INDIANHILLS COMMUNITY COLLEGE

NSF

Basics of Photonics Fundamentals (lasers & optics)

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Life. Changing.

WELCOME & THANK YOU FOR YOUR INTEREST

This presentation will cover the following.

- Intro: Motivation, Photonics Occupations & Industries
- Mod #1: Light & the Nature & Properties of Light
- Mod #2: Optical Components & Handling
- Mod #3: Basic Laser Safety
- Mod #4: Geometrical (RAY) Optics
- Mod #5: Physical (WAVE) Optics
- Mod #6: Principles of Lasers

Modules are from the text *Fundamentals of Light & Lasers*

Motivation

- Currently the U.S. laser & optics technician demand is ~2000 *entry level* positions per year with ~20% filled.
- The medical/bio-science area is the fastest growing followed closely by manufacturing.
- IHCC's Laser & Optics 2020 graduates received an average starting salary of $61,800.00.
- WE must market lasers & optics to our students.
- IHCC's NSF ATE Grant has the main objective of increasing the number of Photonics Techs in the U.S.
- One way to do that is to introduce teachers to the world of photonics.
  - **Therefore, this opportunity is provided for you to learn more about lasers & optics with hope that you will include it in your course work.**

Motivation

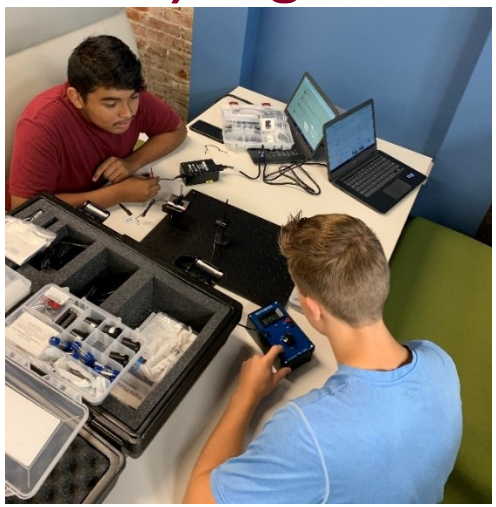
Albia High School

Centerville High School

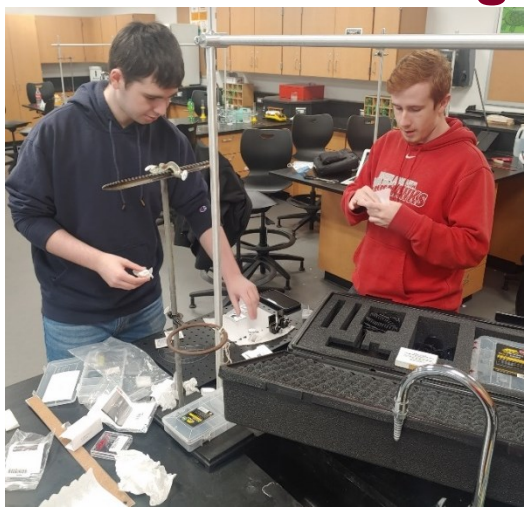
Davis County High School

Hybrid (online & hands-on) High School Photonics Training

Davis County High School

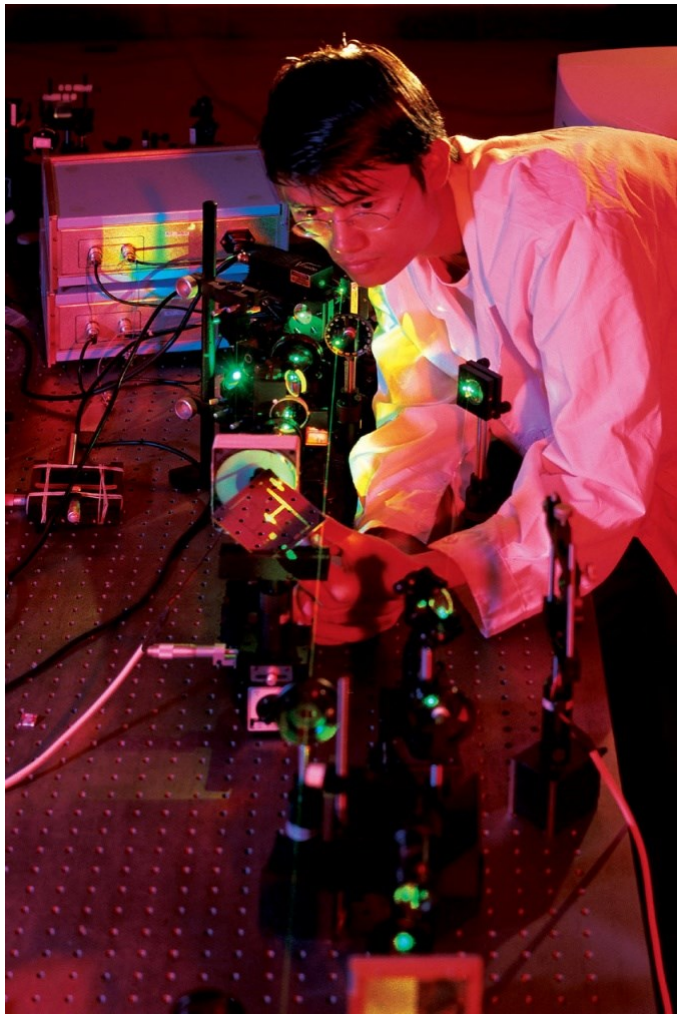


Ottumwa High School



North Mahaska High School

Photonics Occupations



- Laser Technician
- Optics Technician
- Research & Development Technician
- Field Service Engineer
- Applications Technician
- Sales Engineer
- Plus a plethora or others

Photonics Industries

- Aerospace
- Agriculture
- Communication
- Computers
- Energy
- Entertainment
- Environmental
- Manufacturing
- Medicine, Bio-Medicine
- Nanoscience
- National/Public Defense
- Research & Development
- Transportation
- Plus a plethora of others

DRS DAYLIGHT SOLUTIONS
Mid-IR Lasers, Sensors & Systems

BAE SYSTEMS

ADAPT LASER SYSTEMS

IDEX HEALTH & SCIENCE

LUMENIS
Enhancing Life. Advancing Technology.

Medtronic

COHERENT

mks

LAWRENCE LIVERMORE NATIONAL LABS:
National Ignition Facility

TRUMPF

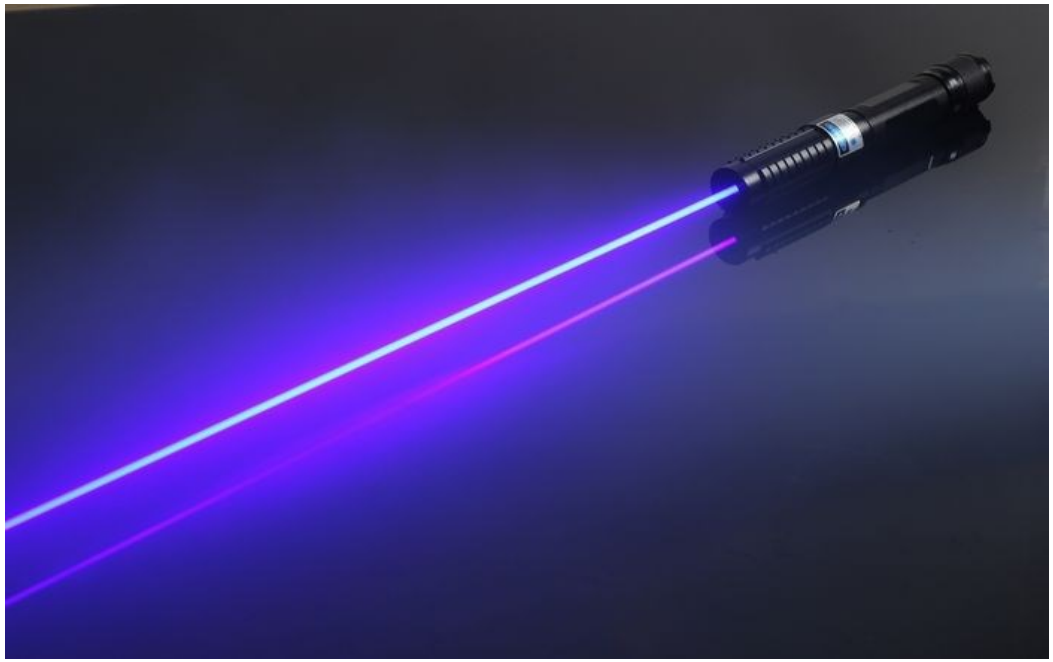
Mod #1: Light

- Photons (particles of light) exists everywhere at the same time.
- It is a form of energy emitted from a source that reacts with all materials in one way or another.

Light

Laser Light

- Monochromatic: Single frequency or single color
- Collimated: very low in divergence and unidirectional
- Coherent: photons travel in phase
- High Intensity or radiant power per unit area (irradiance)
  - Creates a demand for laser safety.



Wavelength

- Distance over which a wave repeats
- Measured in meters.
- Wavelengths are on the order of a few hundred Nanometers (10^{-9})
- A value not visible to the naked eye

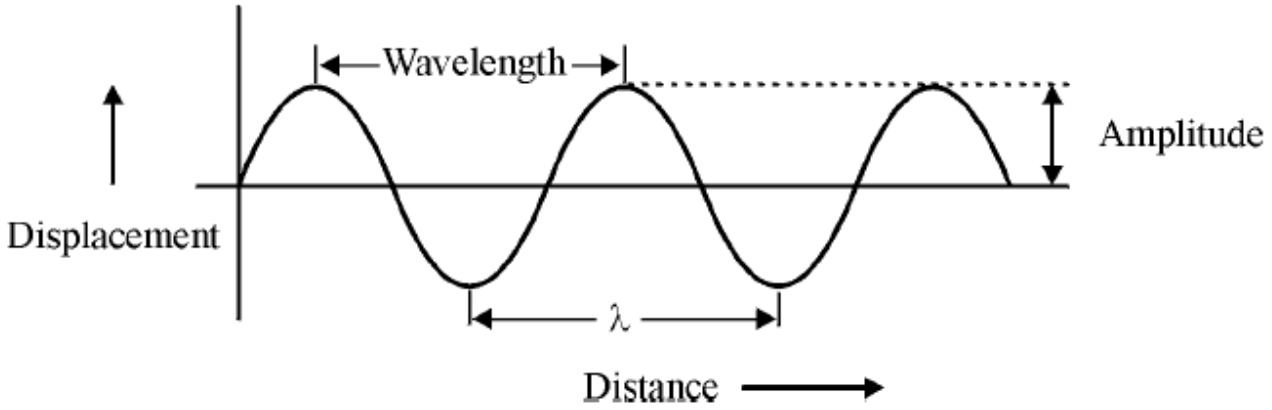
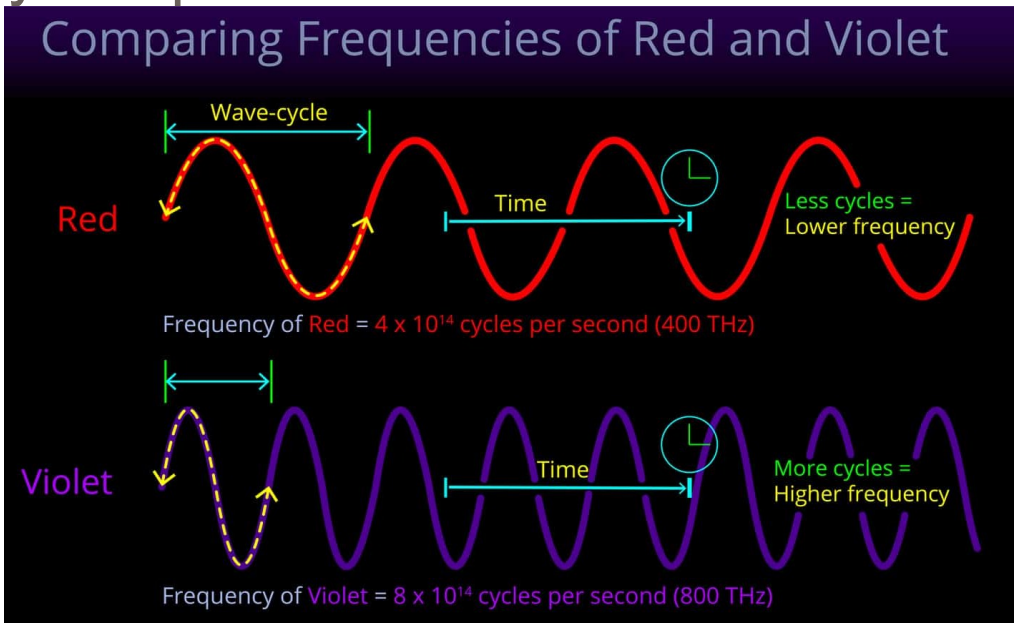


Figure 1-1 *Displacement versus distance along a wave at an instant of time*

Frequency

- The number of times a wave repeats itself in one second.
  - # of cycles per time
- Never changes
  - Wavelength and speed of light can change
- Frequency and color are directly correlated
  - 566 THz is green light at 530 nm at 3.0 X 10^8 m/s
- Represented by Hertz or cycles per second.

