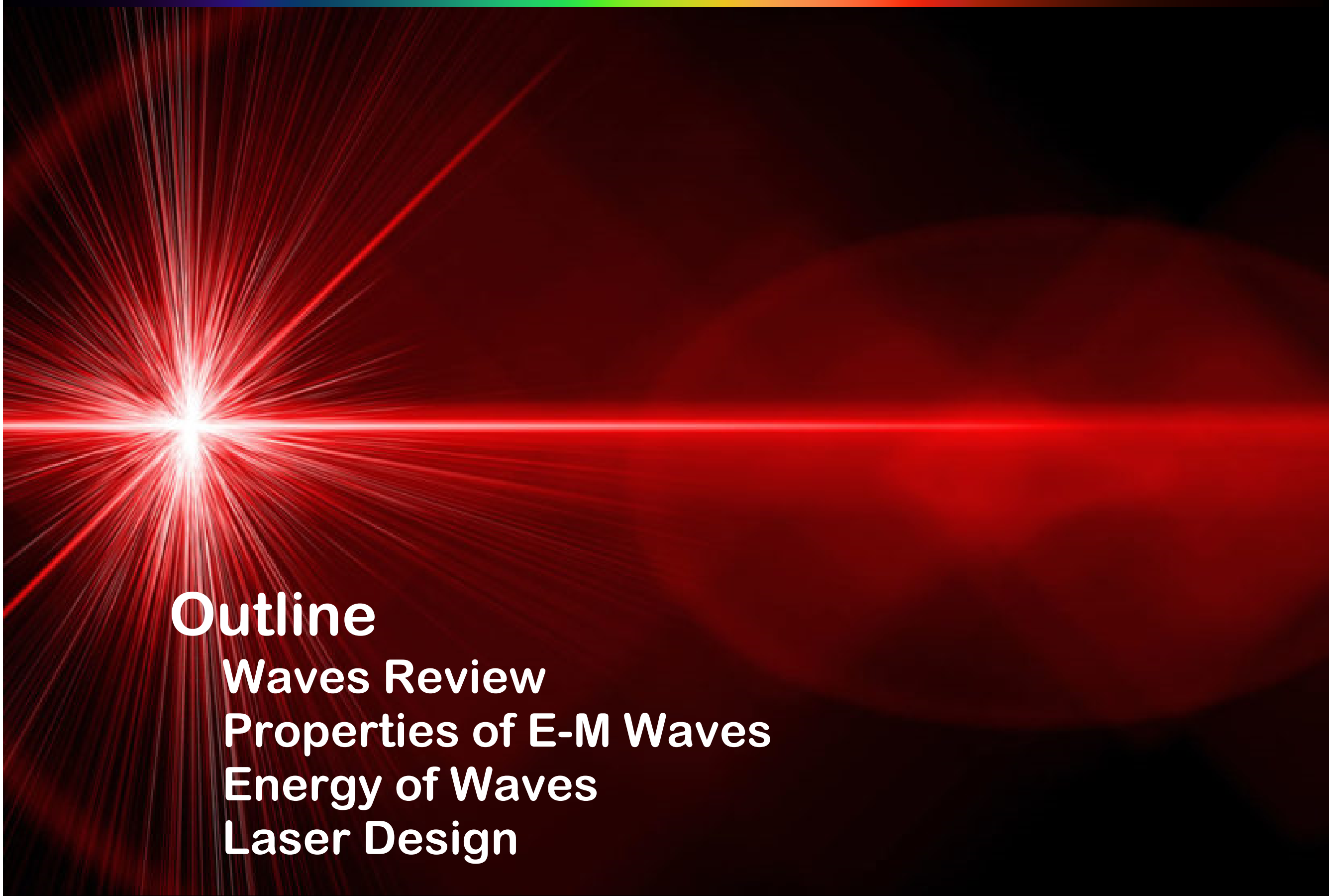
WAVE NATURE OF LIGHT



Outline

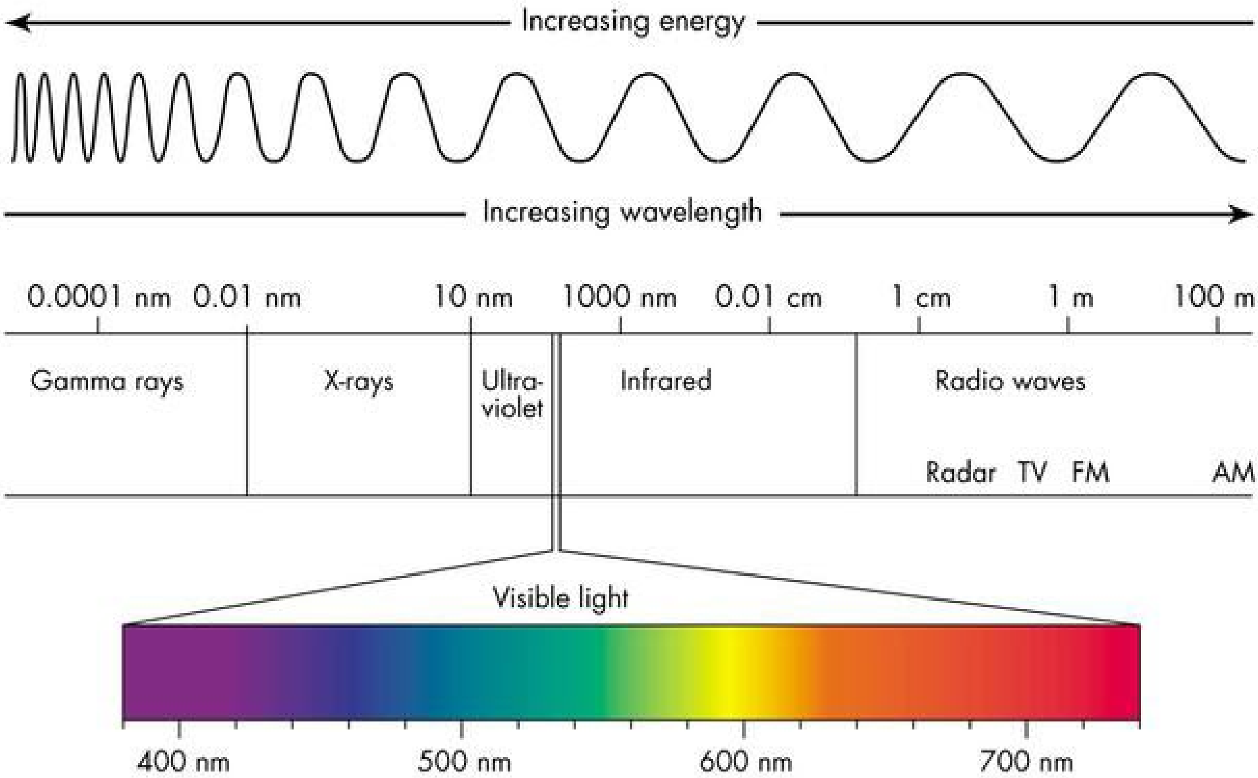
- Waves Review
- Properties of E-M Waves
- Energy of Waves
- Laser Design

