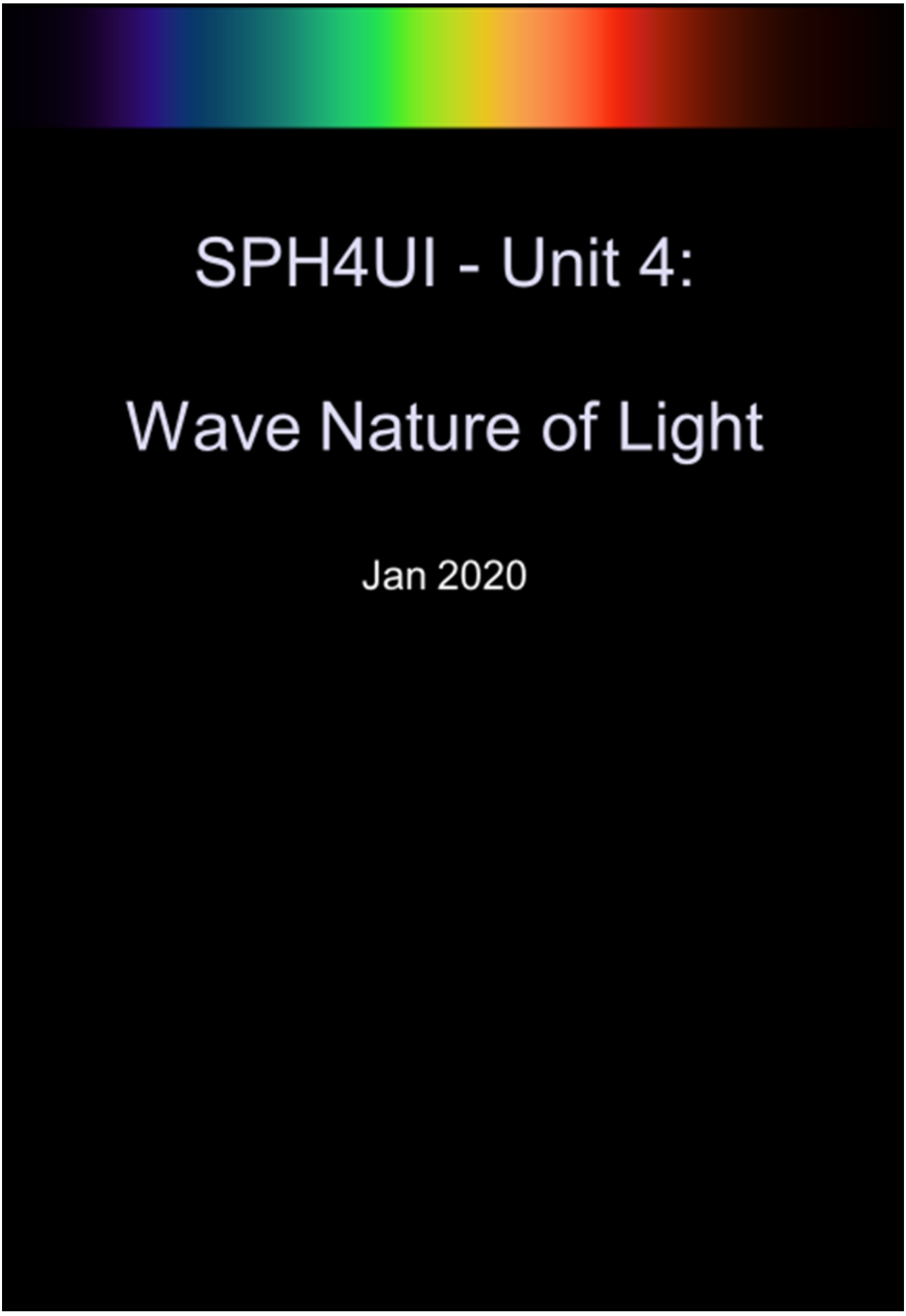

SPH4UI - Unit 4:
Wave Nature of Light
Jan 2020

SPH4UI : Unit 4 Wave Nature of Light

$V = f\lambda$

The Universal Wave Equation

$v = f\lambda$ v= speed of wave (m/s), f=frequency of wave (Hz), λ = wavelength of wave (m)

$f = \frac{1}{T}$ T= period (s)

$c = 3.0 \times 10^8 m/s$ c= speed of light in a vacuum

Solve the following problems:

1. Calculate the wavelength of a laser beam if the frequency is 6.50×10^{14} Hz

2. The wavelengths of the visible spectrum range from 400 nm to 750 nm. Calculate the range of the frequencies of visible light. (1nm = 1×10^{-9}m).

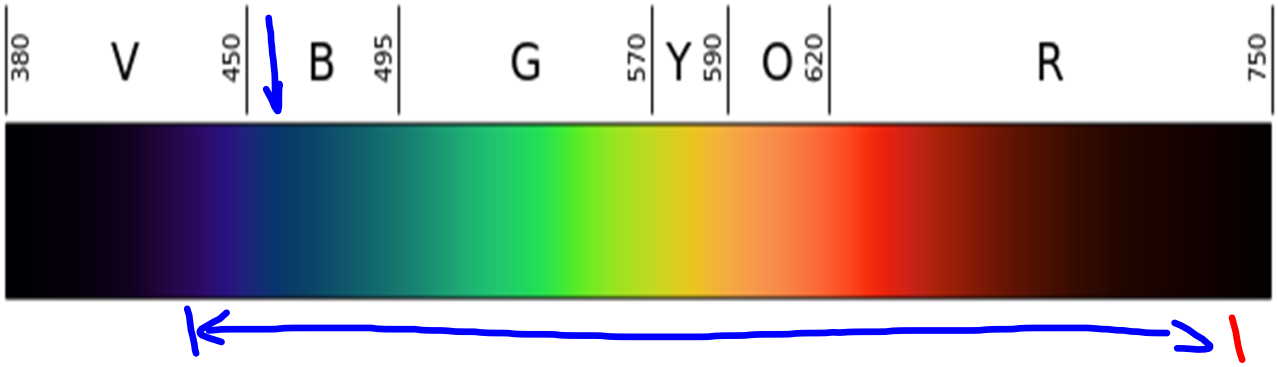
3. If the sun is 149.6 million km from earth, how long does it take for light to travel from the sun to earth?

$1nm = 10^{-9}m$

---

1. $\lambda = \frac{v}{f} = \frac{3.0 \times 10^8 m/s}{6.50 \times 10^{14} Hz} = 4.6 \times 10^{-7} m$

$= 460\,nm$



2. $f = \frac{v}{\lambda} = \frac{3.0 \times 10^8 m/s}{400 \times 10^{-9} m} = 7.5 \times 10^{14} Hz$

$= \frac{3.0 \times 10^8 m/s}{750 \times 10^{-9} m} = 4.0 \times 10^{14} Hz$

3. constant v, $v = \frac{\Delta d}{t}$

$t = \frac{\Delta d}{v} = \frac{149.6 \times 10^9 m}{3.0 \times 10^8 m/s} = 499 s$

~ 8.3 mins

Wave Nature of Light :
Day 1 - Properties of E-M Waves

Tues Jan 7th

Mon	Tues	Wed	Thurs	Fri
D 9	D10	D11	D12	D13
D16	D17 Fields	D18	D19	D20
Christmas Break				
Christmas Break				
J 6	J 7 WNL	J 8	J 9 Field Quiz	J 10 ***IQC Visit***
J 13	J 14 Assign WNL MP	J 15	J 16	J 17
J 20	J 21	J 22	J 23	J 24 Exams Period A Classes SNC2DI-01
J 27 Exams Period B Classes SNC2DI-02	J 28 Exams Period C Classes	J 29 Exams Period D Classes SPH4UI-01	J 30	J 31 ***PD Day***

Topic Outline

- Waves Review (sound unit from grade 11)
- Compare mechanical and electromagnetic waves
- Clues that light is wave
- Clues that light is not wave
- What is light really?

What is a Wave?

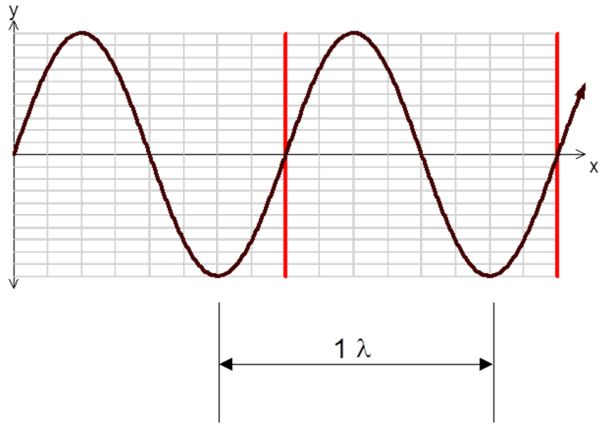
Definition:

- 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
gravity waves

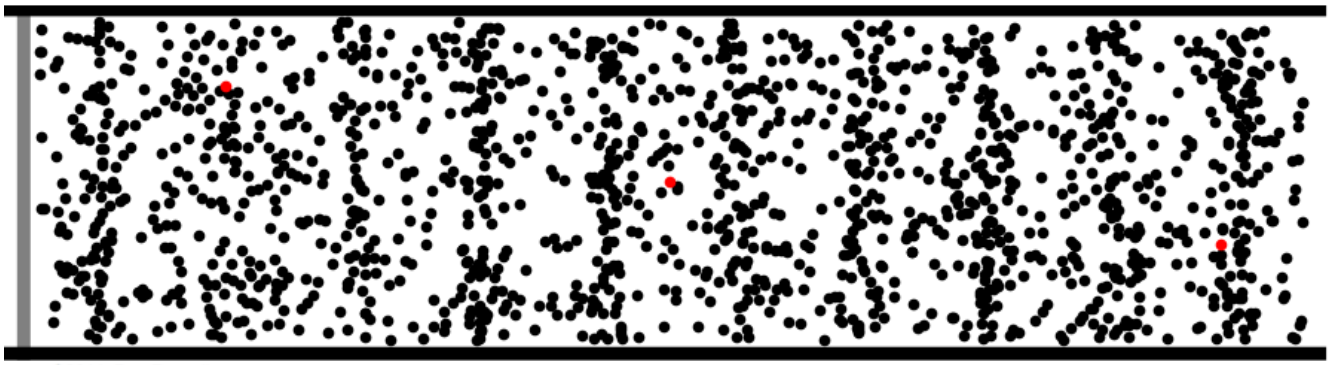
Wave Properties

Periodic waves originate from periodic vibrations (oscillations).