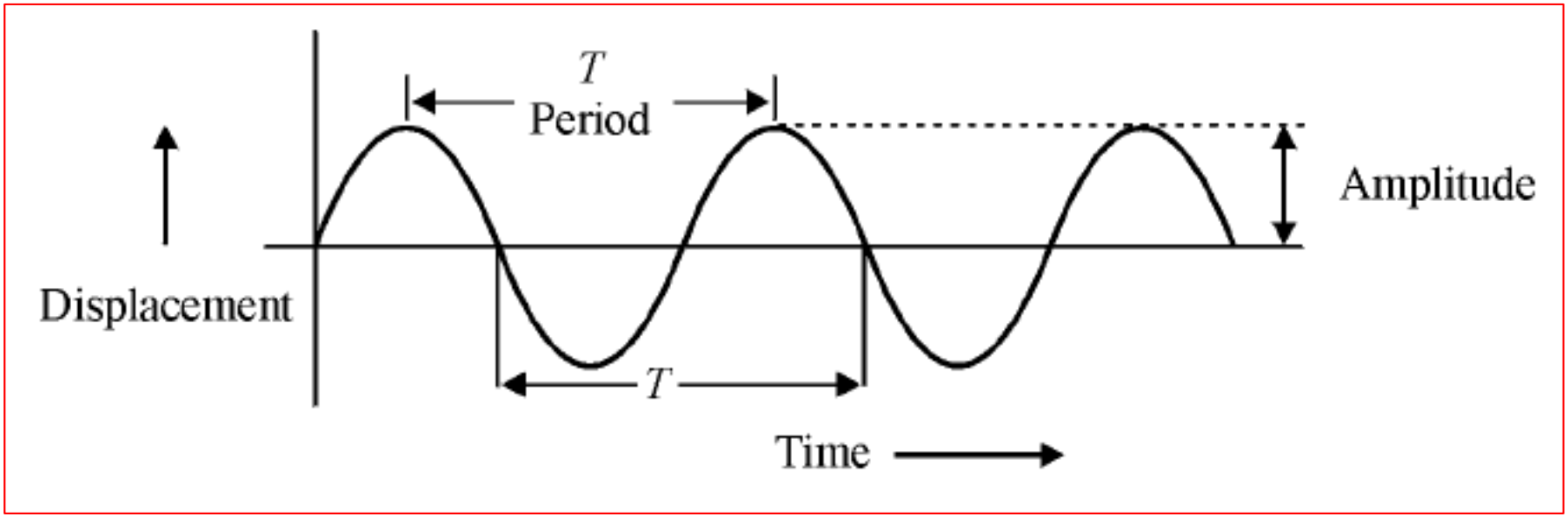


Speed

- Wave velocity is distance traveled per unit of time
- When ALL light is traveling through a vacuum it travels at the same speed or the speed of light.
- 300 million meters per second or 186,284 miles per second which is around 670 million mph.
- Light from the Sun takes a little over 8 minutes to reach Earth.

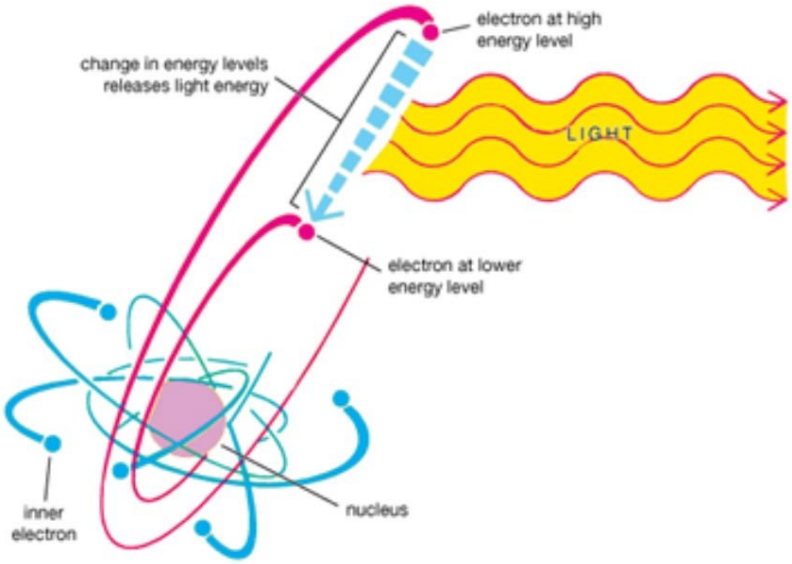
Period - Amplitude

- Period - time over which a wave repeats itself
- Amplitude - maximum displacement of the wave from a certain reference point.

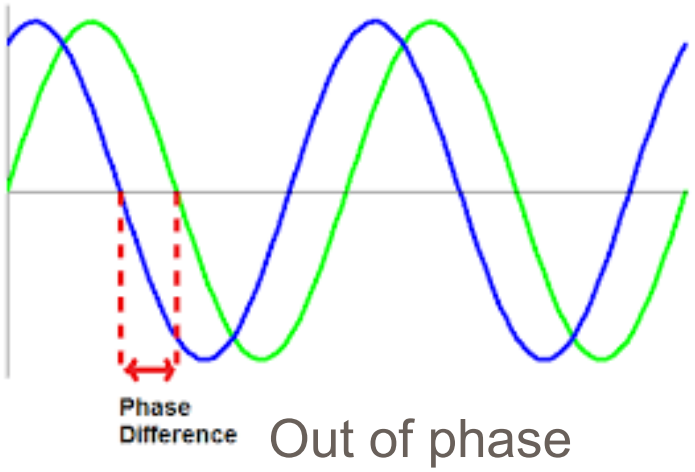


Energy - Phase

- Each photon generated has a specific direction, *energy*, frequency, polarization, wavelength, and phase.
- The higher the frequency, the greater the energy.
- Light energy is the only form of energy visible to the human eye



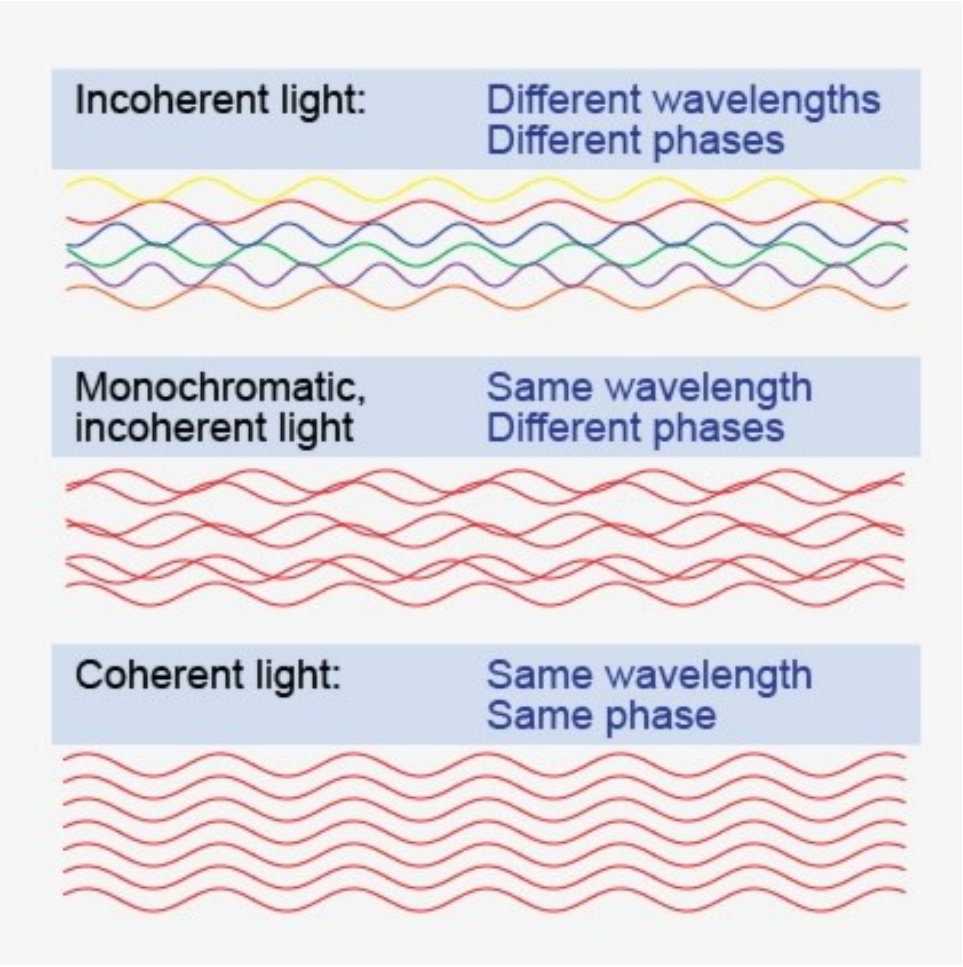
- Phase: point of angular displacement in radians or degrees at a particular time.
- Involves the position relationship of two waveforms.
- In phase: When the peaks of two waveforms with the same frequency are in exact alignment at the same time



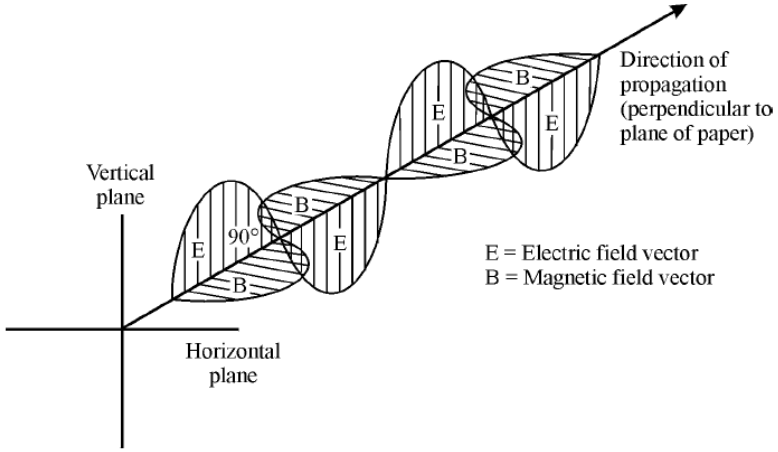
Out of phase

Coherence

- Occurs when most of the light is in step or in phase
- Coherent light is necessary to focus light to create a clear image
- Why we can create holograms and measure chemical makeup of the atmosphere