What is a Wave?

Definition:

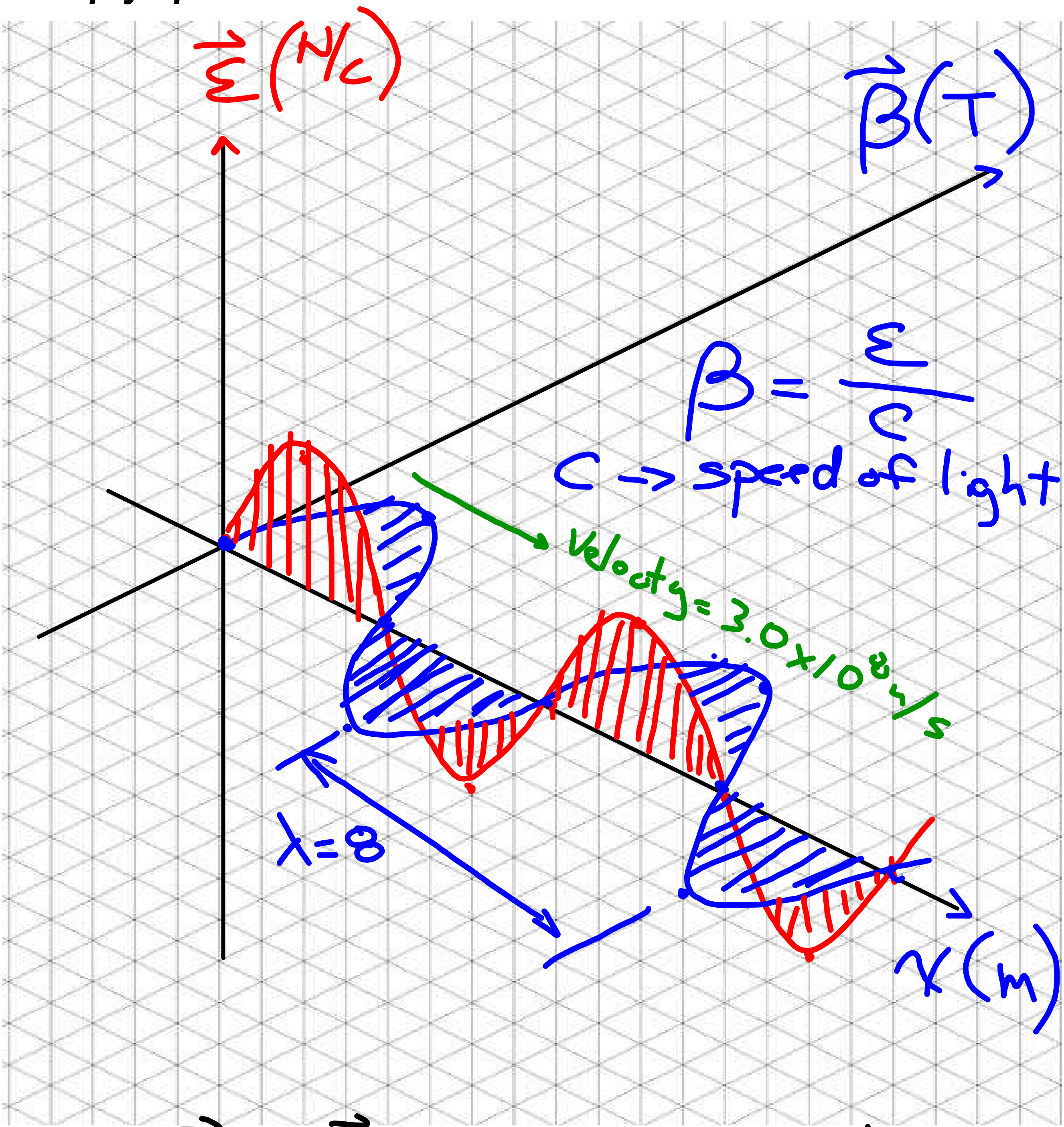
- A wave is a transfer of energy over a distance in the form of a disturbance. Most waves originate from a vibrating source.
- Mechanical Waves : require a physical medium to travel through
  - examples : waves on a slinky, sound waves
- Non Mechanical Waves – do not required a medium to transmit the energy