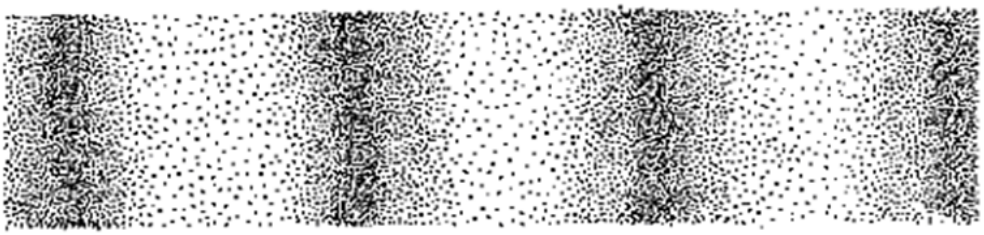


One wavelength (λ) is the distance between successive crests or troughs.

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)



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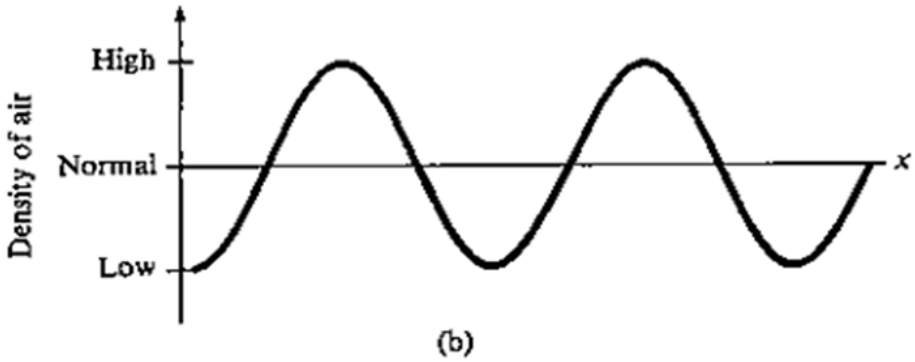
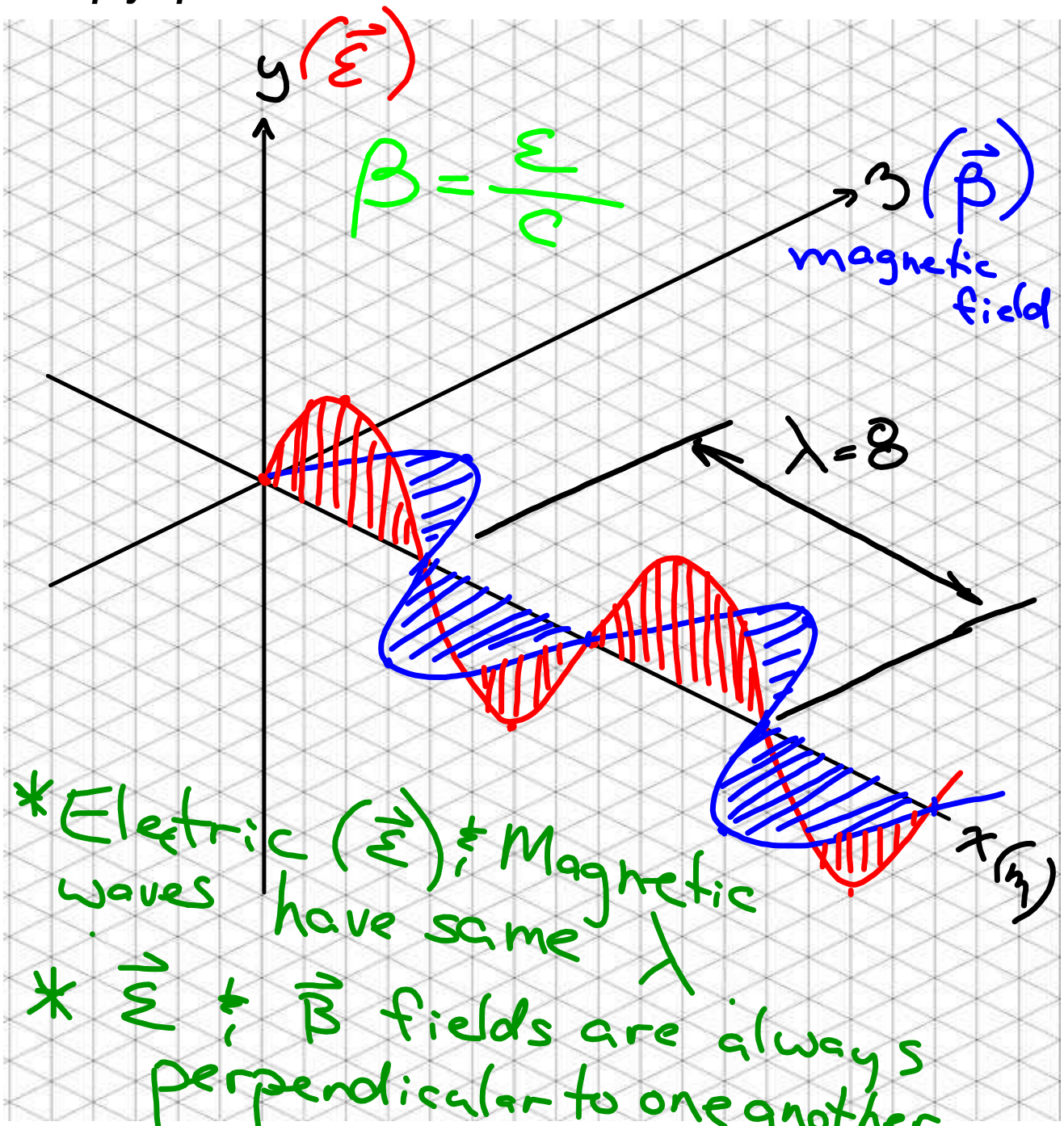


(b)

Electromagnetic Waves

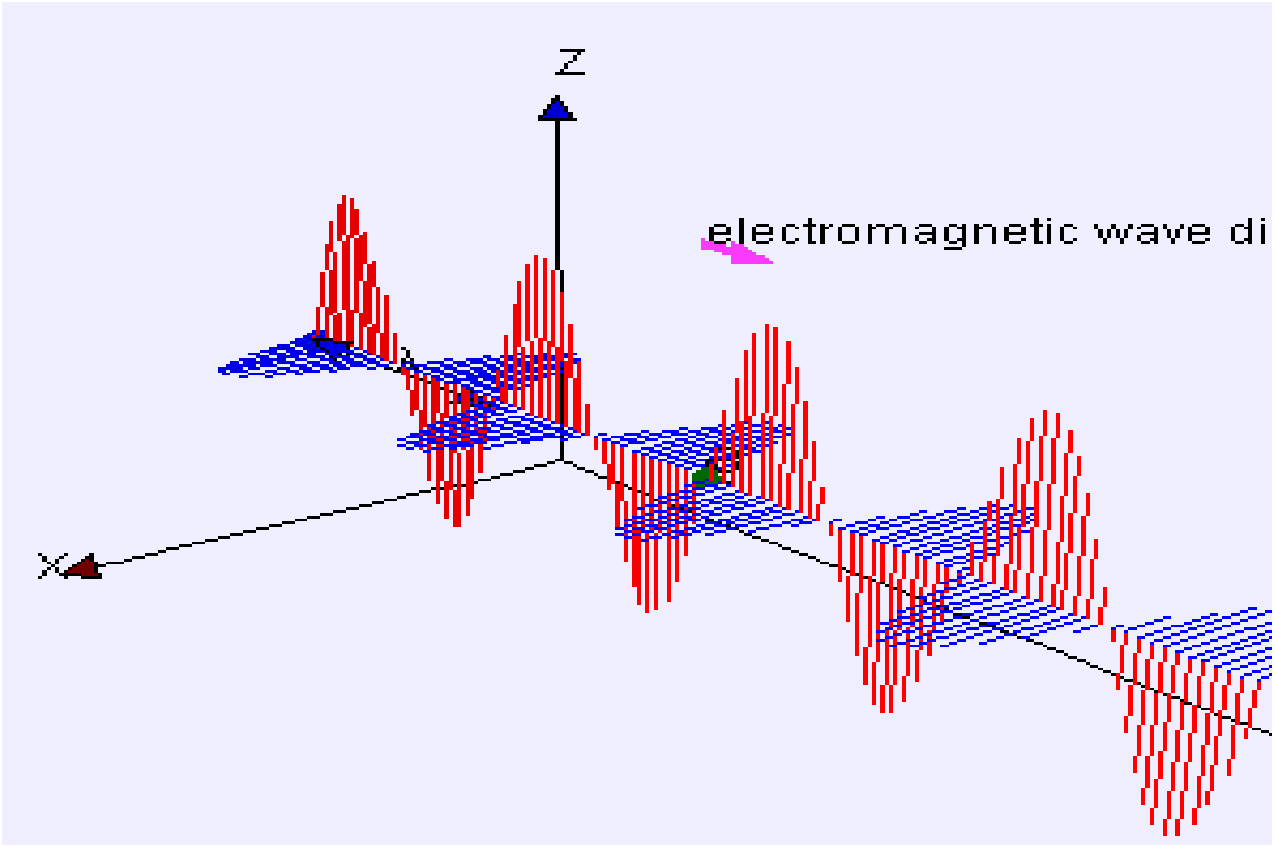
Electromagnetic (EM) radiation consists of oscillating electric and magnetic fields that can propogate through empty space.