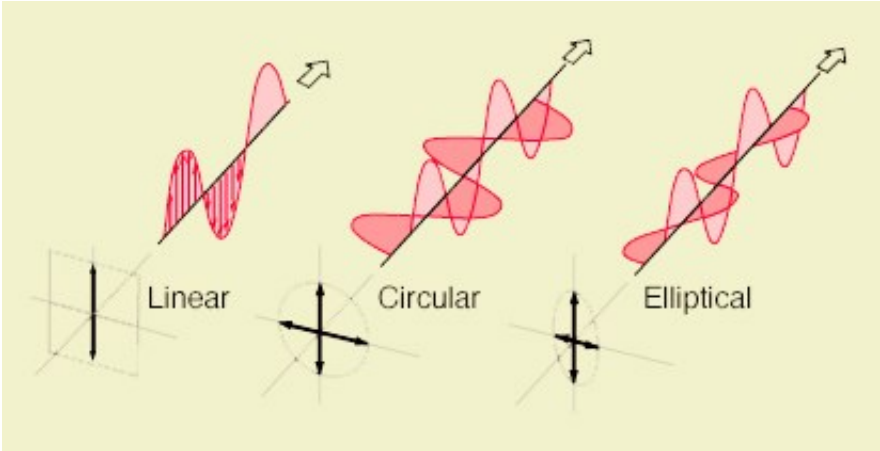


Polarization



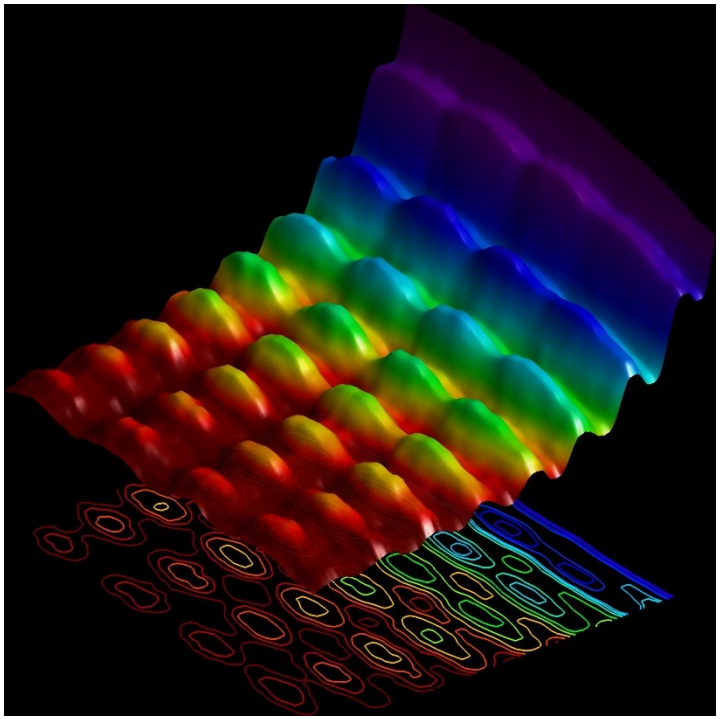
Three dimensional view of an electromagnetic wave.

- Aligning or Controlling the orientation of the E-vectors
- Liner, Circular, and Elliptical polarization



Dual Nature of Light

- Light can be modeled and predicted as a particle or a wave.
- Particle
  - Photon or packet of energy,
- Wave
  - Photons travel in wavelets creating a wave front
- Every photon has a specific energy, phase, frequency, polarization, and direction.

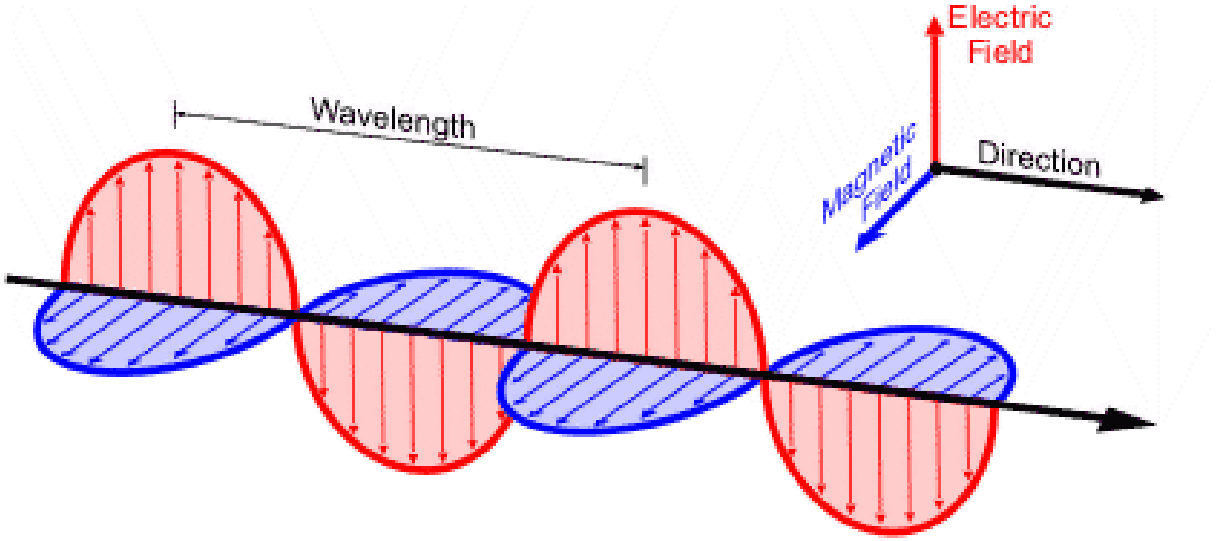


Electro-Magnetic Radiation

- Light Energy moves or propagates via changing electric and magnetic fields

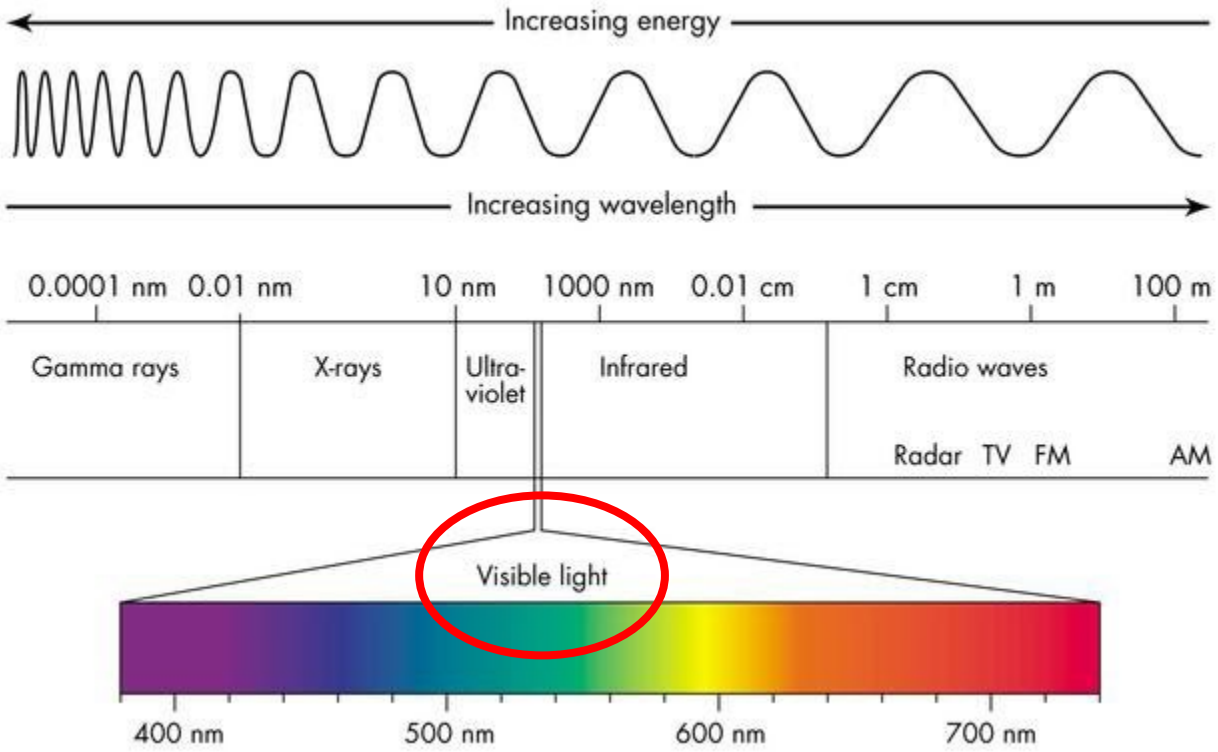
- Oscillations in electric and magnetic fields working together, 90 degrees from each other, and 90 degrees from the direction of propagation

- It travels with no medium required



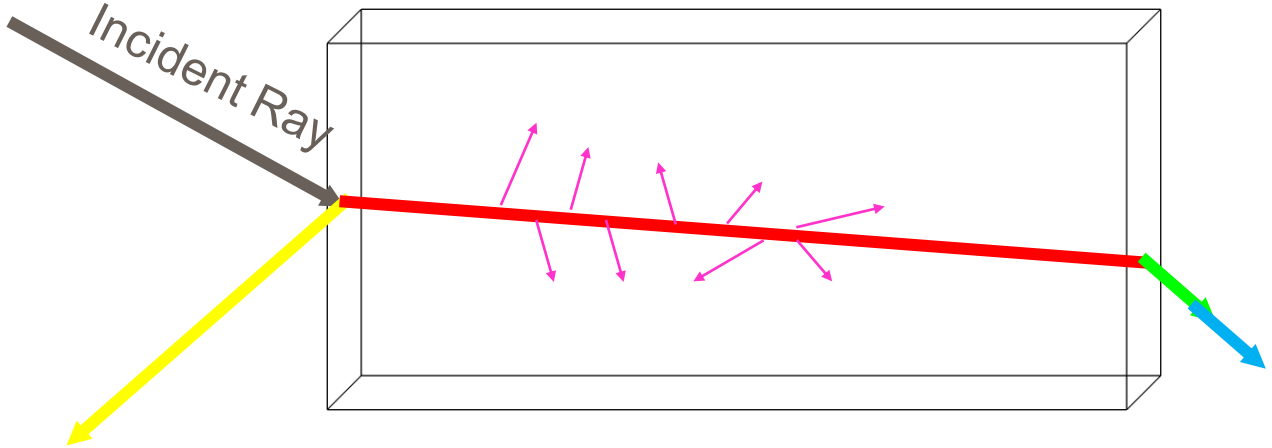
Electro-Magnetic Radiation Spectrum

- In photonics, white light is a mixture of the wavelengths/colors of red, green and blue (RGB).
- Shorter wavelengths = higher frequencies



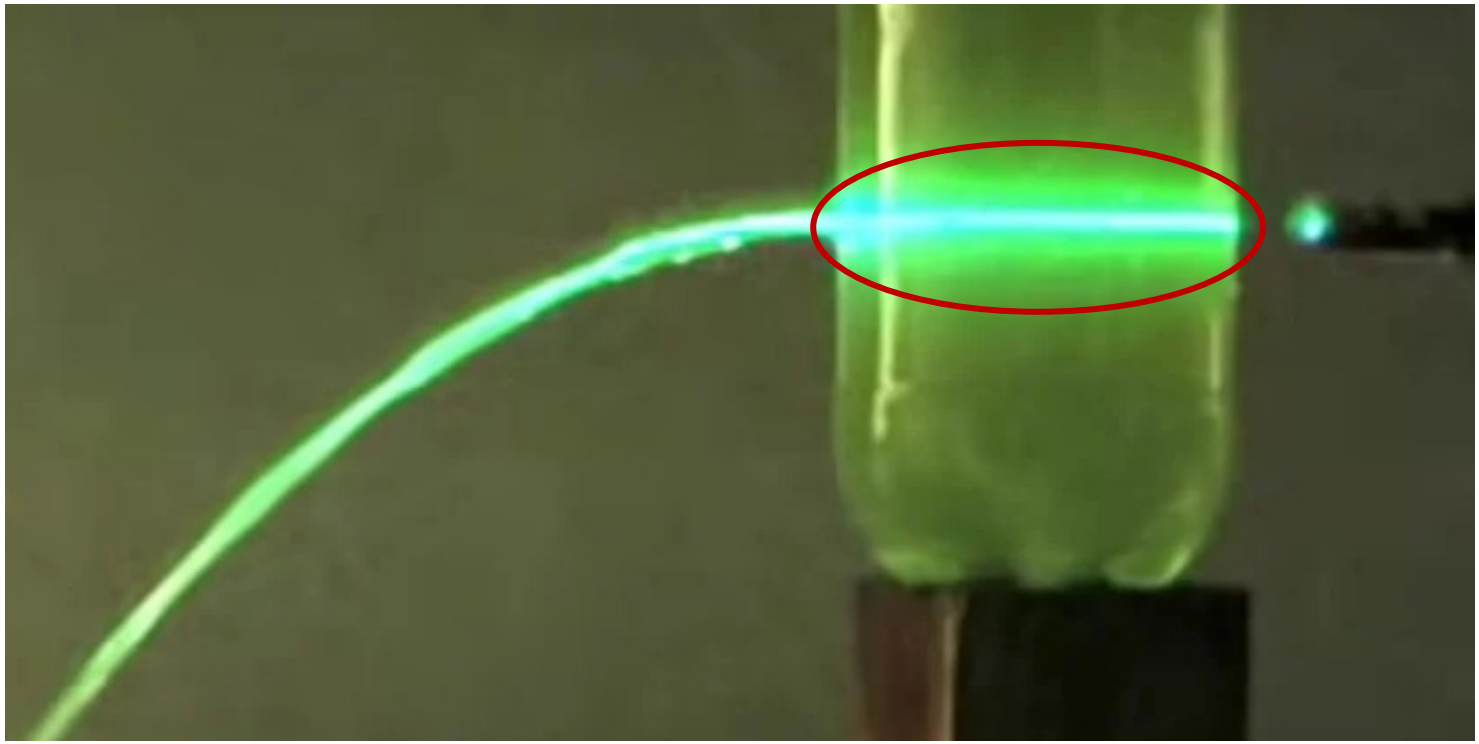
S.T.A.R.R.

