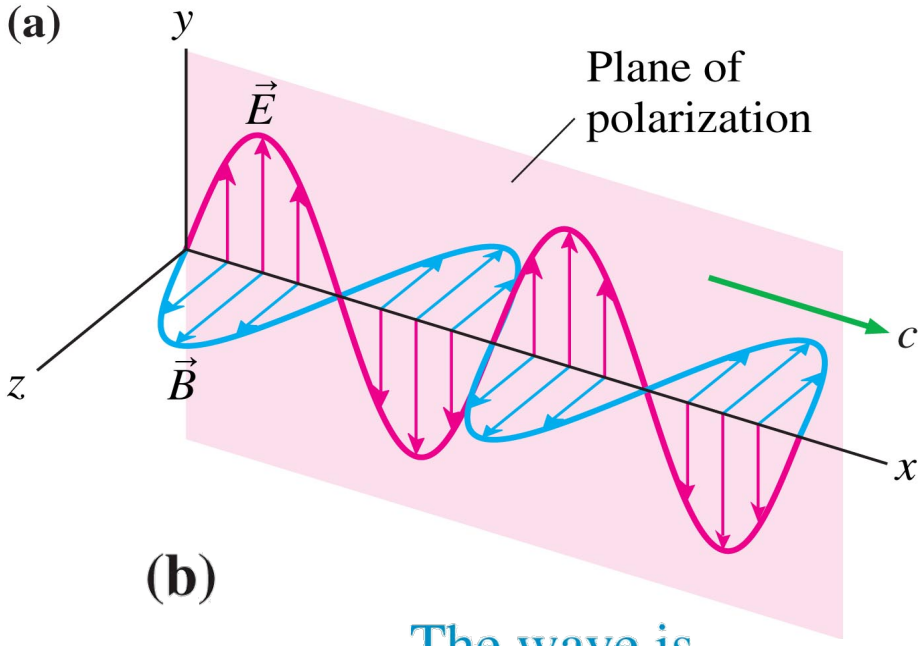
c = 3x10^8 m/s



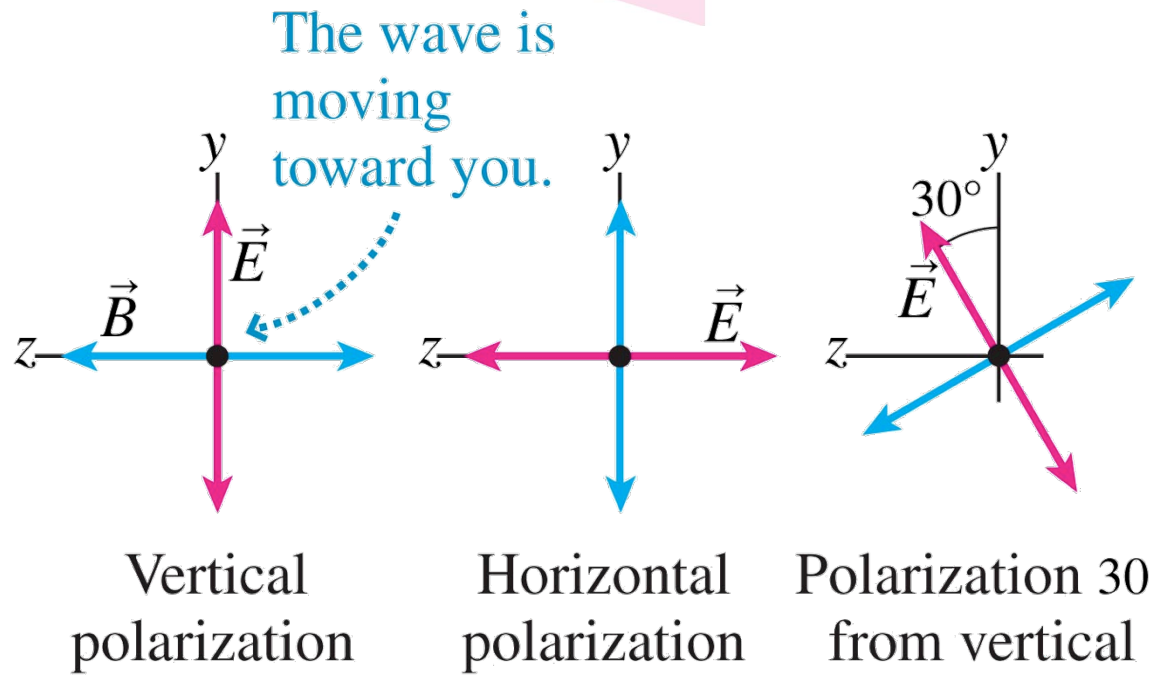
- EM waves carry energy and momentum
- The **speed is constant** so the frequency f is determined by the wavelength λ and speed of light c:

$$f = c / \lambda$$

Polarization



Polarization is defined with respect to the E-field.



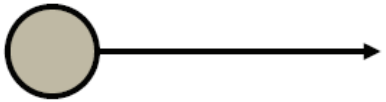
Intensity of an Electromagnetic Wave

$$I = \frac{P}{A} = \frac{1}{2} c \epsilon_0 E_0^2 = \frac{1}{2} \frac{c}{\mu_0} B_0^2$$

Intensity of an electromagnetic wave with field amplitudes E_0 and B_0

We will discuss in details in Ch. 4-8.

Particle Nature of Light

Photon=elementary light particle 

Mass=0

Speed c=3×10^{8} m/sec

According to Special Relativity, a mass-less particle travelling at light speed can still carry energy (& momentum)!

Energy E=$h\nu$ ⟹ relates the dual particle & wave nature of light;

h=Planck's constant

$=6.6262\times10^{-34}$ J sec

$=4.1357\times10^{-15}$ eV s

ν is the temporal oscillation frequency of the light waves

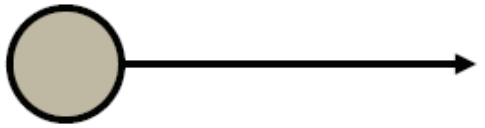
$$N\,[\#/s]=\frac{Power}{Energy/photon}=\frac{[Watt=J/s]}{[J]}$$

N is the number of photons per second.

See Example 1-2, page 10 in Pedrotti[3].

Wave-Particle Duality of Light

Photon=elementary light particle



Energy $E=h\nu$

h=Planck's constant
$=6.6262\times10^{-34}$ J sec

ν=frequency (sec^{-1})
λ=wavelength (m)

$$c=\lambda\nu$$

"Dispersion relation"

(holds in vacuum only)