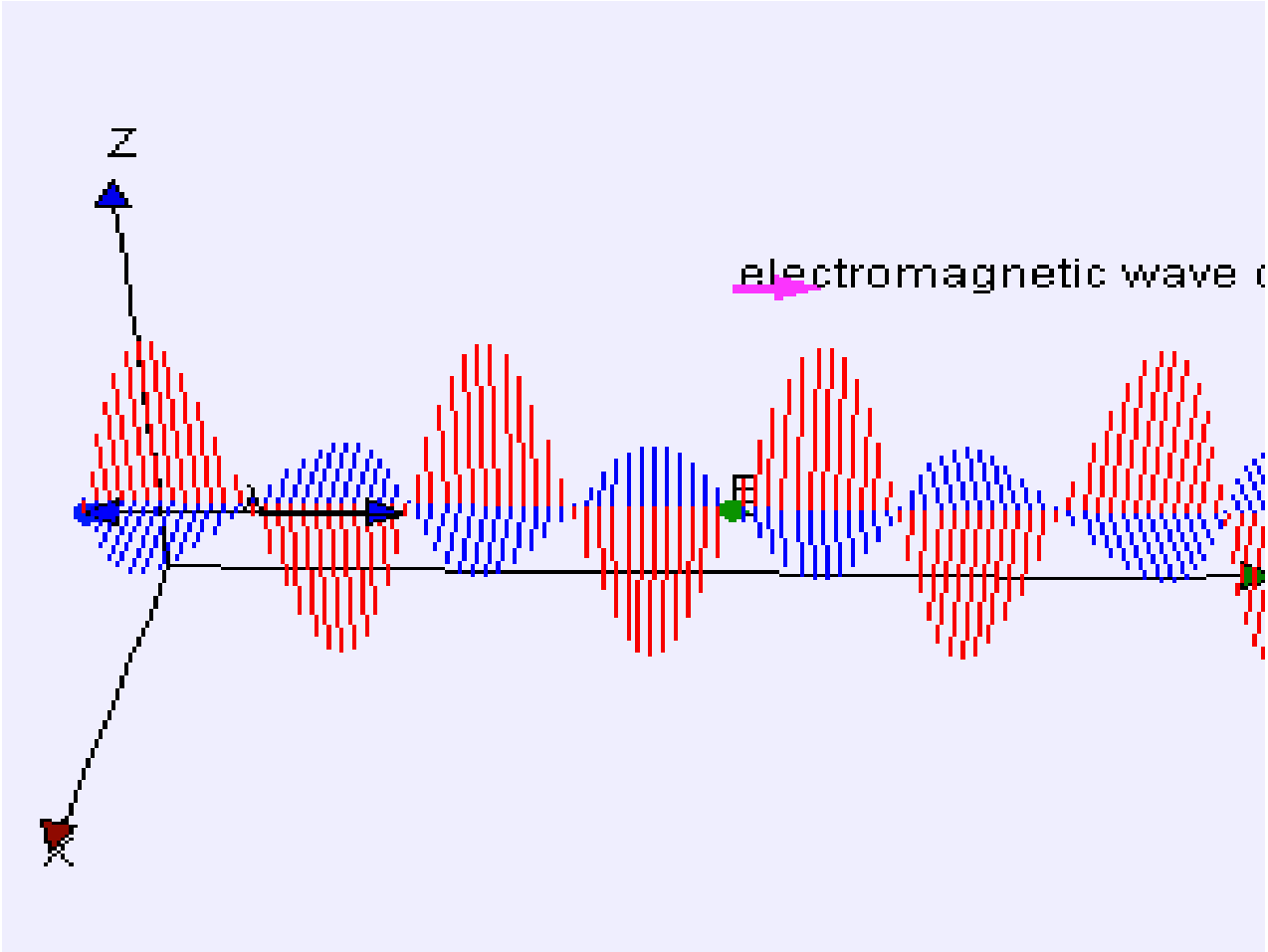


* Electric ($\vec{E}$) & Magnetic waves have same λ.

* $\vec{E}$ & $\vec{B}$ fields are always perpendicular to one another.

* these waves always travel at the same speed $c = 3.0 \times 10^8$ m/s


Z
electromagnetic wave di
X


Z
electromagnetic wave
X

Characteristics of Waves

- Period – T (seconds)
- Frequency – f (Hz)
- Wavelength – λ (m)
- Velocity – V (m/s)

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

$$V = f\lambda$$

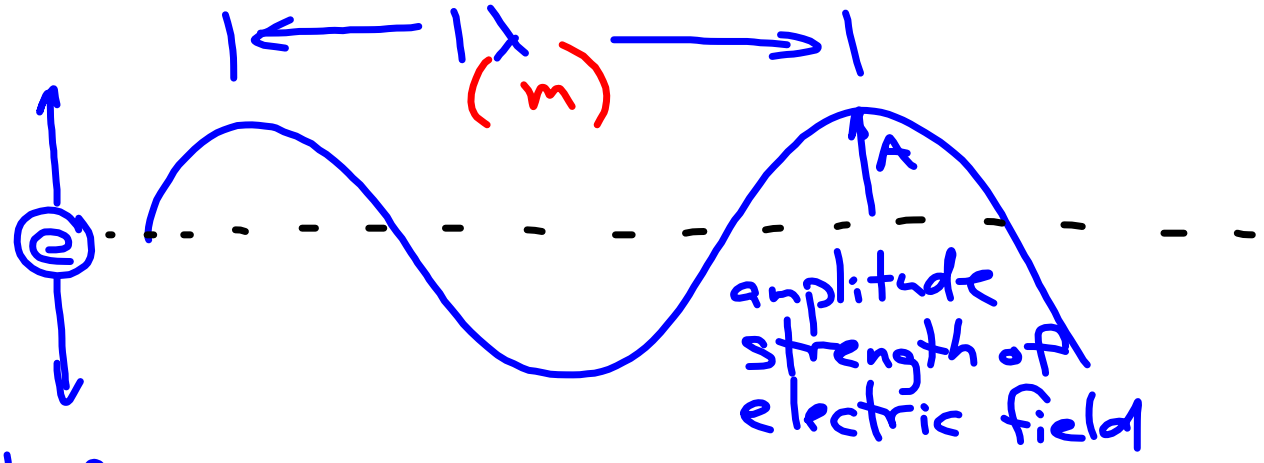
- Amplitude – the measure of the amplitude
  depends on the type of wave
  Wave on a string – postion (m)
  Sound Wave – air pressure (psi, kpa etc)
  Electromagnetic Wave – strength of electric or magnetic field (ε or β)

N/C Teslais (T)

energy mechanical wave $\propto A^2$

energy non-mechanical wave $\propto$ frequency. *

EM radiation is caused by a rapidly oscillating electric charge.
(a classical (non-quantum) approach to waves...)