Electromagnetic Waves

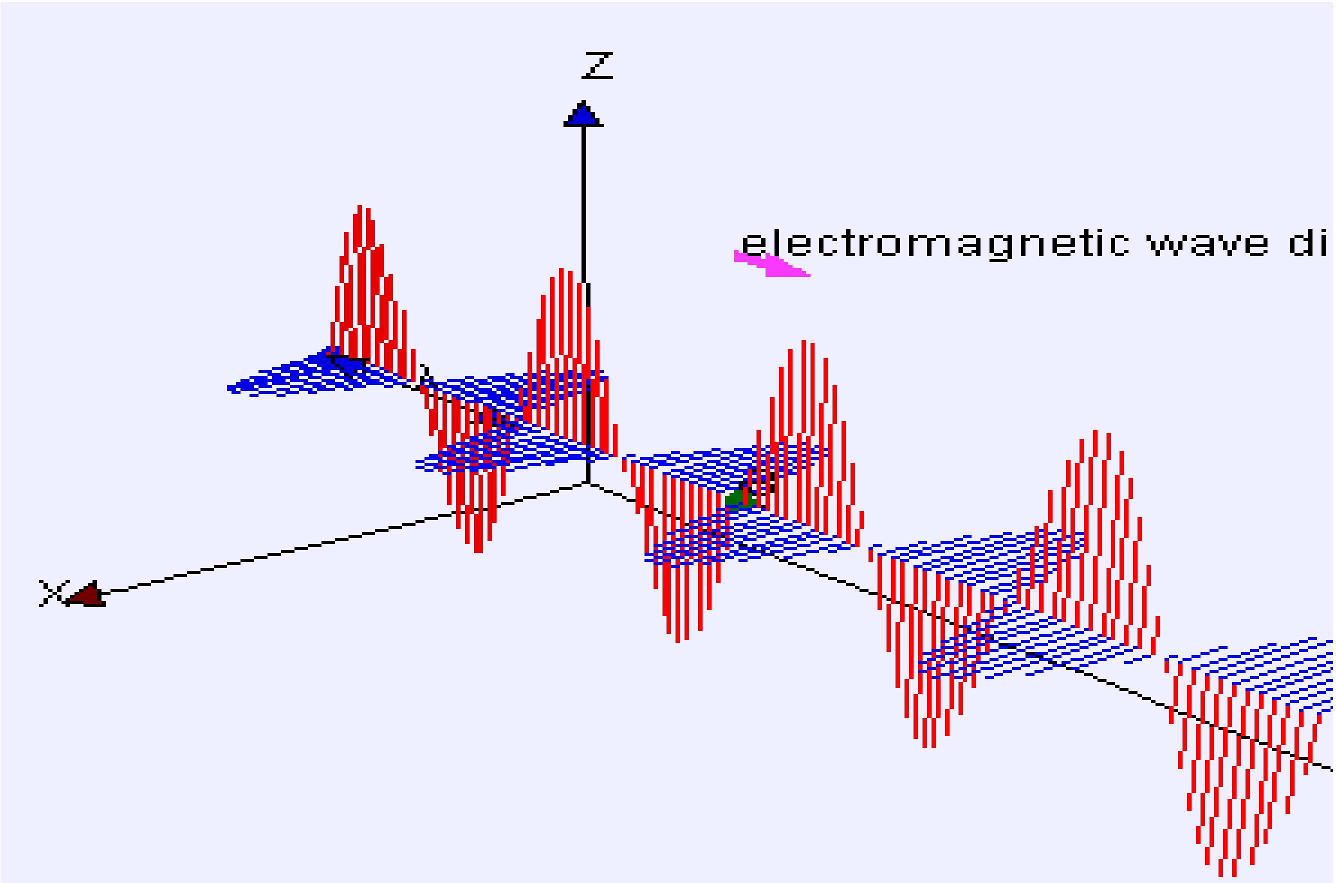


Electromagnetic Waves

Electromagnetic (EM) radiation consists of oscillating electric and magnetic fields that can propogate through empty space.



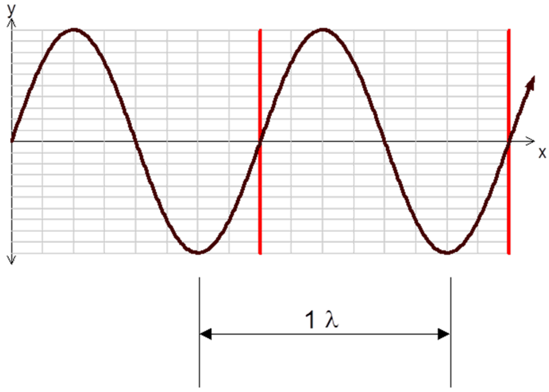
1. $\vec{E}$ & $\vec{B}$ waves are synchronized (same wavelength & frequency)



Z
electromagnetic wave di
X

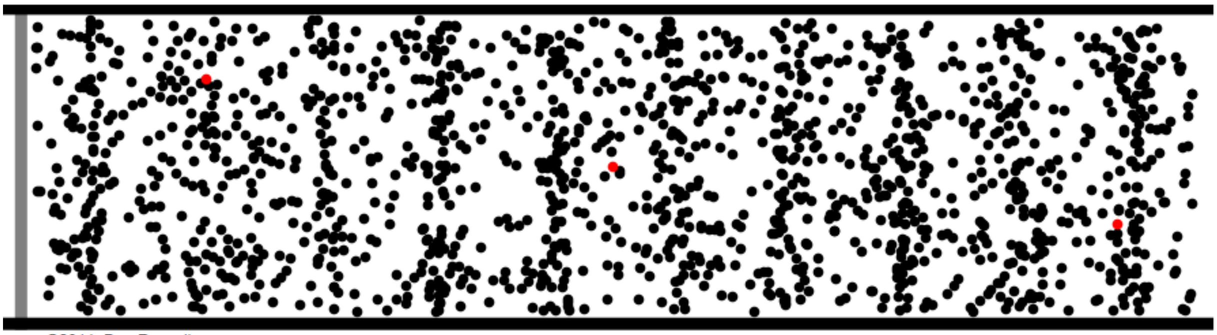
Wave Properties

Periodic waves originate from periodic vibrations (oscillations).