- S-T-A-R-R: light incident on and traveling into or through a material will undergo S.T.A.R.R.
  - Scatter
  - Transmit
  - Absorb
  - Reflect
  - Refract



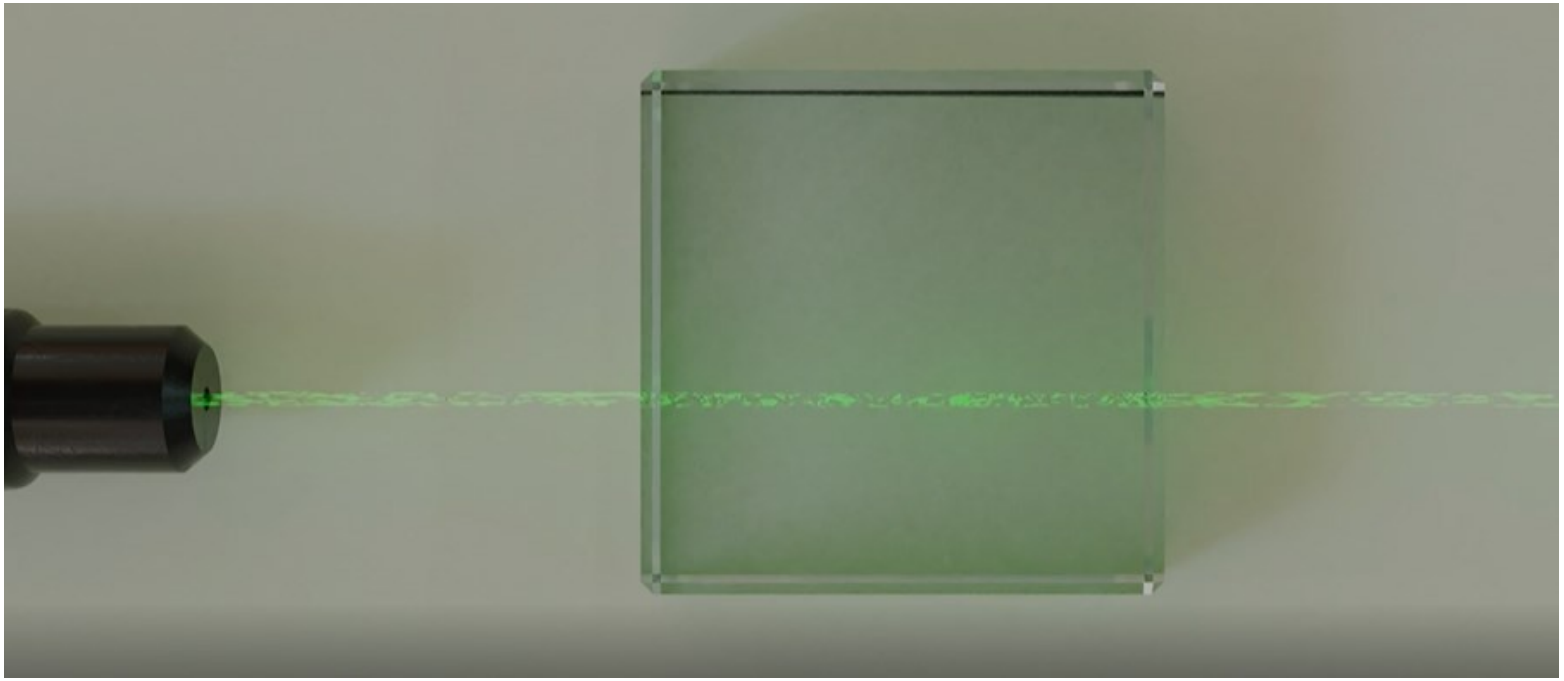
Scatter

- When a beam of light is attenuated by a physical deflection of a photon from the direct beam.
- Happens when light collides with a small molecule
- Wavelength dependent



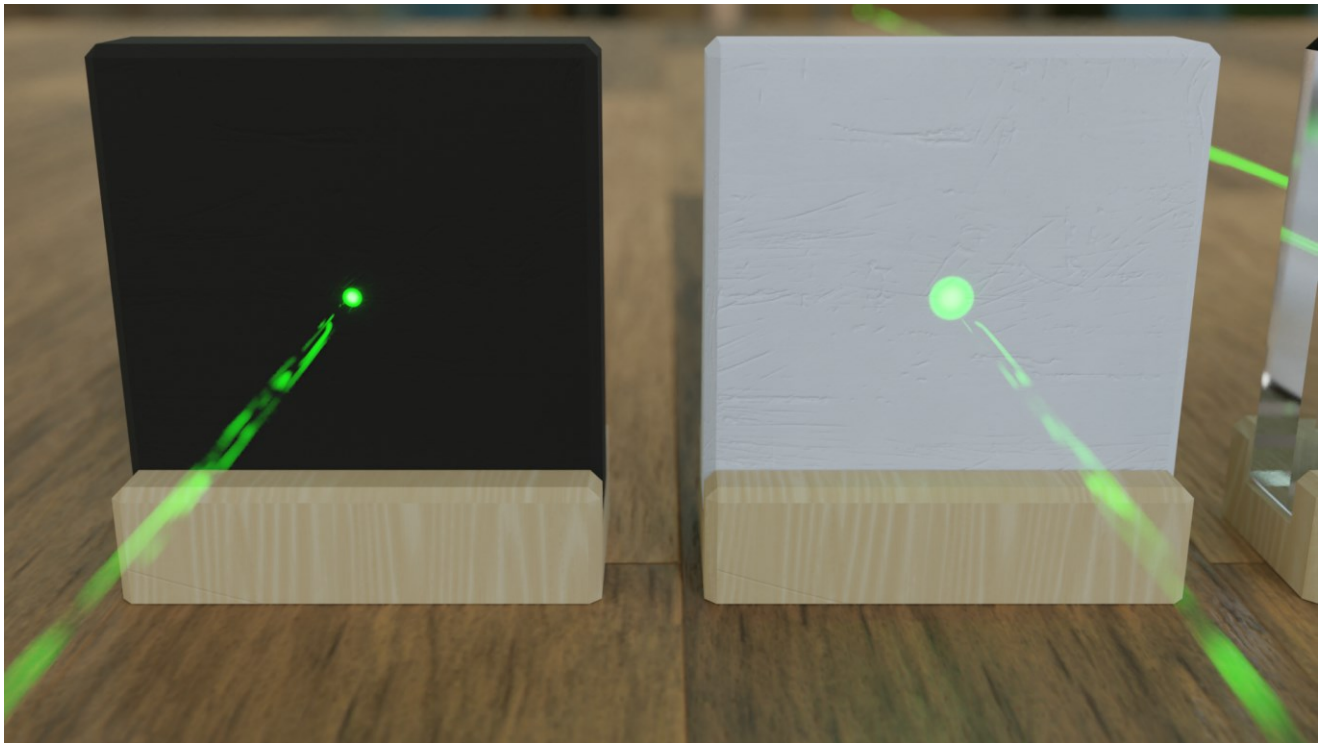
Transmit

- When light transmits through one medium to another, it changes speed and wavelength, but not frequency
- The photo shows straight line transmission with reflection, absorption and scatter thereby decreasing the power out compared to the power in.



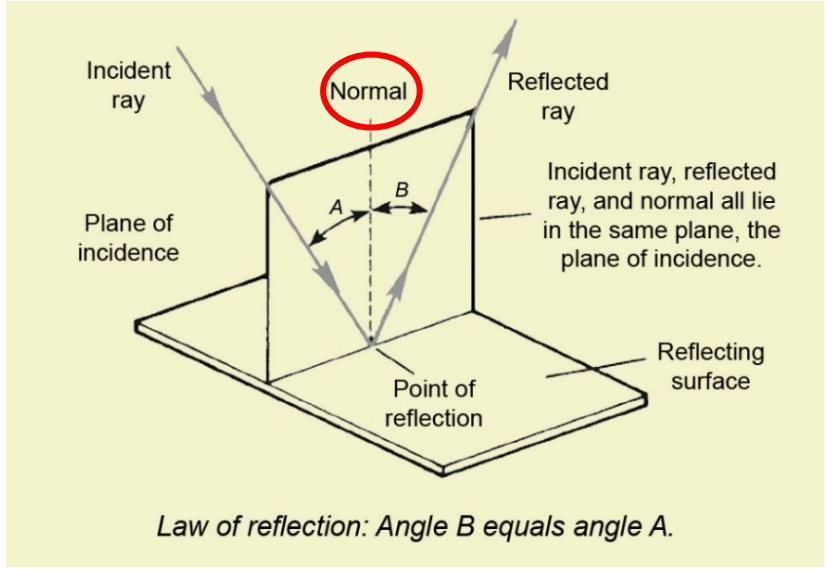
Absorb

- Refers to the “taking up” of radiant energy by an irradiated object
- On the left, the green light is strongly absorbed by the black surface and therefore its reflection is highly diminished.
- On the right, the white surface absorbs less light and therefore reflects more.
- The light spot therefore appears larger and more intense.



Reflection

- If a laser beam is directed onto a mirror, the light beam is deflected with little loss of energy/power.
- Specular Reflection off of smooth surfaces such as mirrors or a calm body of water.
- Diffuse Reflection off of rough surfaces such as clothing, paper, and the asphalt roadway.