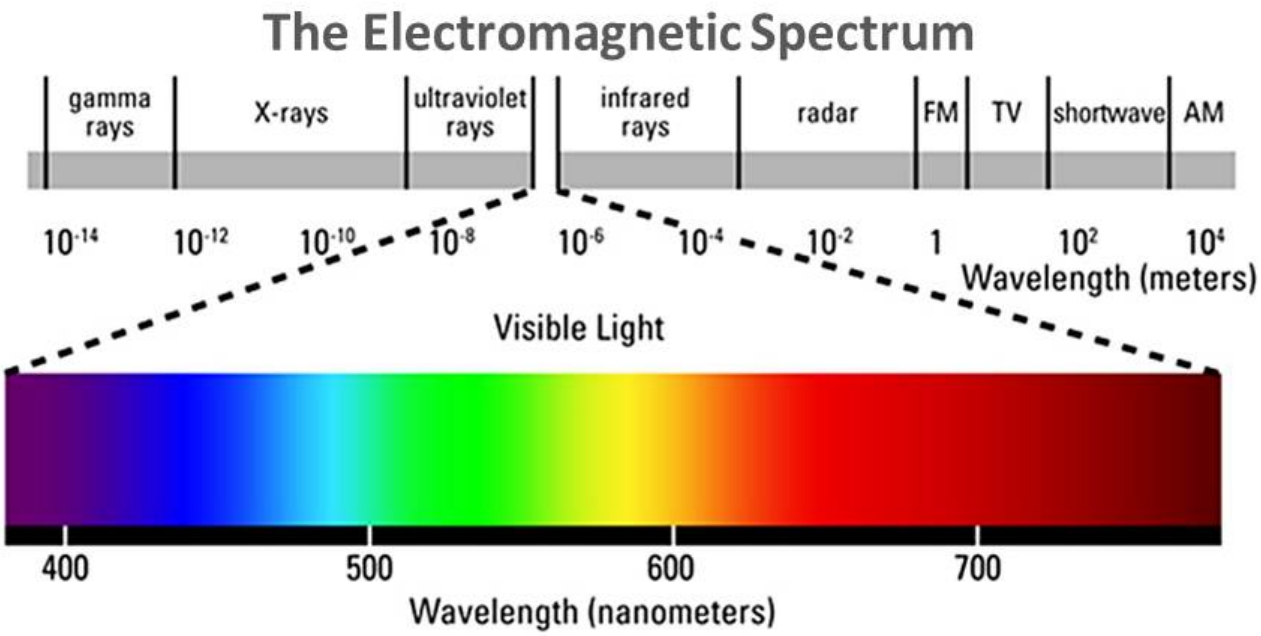
# of ups & downs per second is frequency (Hz)

Universal Wave Equation

$$V = f\lambda$$

$$V = C = 3.0 \times 10^{8}\ m/s$$

Properties of Electromagnetic (EM) waves.

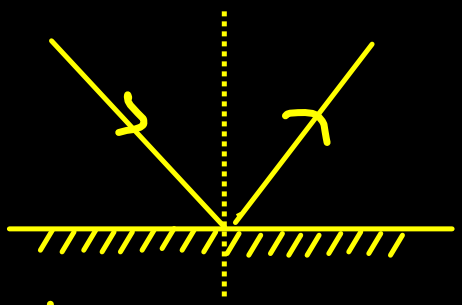


ElectroMagnetic Wave Phenomenon

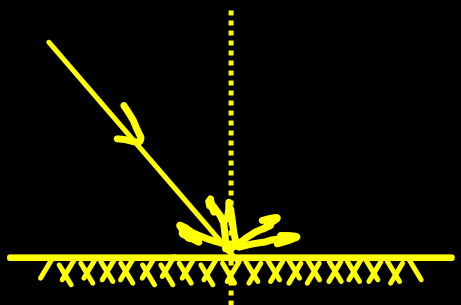
1. Reflection
2. Diffraction
3. Refraction
4. Interference
5. Polarization

ElectroMagnetic Wave Phenomenon

1. Reflection



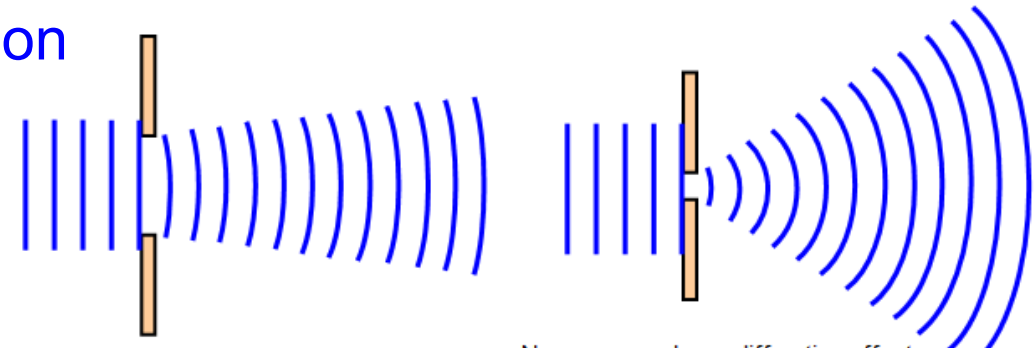
mirror
→ Specular Reflection



paper, walls
→ Diffuse Reflection

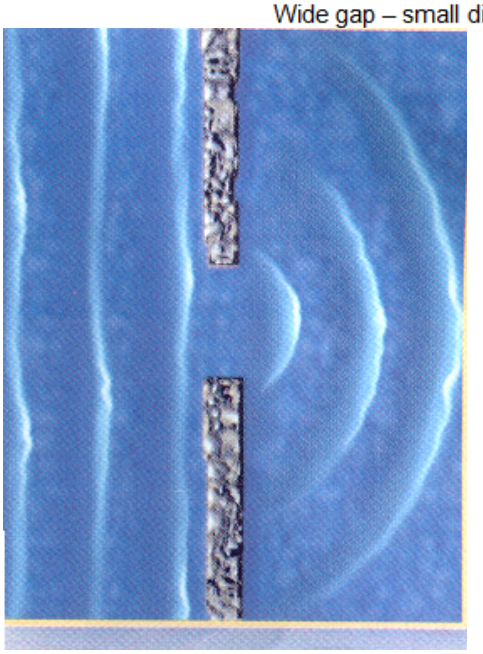
laser
reflectance
→ 99.9%

2. Diffraction



Wide gap – small diffraction effect

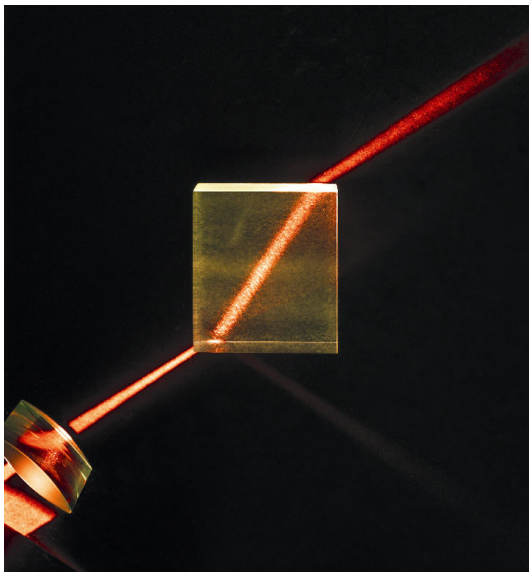
Narrow gap – large diffraction effect



Diffraction is the spreading out of light waves as the waves propagate thru a gap (or past an edge)

amount of diffraction depends on λ (wavelength)

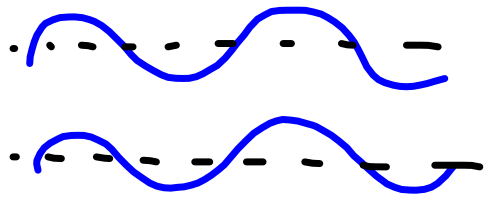
3. Refraction



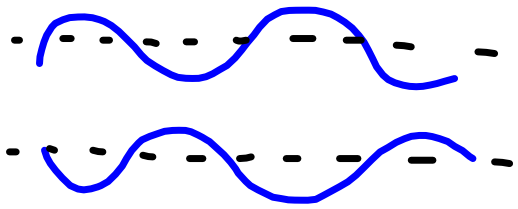
Bending of light as it moves from one material to another.
(when the refractive index changes)

4. Interference

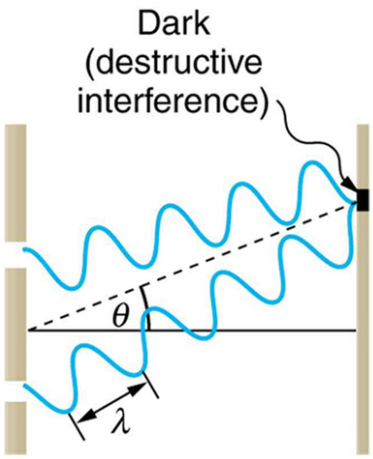
E-M waves can interfere constructively or destructively



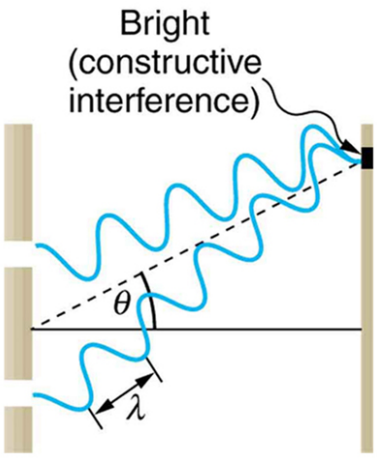
Constructively Interfere



Destructive Interference.