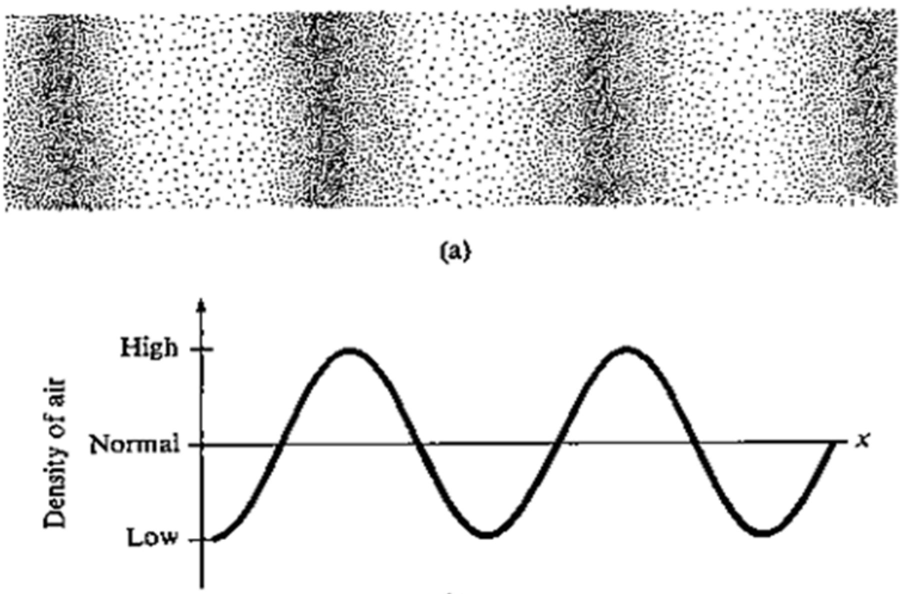


One wavelength (λ) is the distance between successive crests or troughs.

Sound Waves



Sound is a longitudinal wave of air pressure variations, caused by a rapidly vibrating source (i.e. a tuning fork or your vocal cords)



(a)

(b)

Characteristics of Waves

- Period – T (seconds)
- Frequency – f (Hz)
- Wavelength – λ (m)
- Velocity – V (m/s)
- Amplitude – the measure of the amplitude depends on the type of wave
  Wave on a string – postion (m)
  Sound Wave – air pressure (psi, kpa etc)
  Electromagnetic Wave – strength of electric or magnetic field (ε or β)

$P = \frac{1}{f}$

$V = f\lambda$

ε → N/C

β → Tesla's (T)

Energy of Waves.

The energy of a mechanical wave is dependent on the amplitude of the wave.

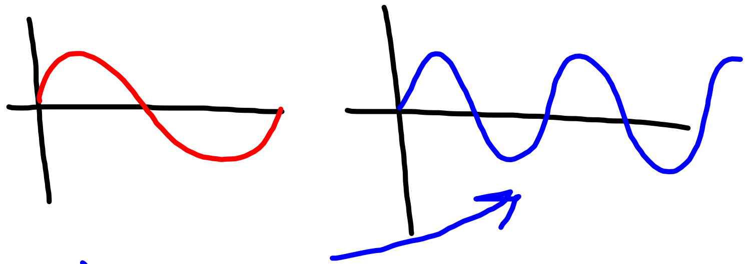
if amplitude doubles the energy goes up by 4.

energy $\propto$ amplitude squared.

$$E \propto A^2 \qquad E = kA^2$$

Energy of Electromagnetic (EM) waves.

The energy of an EM wave is directly proportional to the frequency of the wave.



higher frequency means higher energy.

$$E = hf$$

- E: energy in Joules
- h: Planck's Constant
- f: frequency in Hz

Calculate the energy in Joules of a red photon (λ=650nm) and a blue photon (λ=400nm).

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

$$E = hf = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\,\text{J}\cdot\text{s}\;\; 3.0\times10^{8}\,\text{m/s}}{(650\times10^{-9})\,\text{m}} = 3.1\times10^{-19}\,\text{J}$$

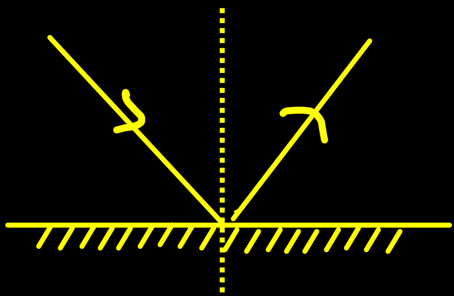
$$E = 5.0\times10^{-19}\,\text{J}$$

ElectroMagnetic Wave Phenomenon

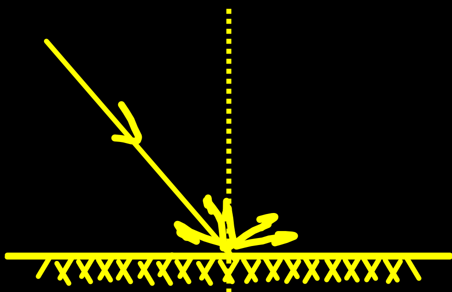
1. Reflection
2. Refraction
3. Diffraction
4. Interference
5. Polarization