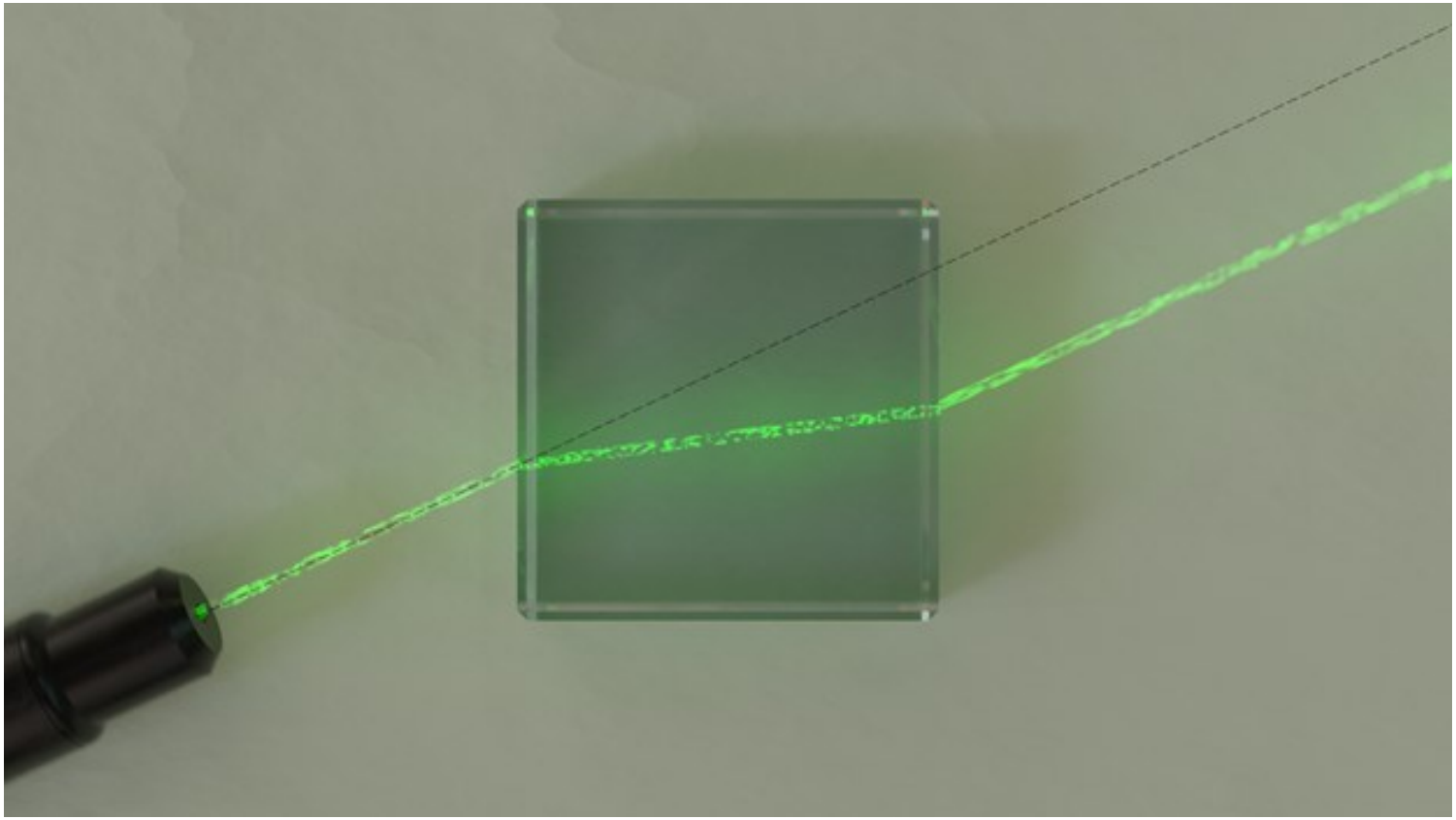


Law of reflection: Angle B equals angle A.

The Law of Reflection: when a ray of light reflects off a surface, the angle of reflection (B) equals the angle of incidence (A) when measured from the Normal.

Refraction

- When a laser beam propagates from one transparent medium into another, its propagation direction will change or be bent therefore changing directions.

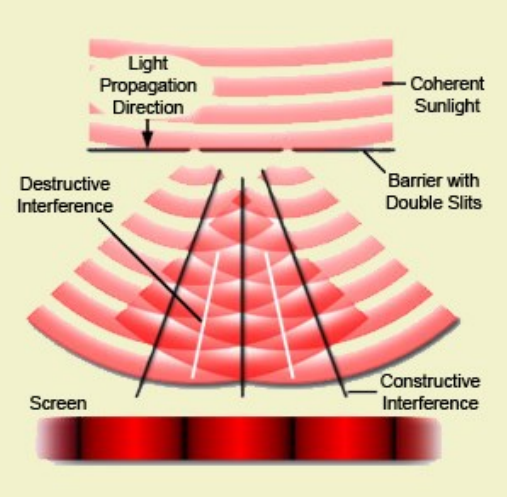


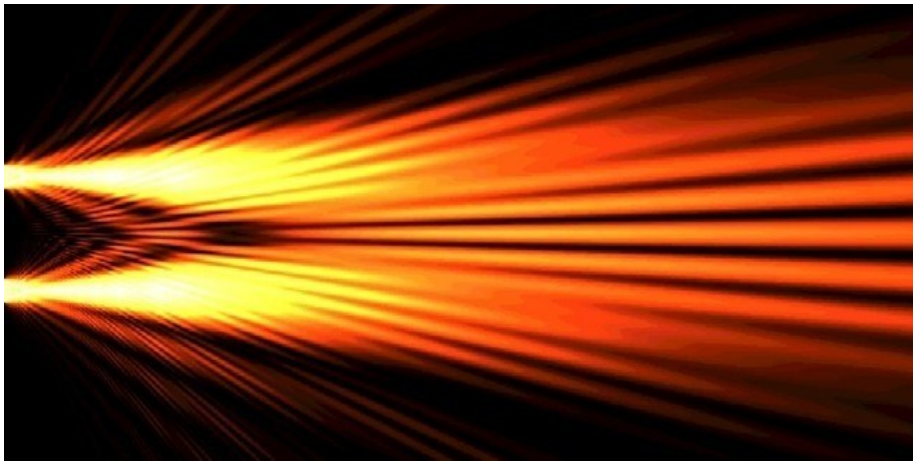
Diffraction

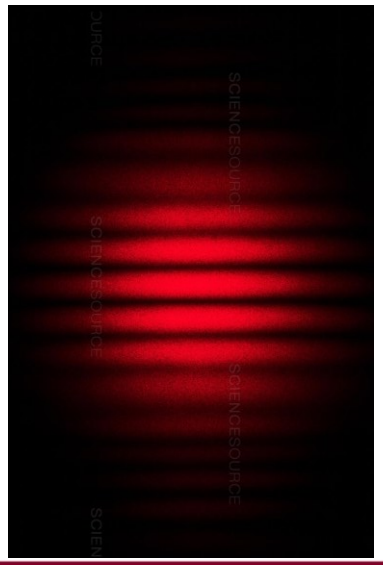
- Occurs when light grazes an opaque edge
- Some of the light turns the corner
- Cannot be eliminated

Interference

- Occurs when two coherent waves superimpose
- The result is bands of light and dark
- Constructive interference is the light
- Destructive interference is the dark







Mod #2: Optical Materials & Properties

Properties of Materials

A transparent optical medium such as a window, prism, or a lens requires:

1. Low absorption
2. Low reflection loss
3. Low refraction of the transmitted light
4. Minimum distortion due to imperfections in or on the material
5. A high damage threshold
6. Minimal optical degradation due to environmental changes

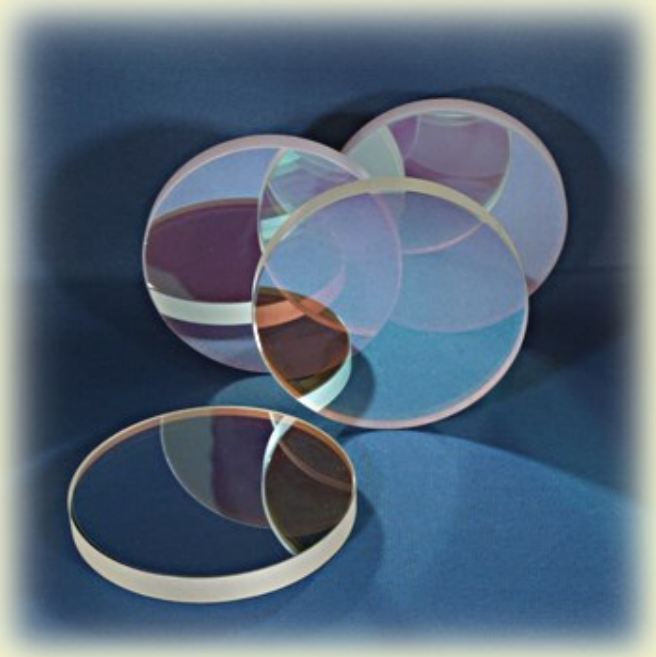
Index of Refraction

- The ratio of the speed of light in a vacuum to the speed of light in a different medium: $n = c/v$
- Unitless and always >1; indicated by the letter “n”.
  - n = 1 is for vacuum and accepted for air
- Varies inversely with wavelength.

Thermal, Mechanical & Chemical

- Thermal:
  - Extreme heat or cold and rapid changes in temperature can cause temporary or permanent changes.
  - Minimal to no changes are required.
  - Without optical systems there would be no lasers or laser processing, etc.
- Mechanical:
  - Stress on an optical component can result in distortion in its material and therefore its surface.
- Chemical:
  - Chemical damage to optical elements is caused mainly by the chemical's ability to etch or dissolve the window material. Such as the effect of acetone on plastics

Surface Imperfections



- Scratch and dig defects: Important to be careful when handling.
- Edge chips: may create crack
- Surface abrasions: extreme heat or cold, improper use of chemicals, etc.

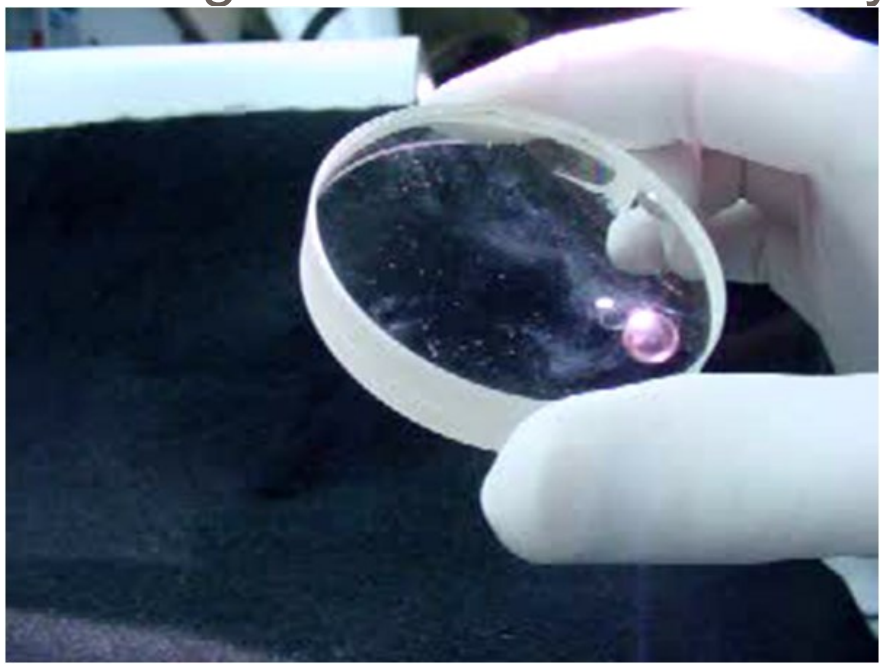
Internal Defects

- Usually occur during the manufacturing process.
- Inclusions: pieces of contamination inside of the glass.
- Bubbles: air trapped in the element.
- Cracks: may occur in an optic & may travel.
- Striae: lines in an optic from index of refraction variations.
- Interfere with the beam path

Care and Cleaning of Optics

Inspection Techniques:

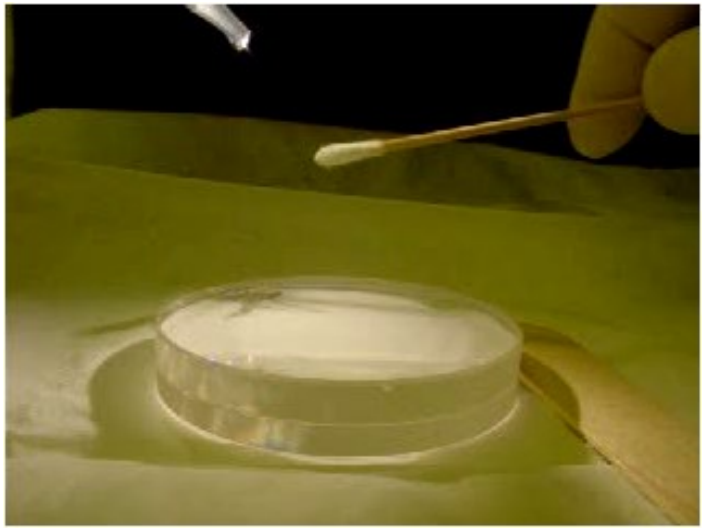
- Handle the optic carefully
- Inspect it for contamination, defects & imperfections
  - Various methods are used but all consist of light reflecting from or transmitting through the optic.
  - Think of cleaning a window at home or your glasses.



Care and Cleaning of Optics

Cleaning Methods:

- Blow off particulate
  - With clean, dry air
  - Your breath is not clean nor dry.
- Detergent method: for very dirty optics
  - Mild detergent and fingers (finger prints are like squeegees)
- Drag-wipe method:
  - Wet a cleaning tissue with cleaning fluid and drag it across the optic.
- Twist-n-wipe method (shown)
  - Use an **optical** "Q-tip", wet with cleaning fluid and twist while wiping.
- One and done; do not reuse.