(a)

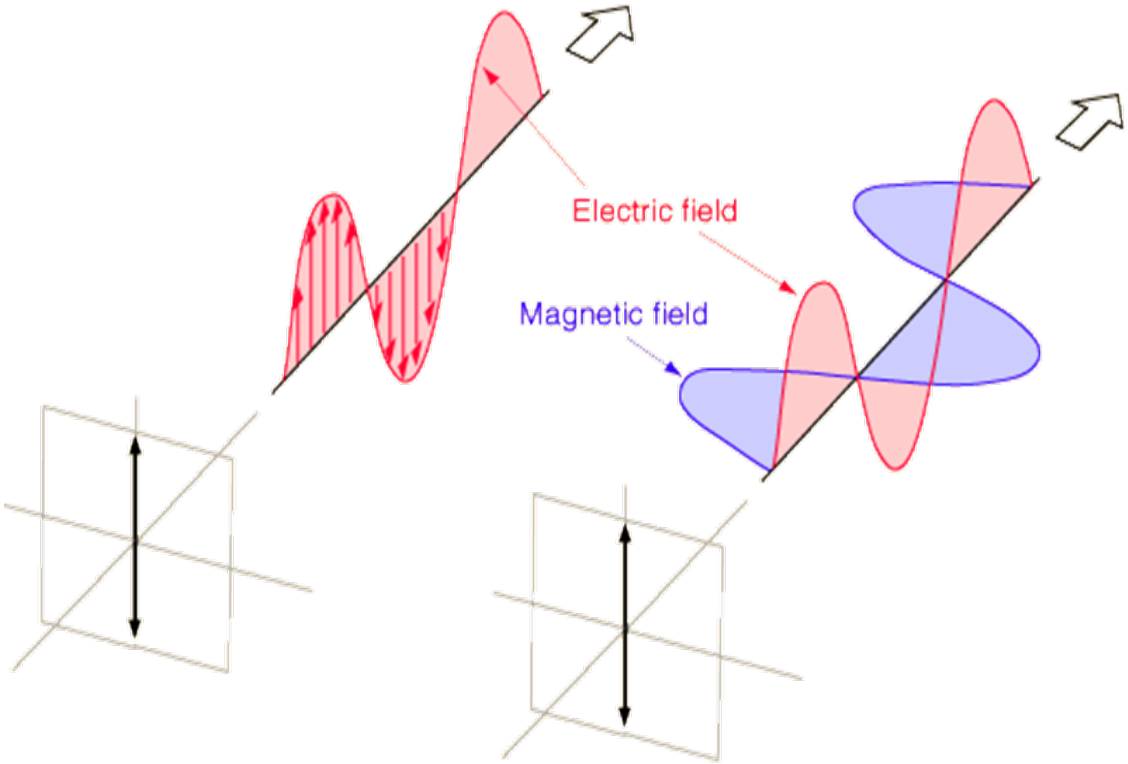


(b)

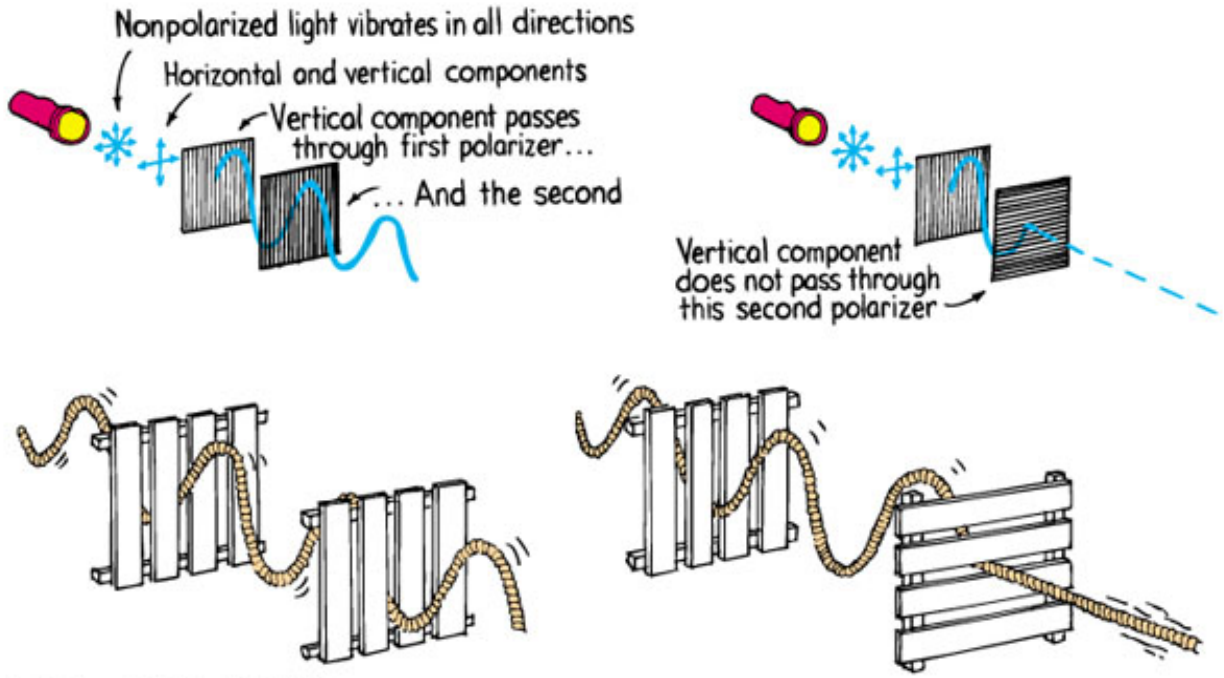
5. Polarization

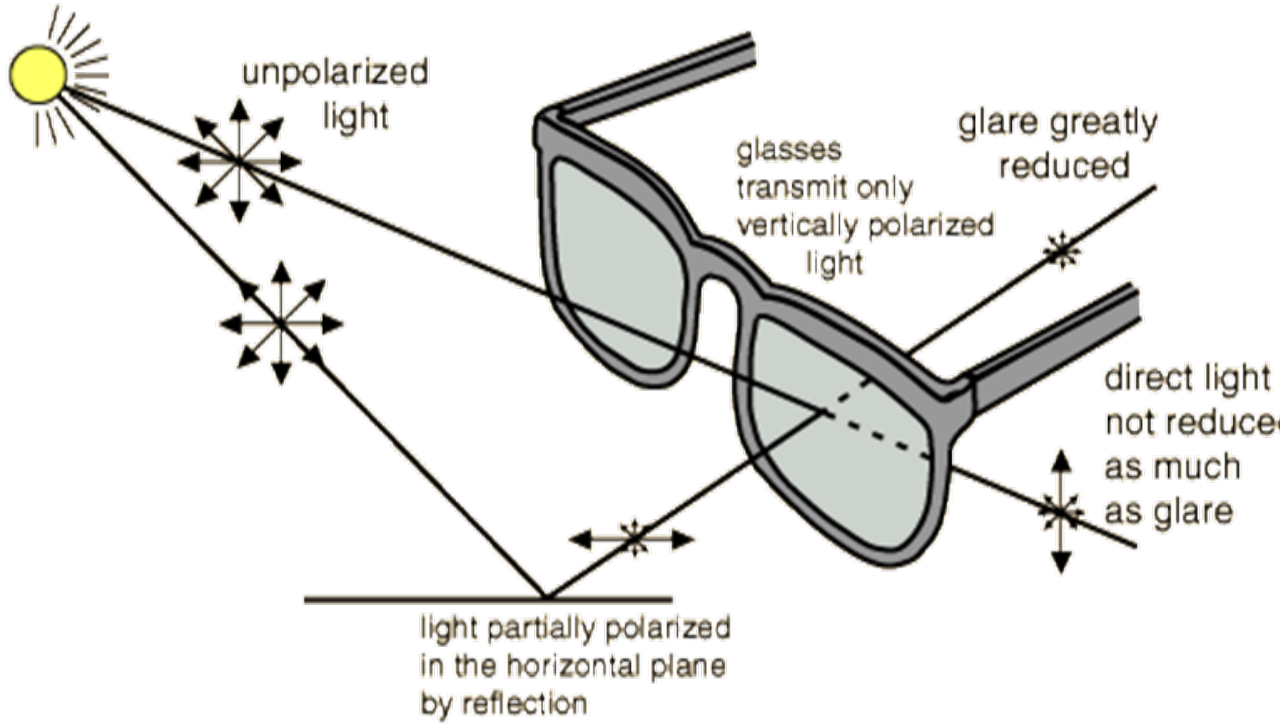
refers to the orientation of the $\vec{E}$ field.

→ normal light (sunlight, room lighting) is randomly polarized



5. Polarization (cont'd)

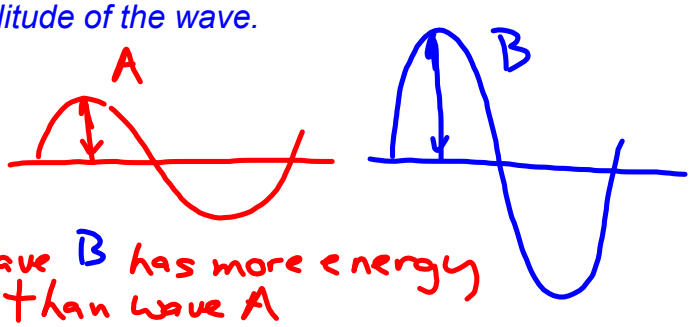




Wave Nature of Light : Operation of a Laser

Energy of Waves.

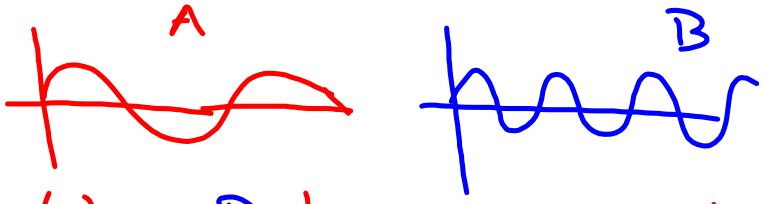
The energy of a mechanical wave is dependent on the amplitude of the wave.