ElectroMagnetic Wave Phenomenon

1. Reflection



mirror
→ Specular Reflection

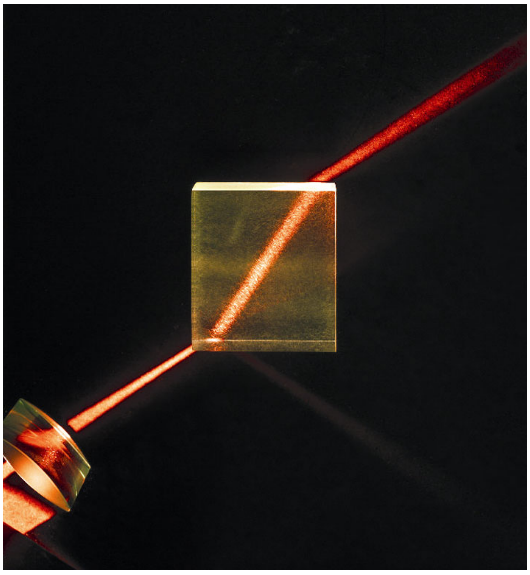


paper, walls
→ Diffuse Reflection

laser
reflectance
→ 99.9%

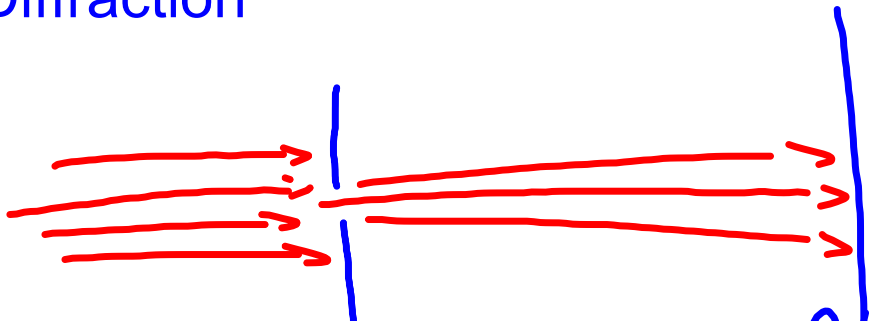
2. Refraction

light slows down as it enters a new medium.

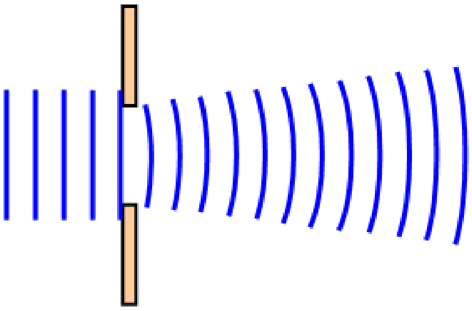


This slowing down of light causes the wavefront to bend.

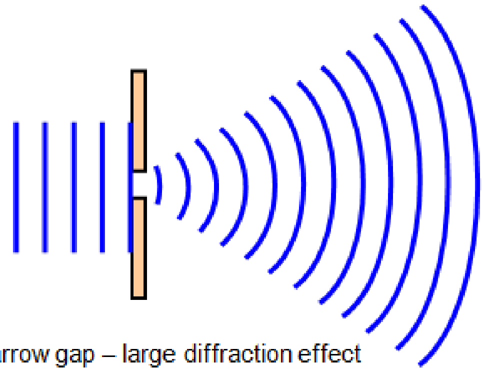
3. Diffraction



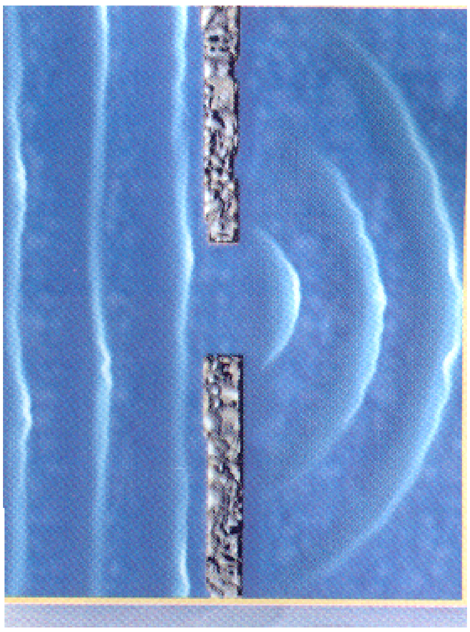
Spreading out of waves after they encounter small gaps