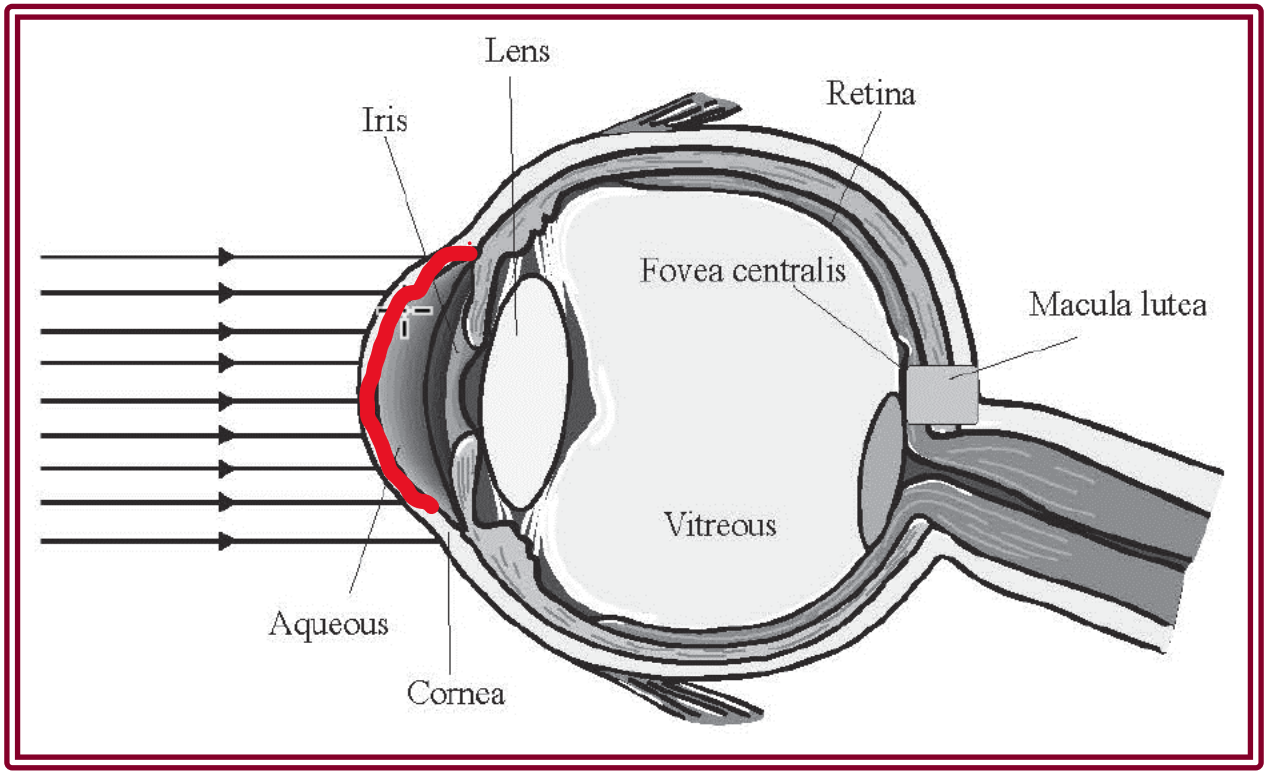


Mod #3: Laser Safety

- When the environment dictates, wearing proper protective equipment (PPE) for eye safety is essential
- Wearing laser safety eyewear is only safe to a point
- One must know the laser power, wavelength, mode of operation and the PPE limits
- Most injuries are caused by the not following the safety training

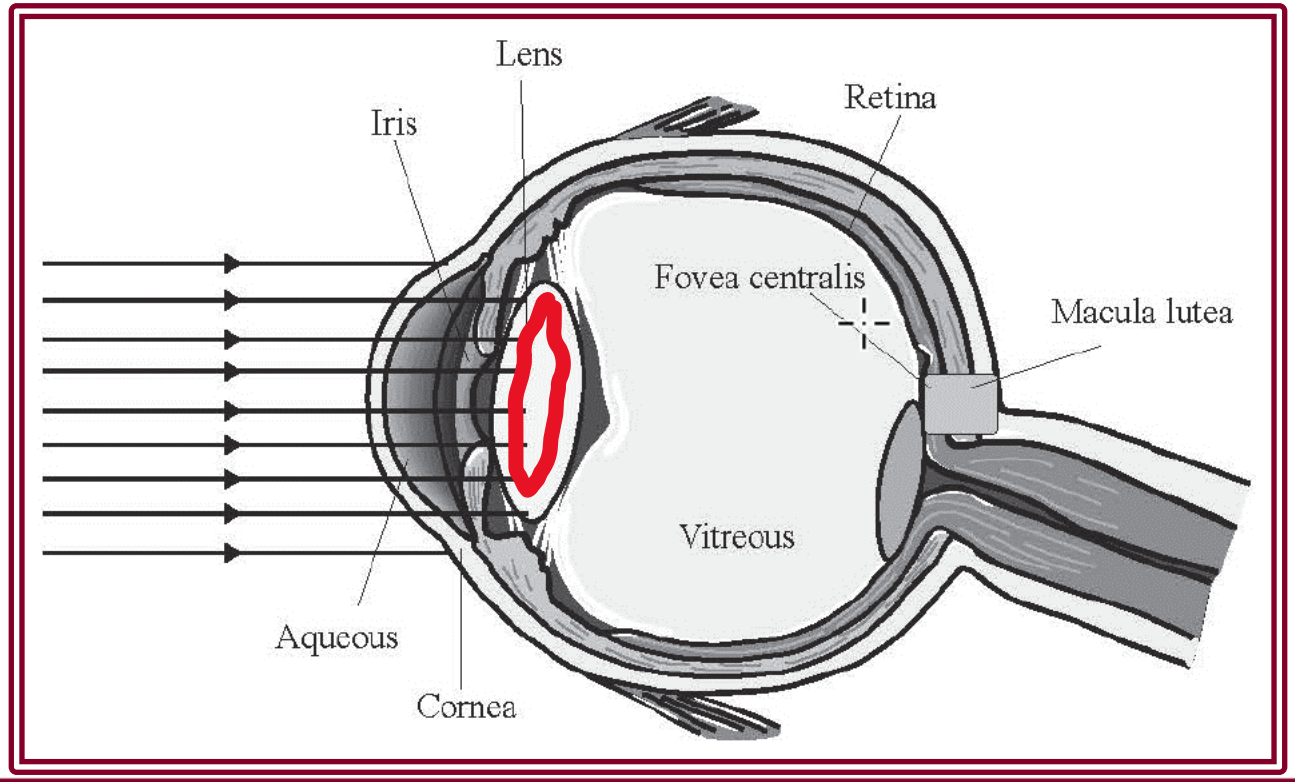
The Eye

- Infrared: 1400 – 10000 nm
- Ultra Violet: 100 – 315 nm
- Absorbed mainly in the **cornea**



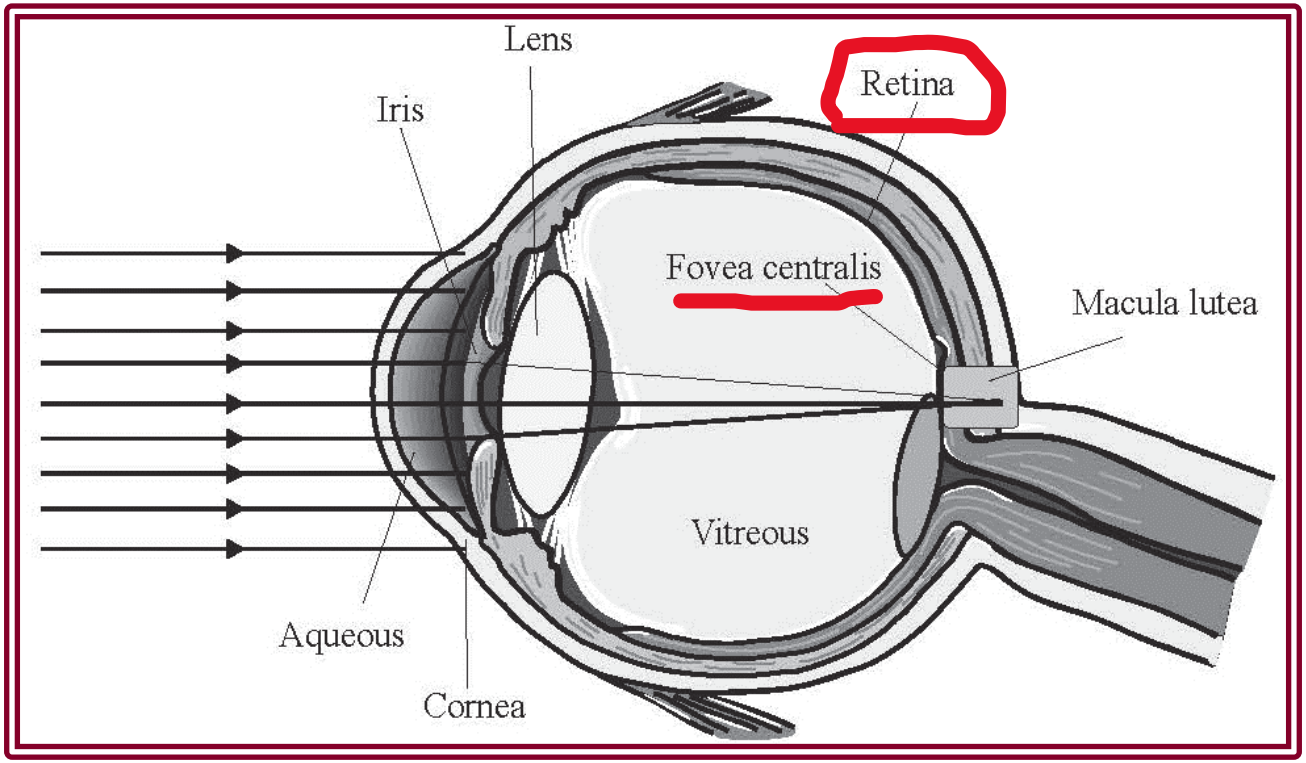
The Eye

- Infrared: 700 – 3000 nm
- Ultra Violet: 315 – 400 nm
- Absorbed mainly by the **lens**
  - **Cataracts**



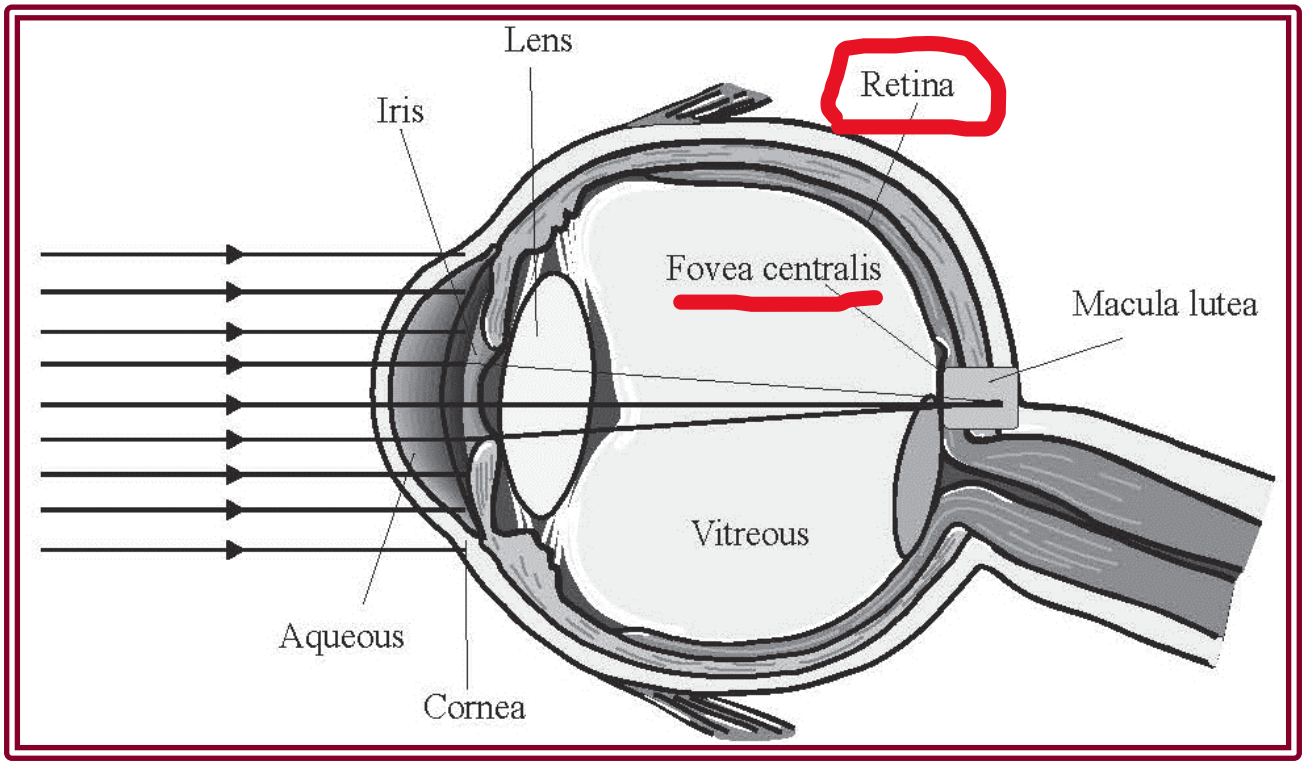
The Eye

- Visible (400 – 700 nm) and Infrared: 700 – 1400 nm
- Focused onto the **retina**.
- Straight line viewing focuses onto the **Fovea**
- Area of most detailed vision