Wave B has more energy than wave A

Energy of Electromagnetic (EM) waves.

The energy of an EM wave is directly proportional to the frequency of the wave. (discovered in late 1800's)

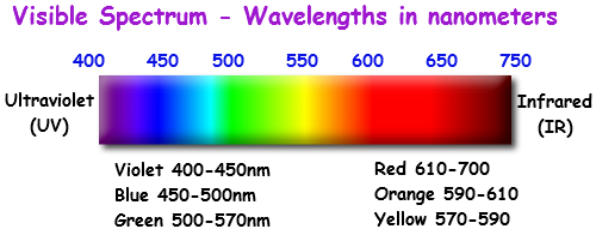


Wave B has more energy than wave A.

$E = hf$

energy (J) ↑ — ↑ Planck's Constant $= 6.626 \times 10^{-34}$ J·s — ↑ frequency (H_3)

→ this formula gives you the energy of a single photon of light at a given frequency.



Energy of Electromagnetic (EM) waves. $1nm = 10^{-9}m$

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

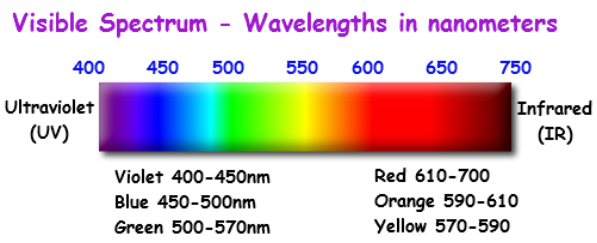
recall $v = f\lambda$, $f = \frac{v}{\lambda} = \frac{c}{\lambda}$

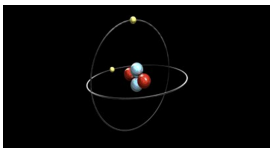
$$E = hf = h\frac{c}{\lambda}$$

$$= \frac{6.626\times10^{-34}\,J\cdot s \times 3.0\times10^{8}\,m/s}{(650\times10^{-9}\,m)}$$

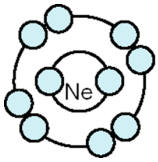
$$= 3.1\times10^{-19}\,J$$

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





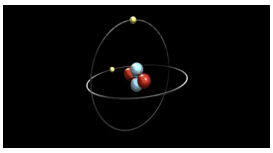
Operation of a Laser



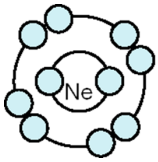
Light Amplification by Stimulated Emmission of Radiation

4 Requirements

1. Lasing medium ✓
2. Optical cavity ✓
3. Laser pumping energy.
4. Output coupler.

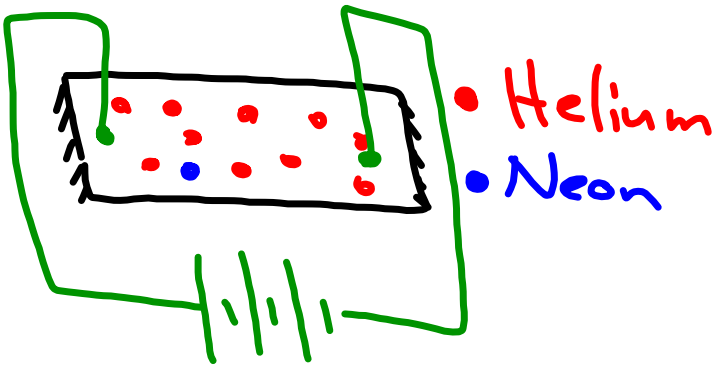


Operation of a Laser

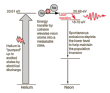


HeNe Laser Design Basics

Helium Neon Gas (10:1 ratio)



1. Lasing Medium



relies on atoms absorbing energy & re-emitting the energy in the form of visible light.

→ when a neon atom loses energy (i.e. an electron changes energy levels)

* 1.96eV of energy is released in the form of radiation.

eV - electron volt.

$1eV = 1.602 \times 10^{-19} J$

① Energy in Joules

$1.96eV \times 1.602 \times 10^{-19} J/eV$

$= 3.14 \times 10^{-19} J$

② find frequency

$E = hf \rightarrow f = \frac{E}{h} = \frac{3.14 \times 10^{-19} J}{6.626 \times 10^{-34} J \cdot s}$

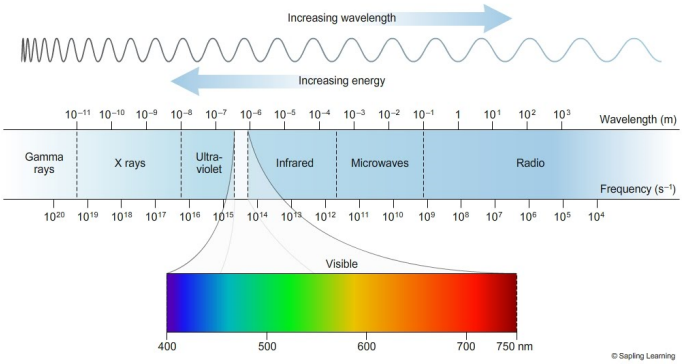
$= 4.74 \times 10^{14} Hz$

③ $c = f\lambda \rightarrow \lambda = \frac{c}{f} = \frac{3.0 \times 10^{8} m/s}{4.74 \times 10^{14} Hz}$

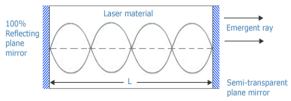
$= 6.33 \times 10^{-7} m$

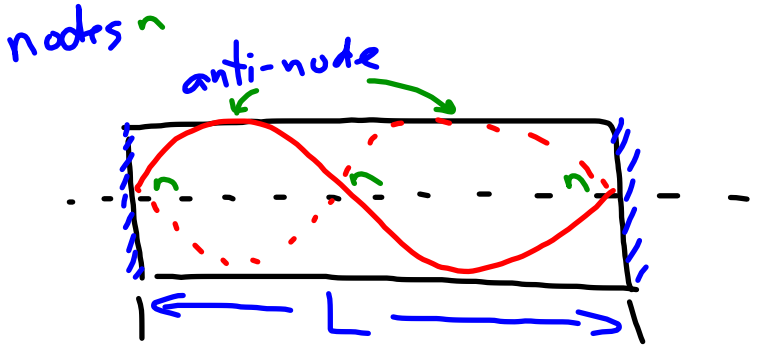
$= 633 nm$

* actual wavelength 632.8 nm



2. Optical Cavity





mirrored ends act as nodal points.

Length (L) of optical cavity must be an integer multiple of ½ wavelengths.

$L = n(\frac{1}{2}\lambda)$ n → any integer

let n = 100

$L = 100(\frac{1}{2}\ 632.8\text{nm})$

$= 31640\text{nm}$

$= 31.640\ \mu\text{m}$ ÷1000

$= 0.031640\ \text{mm}$ ÷1000

let n = 800 000

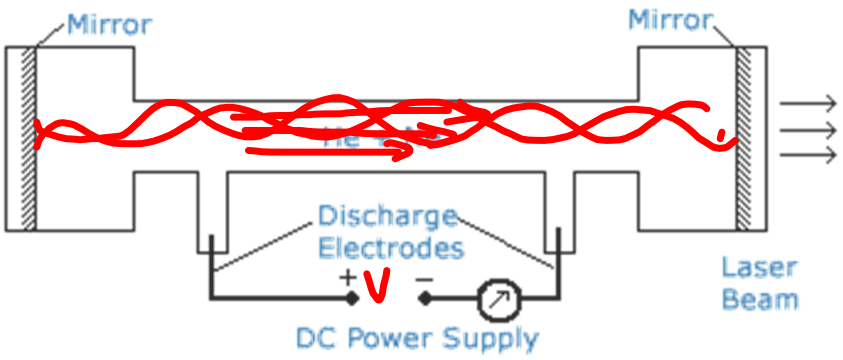
$L = 800000(\frac{1}{2}\ 632.8\text{nm})$