Wide gap – small diffraction effect

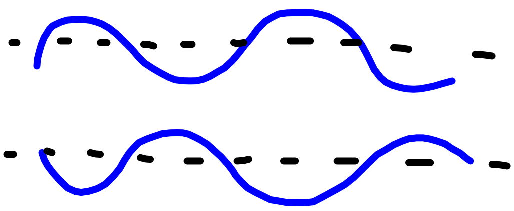


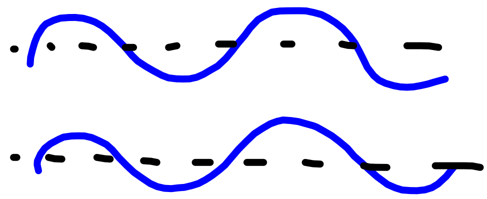
Narrow gap – large diffraction effect



4. Interference

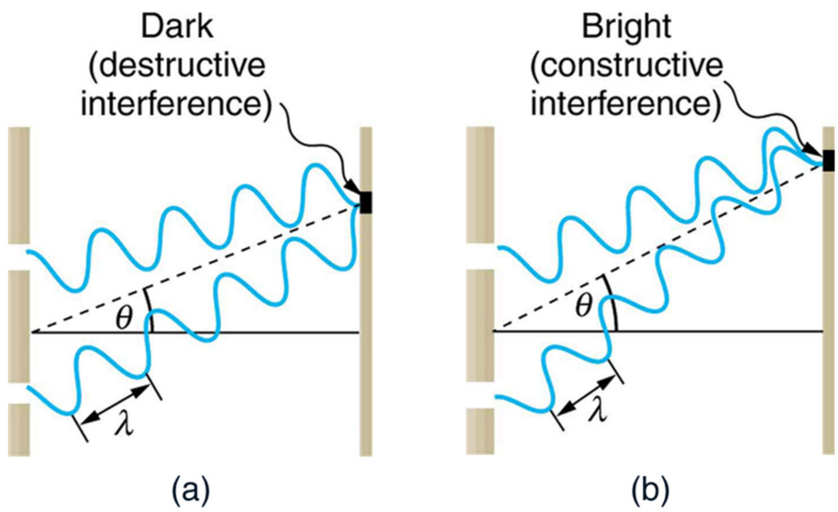
E-M waves can interfere constructively or destructively





Destructive Interference.

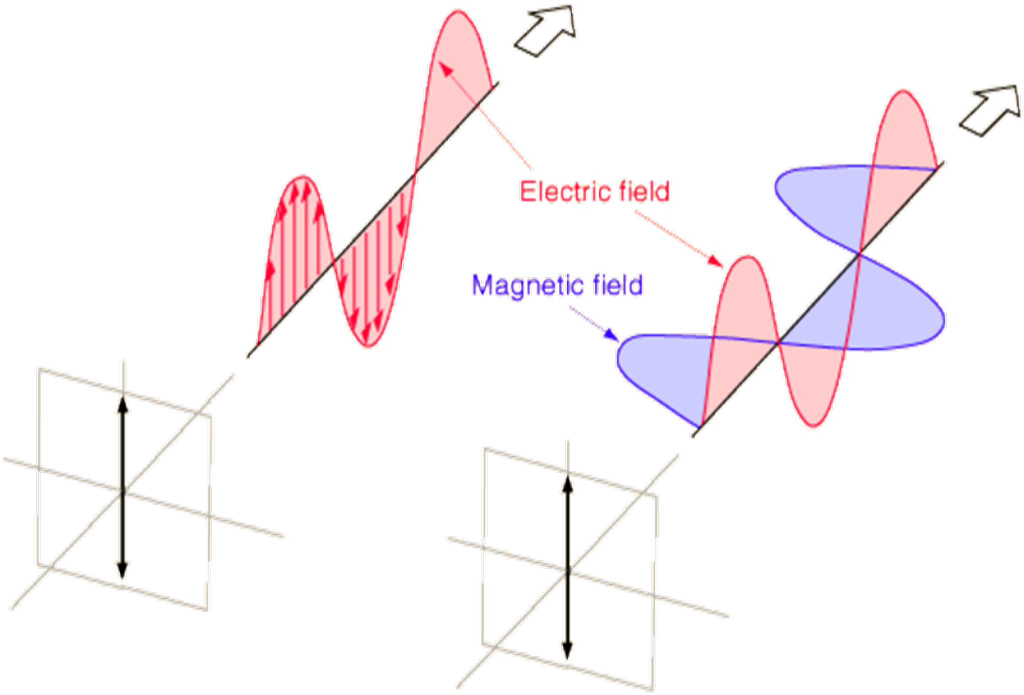
Constructively Interfere

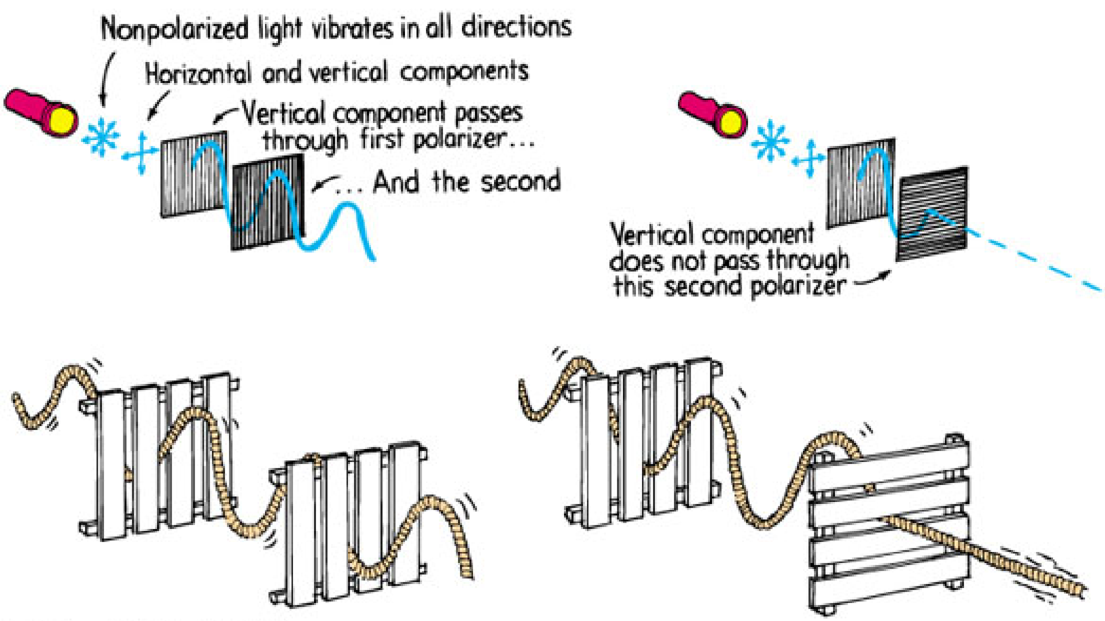


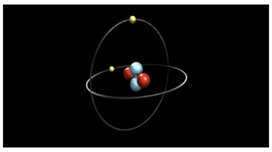
5. Polarization

polarization refers to the orientation of the $\vec{E}$ field.