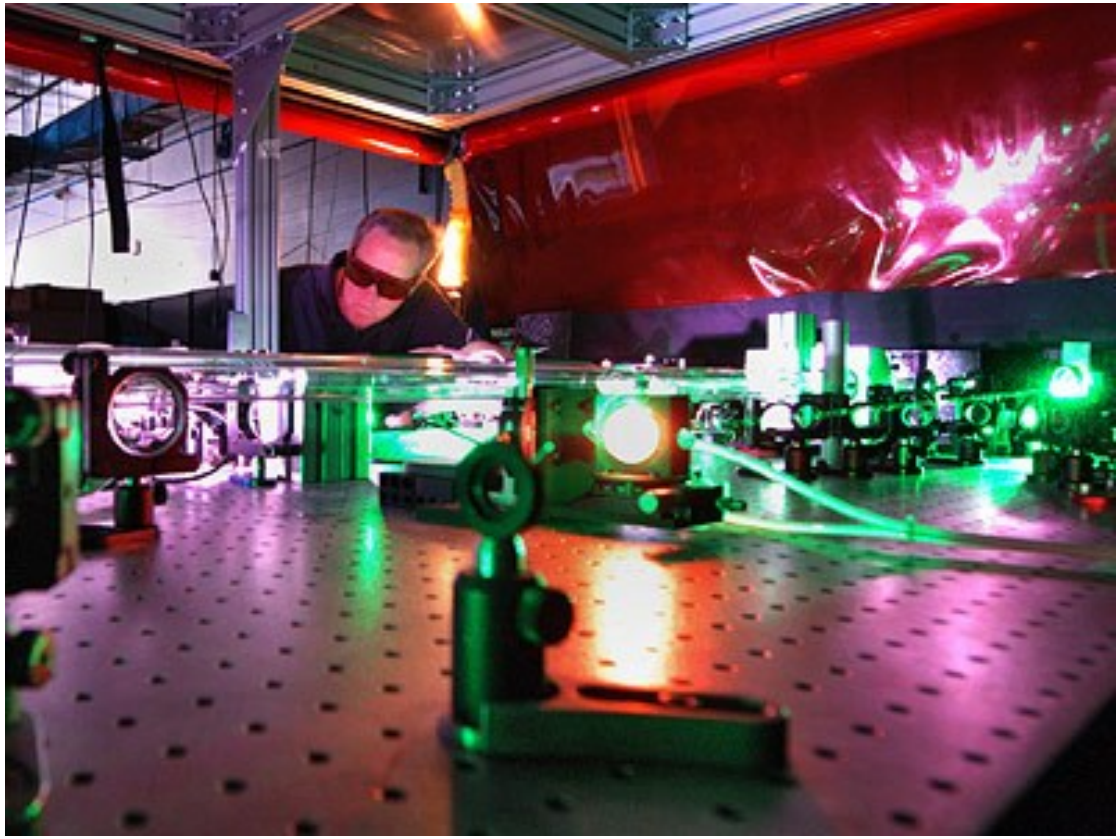
The Eye

- Capable of causing a white burn on retina
- Burn on outside of macula: effect on vision is small
- Burn on inside of macula; effect is much greater

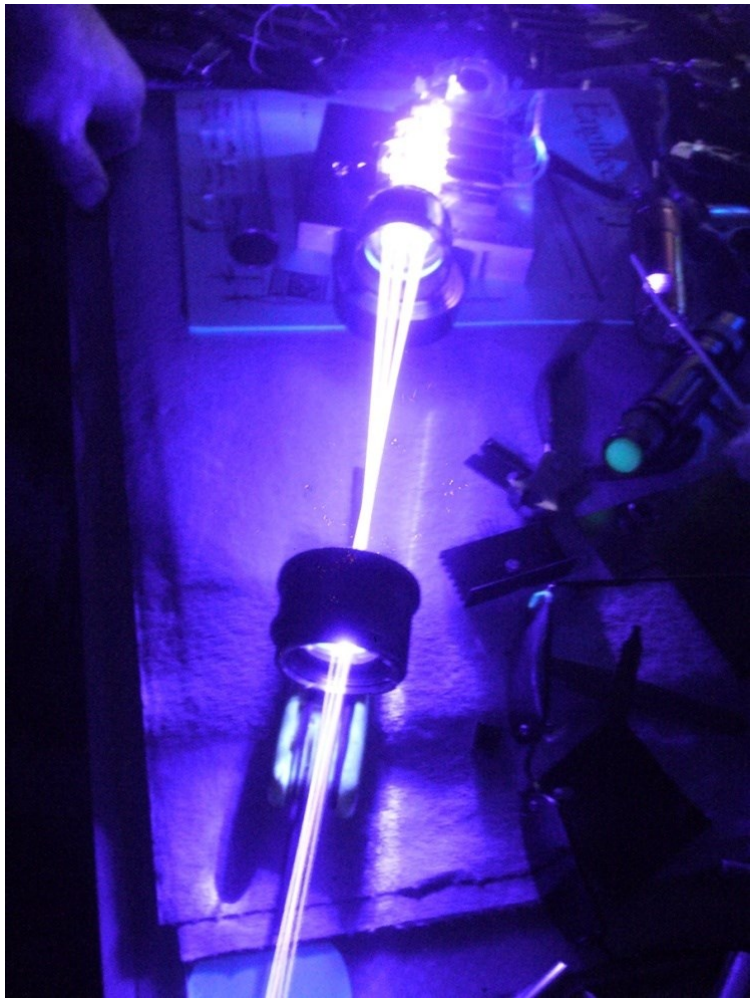


Pulsed Lasers

- Pulsed lasers cause lines of laser burns on the retina
- Pulses create shockwaves that rupture blood vessels
- Permanent destruction of the macular is possible



Irradiance



- Power density of a beam
- Smaller the diameter of the beam the greater the irradiance
- Laser light focused by a lens increases the irradiance significantly
- A human eye (lens) can easily increase irradiance of a beam by 10,000!

$$Irradiance = \frac{Power}{Area}$$

Skin Effects

- The skin is more apt to be exposed to laser light
- Two effects of laser light on the skin
  - Thermal Injuries
    - Surface burns from high power beams
    - Tissue vaporization by focused beams
  - Photochemical Injuries
    - Sunburn from scattered UV
    - Possibility of skin cancer from long term UV exposure such as suntanning

Class 1

- Safe during normal use
- Incapable of causing injury
- Low power or enclosed beam

Nd:YAG Laser Marker

Label not required
May be higher class during maintenance or service

Class 2

- Staring into beam is eye hazard (DUH!)
- Eye protected by aversion response
- Visible lasers only
- CW maximum power 1 mW

Laser Scanners

Class 3R

- Aversion response may not provide adequate eye protection
- CW maximum power (visible) 5 mW
- Laser must have a safety sign

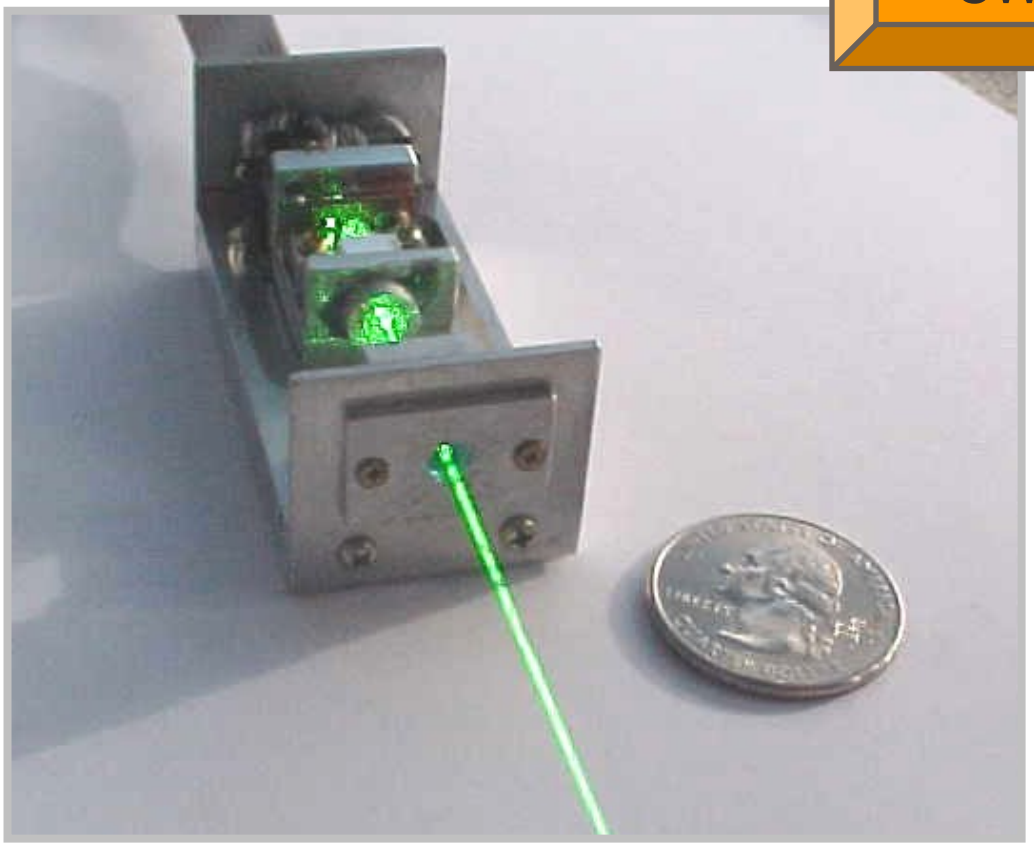
Expanded Beam

Small Beam

Class 3B

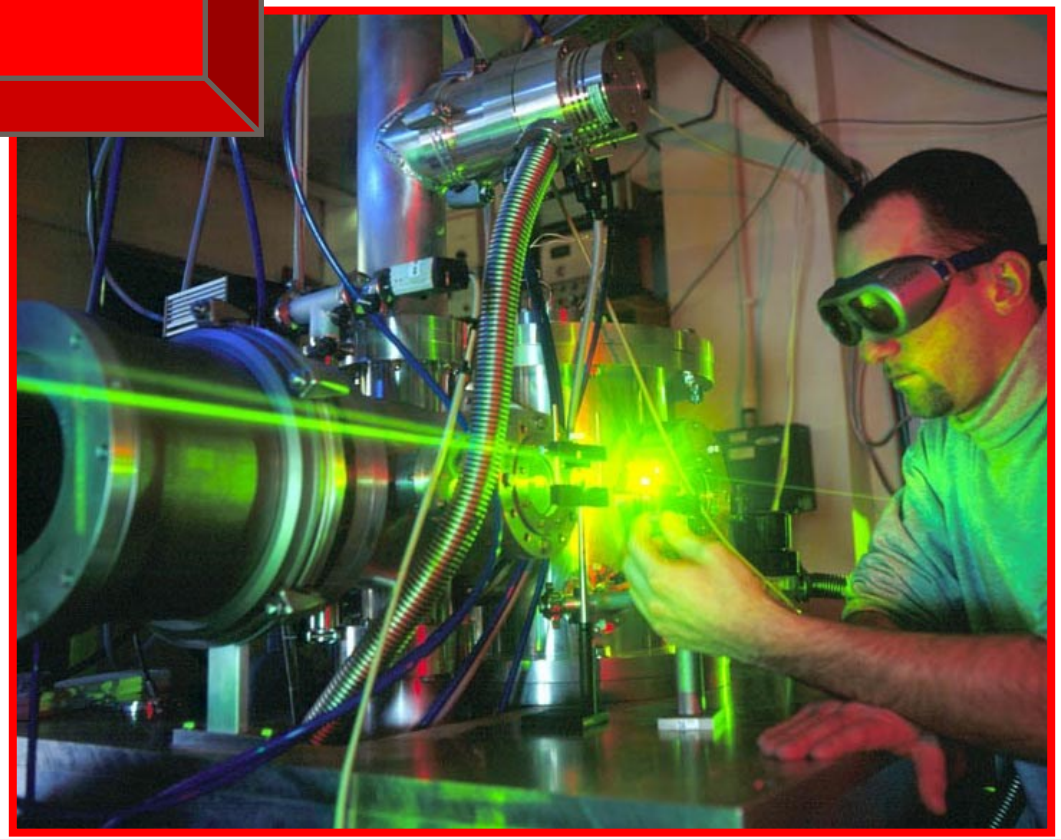
- Hazardous for direct beam viewing
- Be aware of diffuse reflection
- Visible or invisible
- CW maximum power 500 mW