$= 0.25312\ \text{m}$

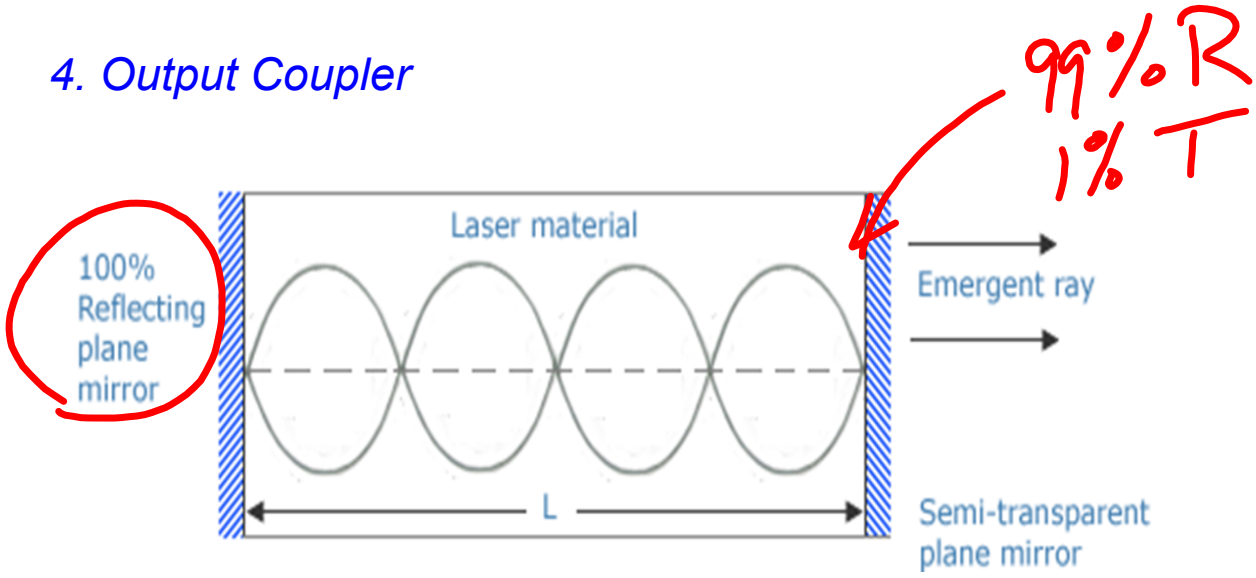
or

$25.312\ \text{cm}$

3. Laser Pumping Energy



4. Output Coupler



Laser Pointer

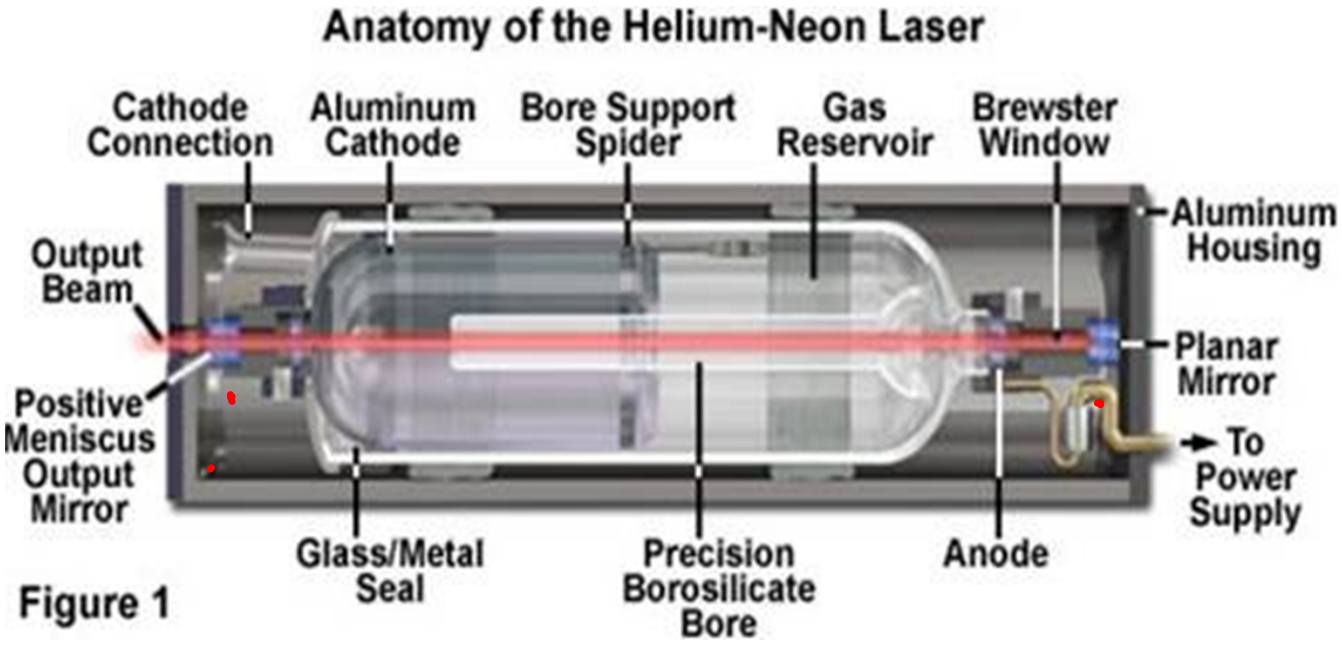

Anatomy of the Helium-Neon Laser
Cathode Connection
Aluminum Cathode
Bore Support Spider
Gas Reservoir
Brewster Window
Aluminum Housing
Output Beam
Planar Mirror
Positive Meniscus Output Mirror
To Power Supply
Glass/Metal Seal
Precision Borosilicate Bore
Anode

Figure 1

Summary of Laser Operation

Light Behaving as a Wave (Classical Physics)

length of laser is determined by setting up a standing wave (constructive interference) inside the optical cavity.

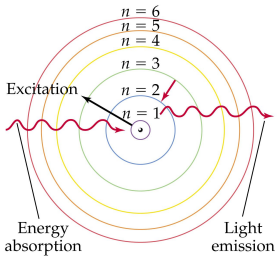
Light Behaving as a Particle (Modern Physics)

energy of a photon is directly proportional to frequency

→ emmission energy dictated the photon's frequency. (colour).

Design an Argon Laser

1. what colour is the laser beam?
2. determine how far apart to place the mirrors in an argon laser

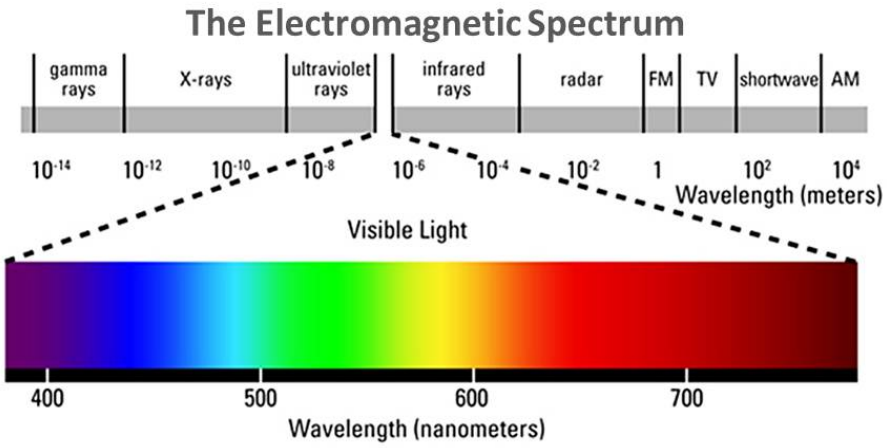


design criteria:

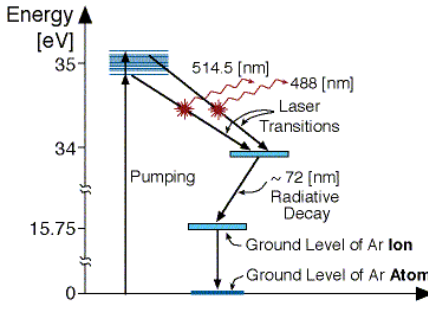
lasing medium - argon gas

emission energy - 2.54eV

Optical Cavity, set n = to 800,000

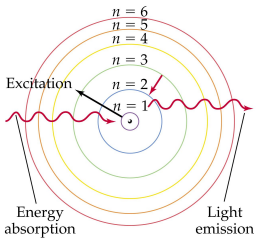


https://perg.phys.ksu.edu/vqm/Laserweb/Ch-6/F6s1t4p1.htm



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:

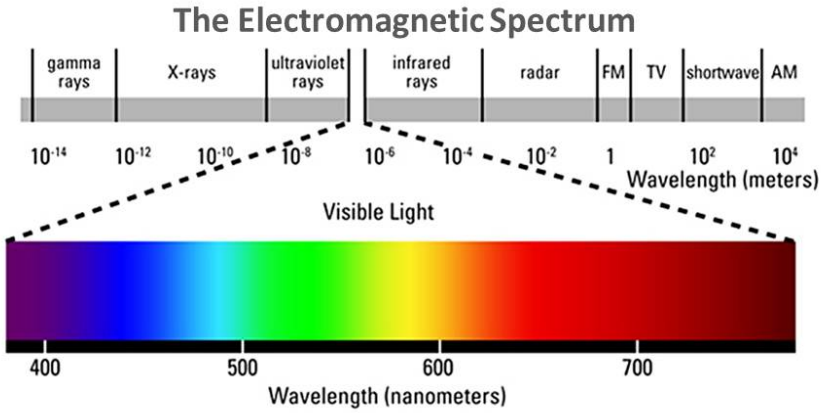
lasing medium - argon gas

emission energy - 2.54eV

Optical Cavity, set n = to 800,000

$1eV = 1.602 \times 10^{-19} J$

$1m = 10^9 nm$



$E = 2.54eV = 4.069 J$

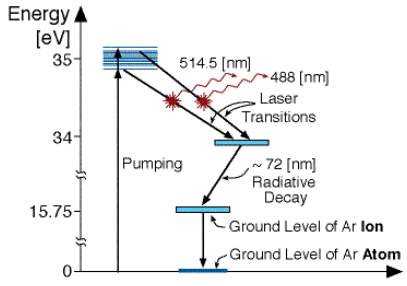
$f = \frac{E}{h} = 6.141 \times 10^{14} Hz$