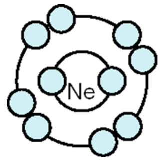
* sunlight is randomly polarized.







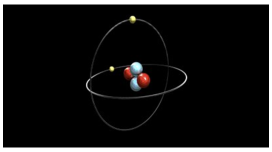
Operation of a Laser



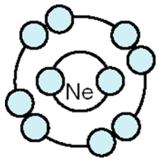
Light Amplification by Stimulated Emission of Radiation.

4 Requirements

1. lasing medium
2. Optical cavity
3. laser pumping energy
4. output optical coupler.



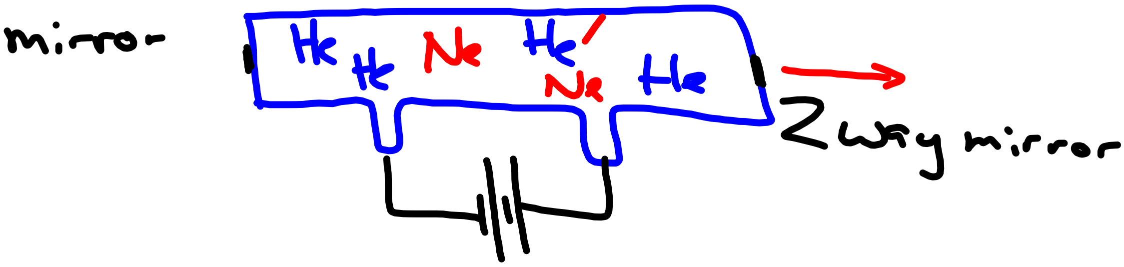
Operation of a Laser



HeNe Laser Design Basics

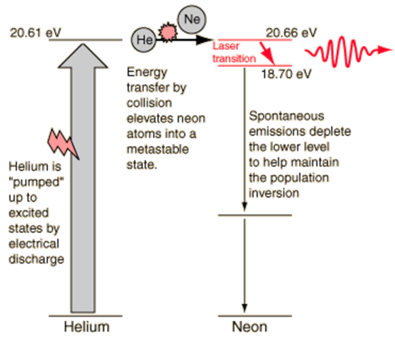
(helium-neon)

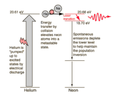
10:1
He:Ne



1. Lasing Medium

Energy is absorbed by the electrons in the gas and re-emitted as electro-magnetic radiation.
As an excited Neon atom returns to ground state (electrons drop energy levels) visible radiation is emitted.





the change in energy levels is 1.96eV
(eV = electron volt)

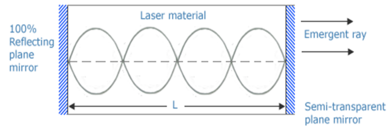
$$E = 1.96\,eV \times 1.602\times10^{-19}\,J/eV$$
$$= 3.14\times10^{-19}\,J$$

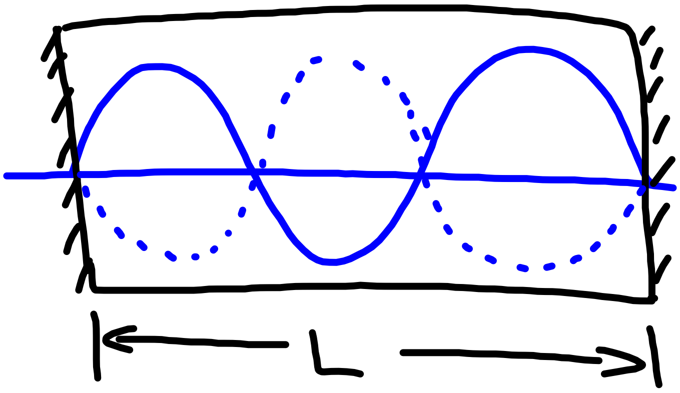
$$E = hf$$
$$E = \frac{hc}{\lambda} \quad \rightarrow \quad \lambda = \frac{hc}{E}$$
$$= \frac{6.626\times10^{-34}\,J\cdot s \times 3.0\times10^{8}\,m/s}{3.14\times10^{-19}\,J}$$
$$= 6.33\times10^{-7}\,m$$
$$= 633\,nm$$

(actual = 632.8 nm)

note : in the video portion of the lesson, I use 633 nm as the calculated wavelength. Using more precise calculations, the actual wavelength is 632.8nm - this is the value I use when calculating the length of the optical cavity on the next page.