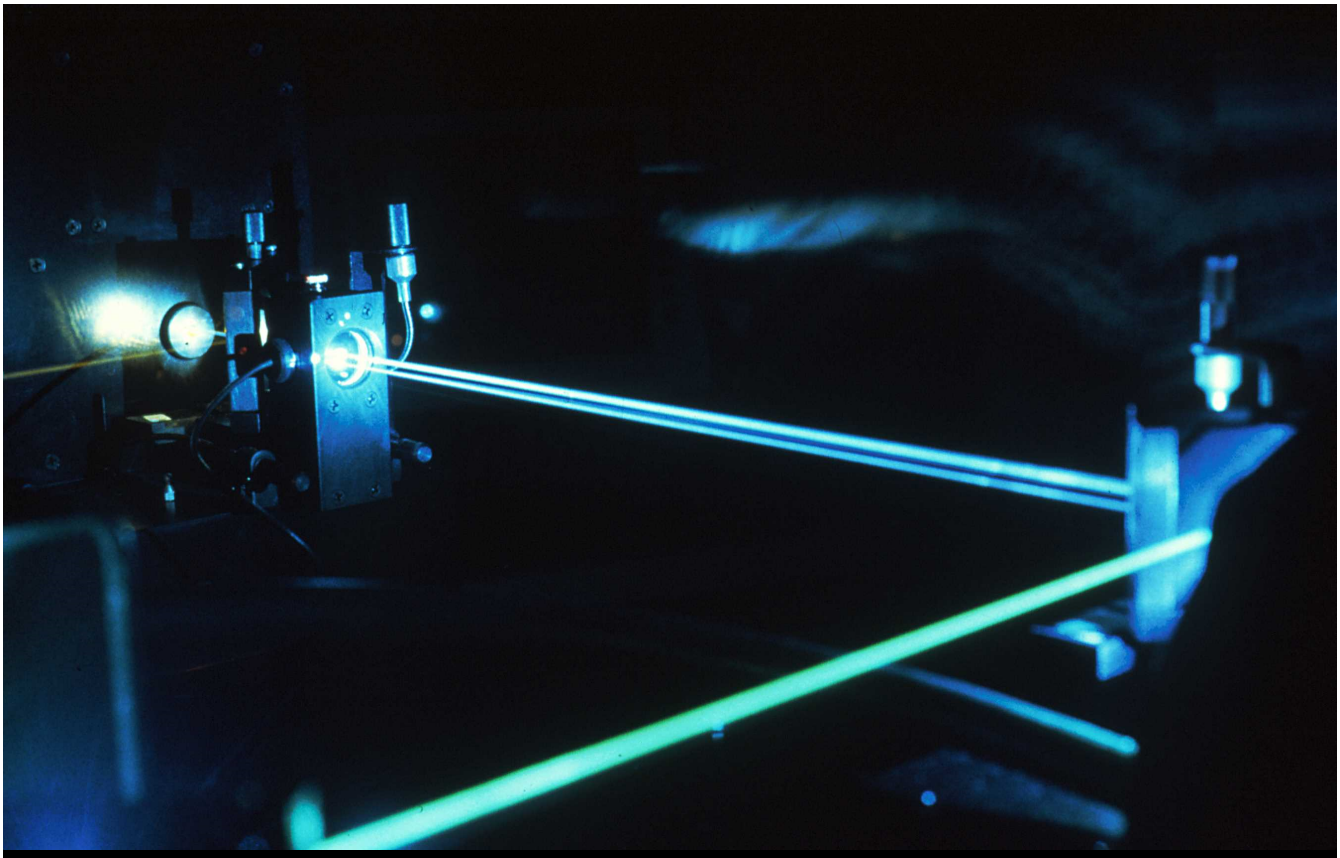
$\lambda = \frac{c}{f} = 488.5 nm$ 0.000000488

$L = \frac{n\lambda}{2} = 19.54 cm$

cdoa- light blue/teal.

https://perg.phys.ksu.edu/vqm/Laserweb/Ch-6/F6s1t4p1.htm



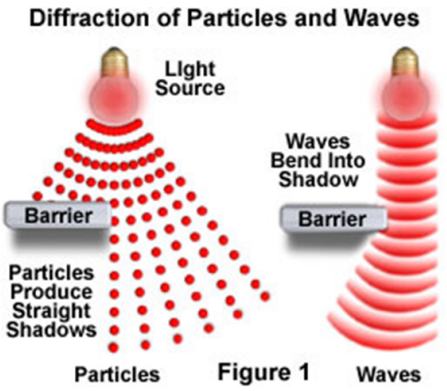


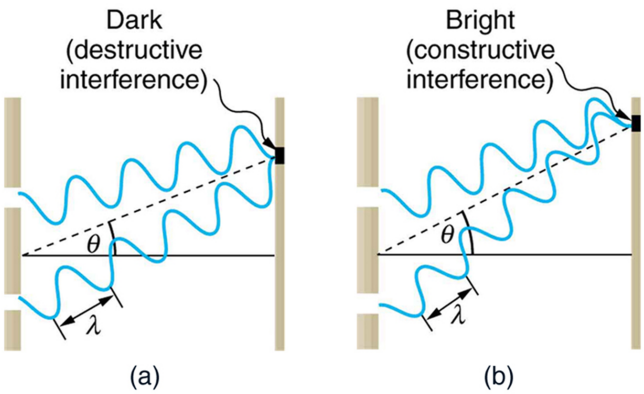
Modern Physics Concepts

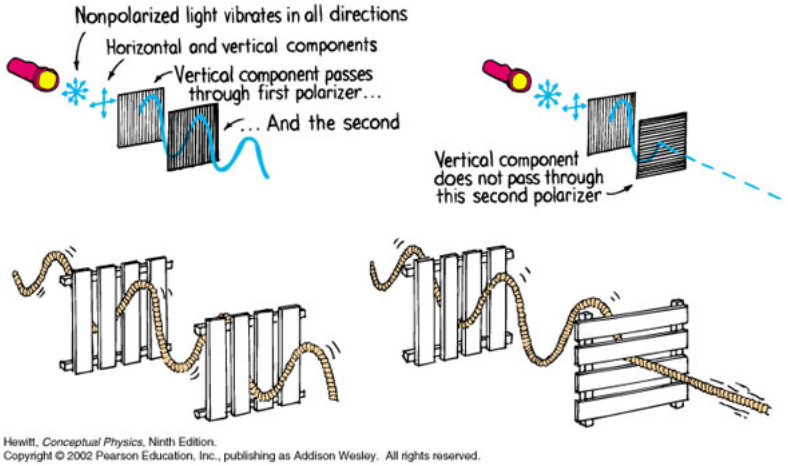
Wave Particle Duality - is light a wave or a particle?

Wave / Particle Duality of Light

diffraction, interference and polarization can only be explained by wave model

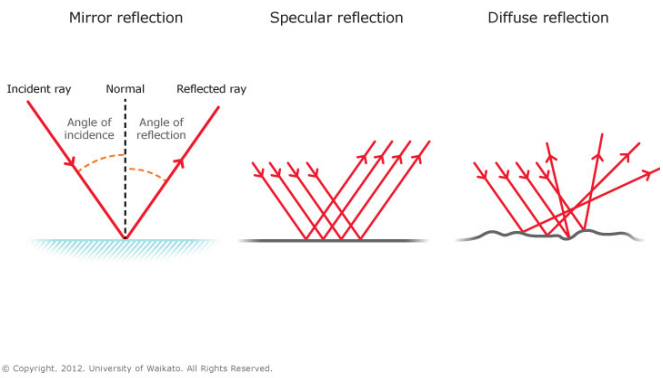




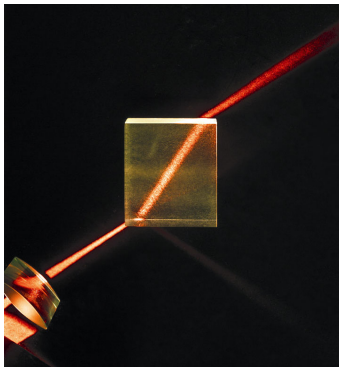


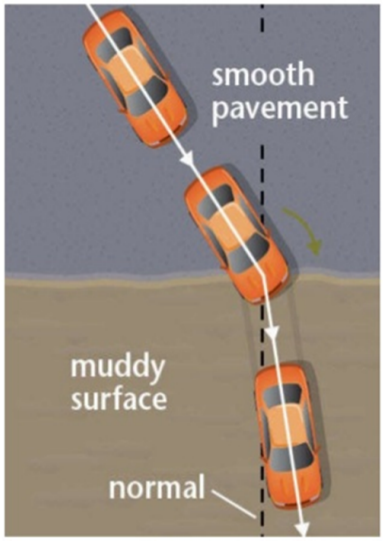
Wave / Particle Duality of Light

reflection and refraction can be explained by wave model or a particle model of light



Cause of Refraction

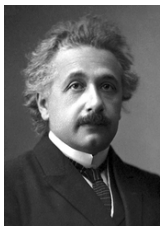




Car Analogy

- Car travelling at an angle towards a muddy surface
- One front wheel hits muddy surface and slows down
- Other wheels continue to move at a higher speed
- Causes the path to bend

Wave / Particle Duality of Light:



Einstein *"It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."*

Property	Classical: Wave Theory	Modern: Particle Theory
Reflection (bounce)	✓	✓
Diffraction (spreading out)	✓	X
Refraction (slowing down, bending)	✓	✓
Interference (constructive & destructive)	✓	X
Polarization (orientation of $\vec{E}$ field)	✓	X
Emission Spectrum	X	✓