2. Optical Cavity





length must be an integer multiple of ½ wavelengths

$L = n\frac{\lambda}{2}$ n is an integer

example ; n=100 , λ=632.8nm

#1 $L = 100\ \frac{632.8\times10^{-9}}{2}$

$= 0.00003164\ m$

$(0.03164\ mm)$

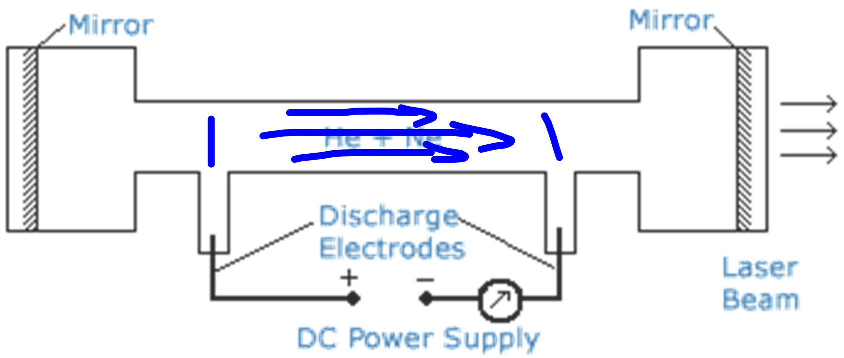
#2 n=800,000

$L = \frac{800000 \times 632.8\times10^{-9}\ m}{2}$

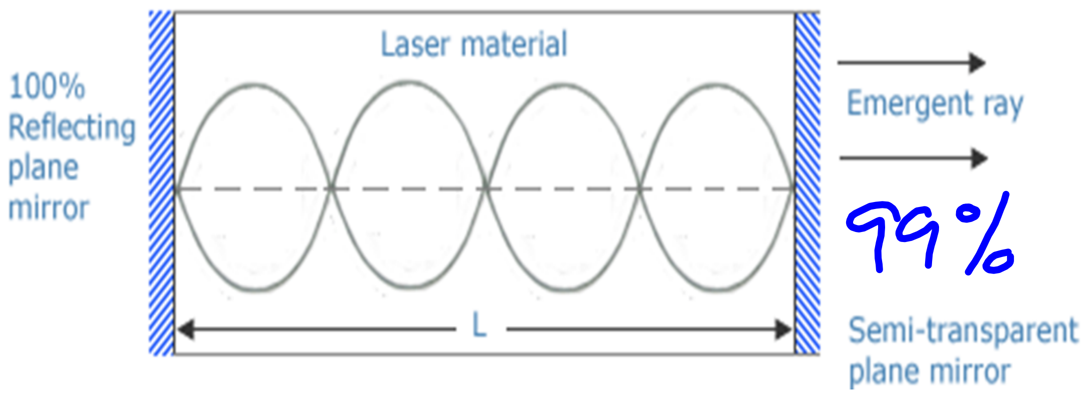
$= 0.25312$

or 25.312 cm

3. Laser Pumping Energy



4. Output Coupler



Anatomy of the Helium-Neon Laser

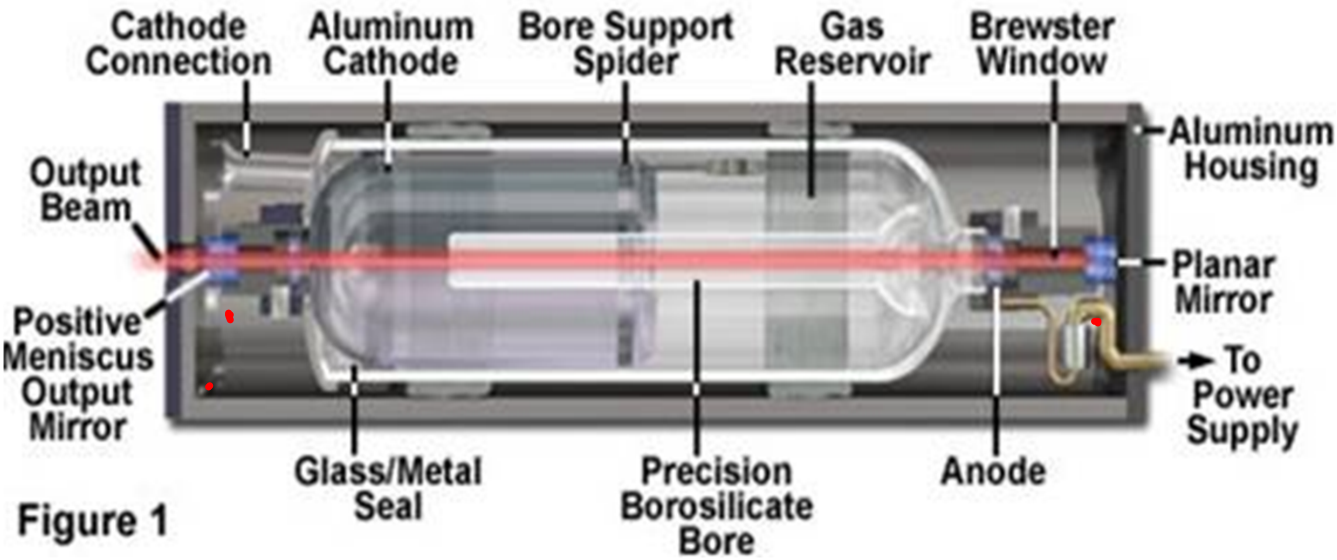
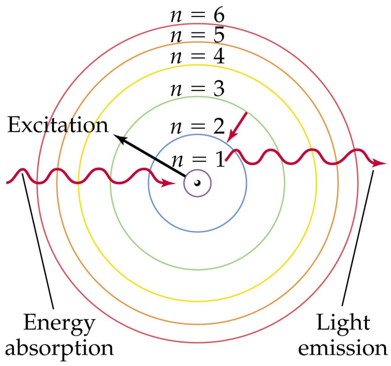


Figure 1

Design an Argon Laser

1. what colour is the laser beam?

2. determine how far apart to place the mirrors in an argon laser



design criteria:

lasing medium - argon gas

emission energy - 2.54eV

Optical Cavity, set n = to 800,000