Diode Pumped Solid State (DPSS) Laser with cover removed



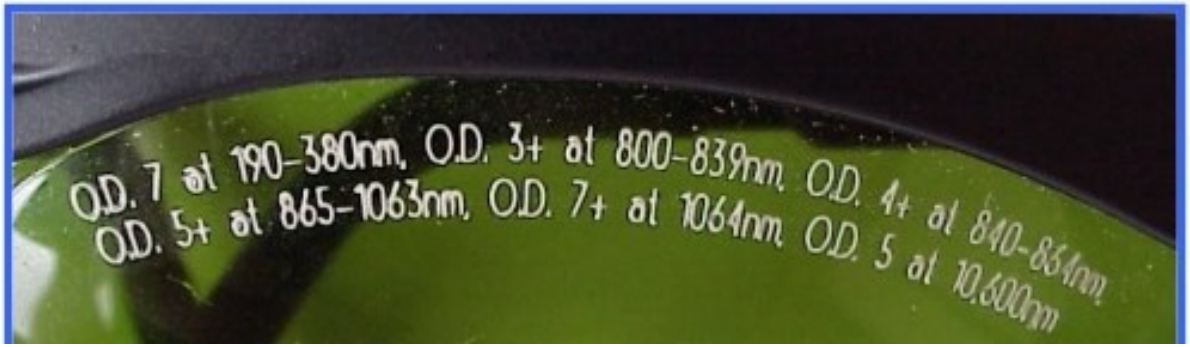
Class 4

- Exposure to direct beam & diffused light is eye and skin hazard
- Visible or invisible
- CW power >0.5 W (500 mW)
- Fire hazard



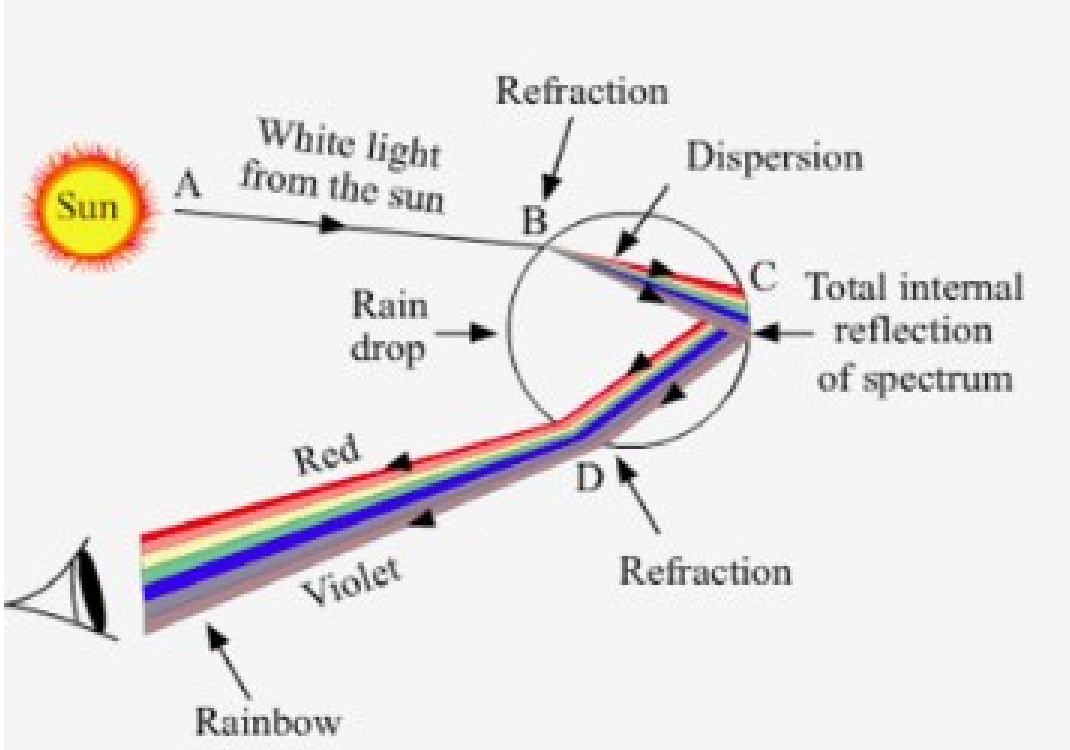
Laser Safety Eyewear

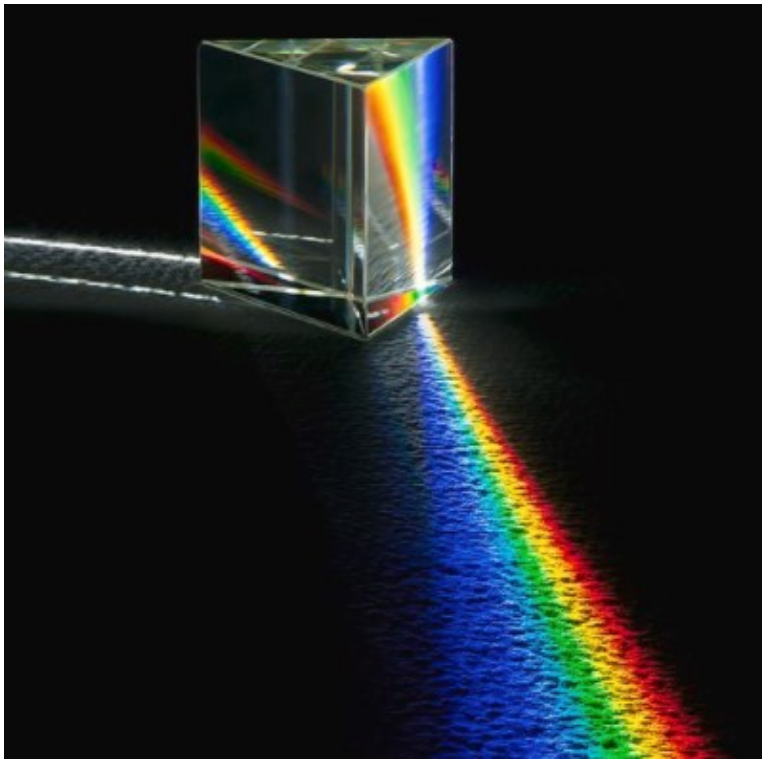
- Optical density (OD): indicates how well a material absorbs light thereby decreasing (attenuating) transmission
- OD of eyewear to exceed the OD calculated in a hazard evaluation
- OD value is on laser eyewear with relevant wavelength



Mod #4: Dispersion

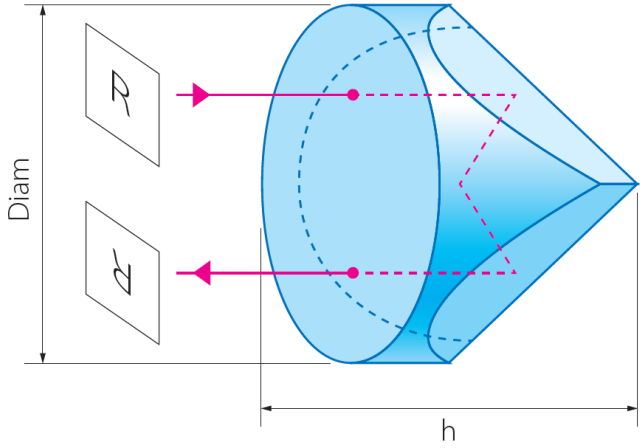
- The variation of refractive index with wavelength is called *dispersion*.
- Dispersion is how white light separates to all visible colors.
- This is why a rainbow is visible after a rain, as the white light from the sun disperses in the raindrops.
- Therefore white is the combination of all colors while black is the absence of all colors.

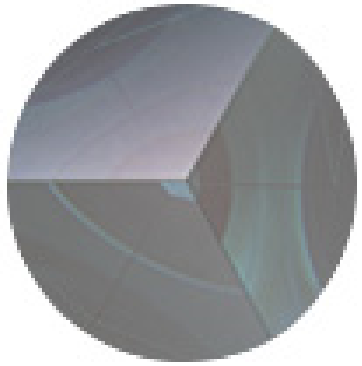


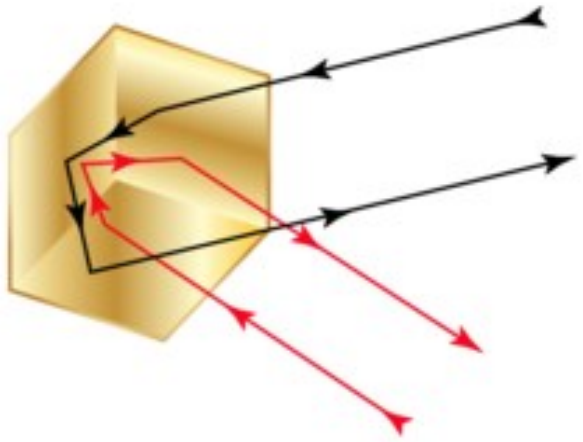


Prisms

- Total internal reflection is used in “retroreflecting” prisms, or those that redirect the reflected light along the **same path** as the entering light.
- Three symmetrical planes form the inside corner of a cube
- When a ray of light reflects from the first side, it’s reversed to the next side, and then transferred to the last plane. It’s then sent back to the source

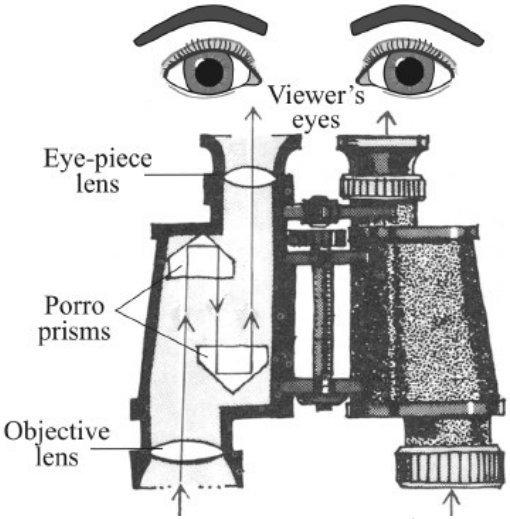






Prisms

- **Right angle: (a)** Deviate the direction of light by 90°
- **Porro: (b)** Right angle prism in a Porro configuration.
  - When light is incident through its hypotenuse, light (image) will be deflected 180-degrees and flipped.
  - Used to change the orientation of an image.
- **Dove: (c)** Right angle prism with apex removed.
  - Used to invert images.
- **Porro: (d)**
  - Used in binoculars, telescopes, and microscopes where there are space restrictions.



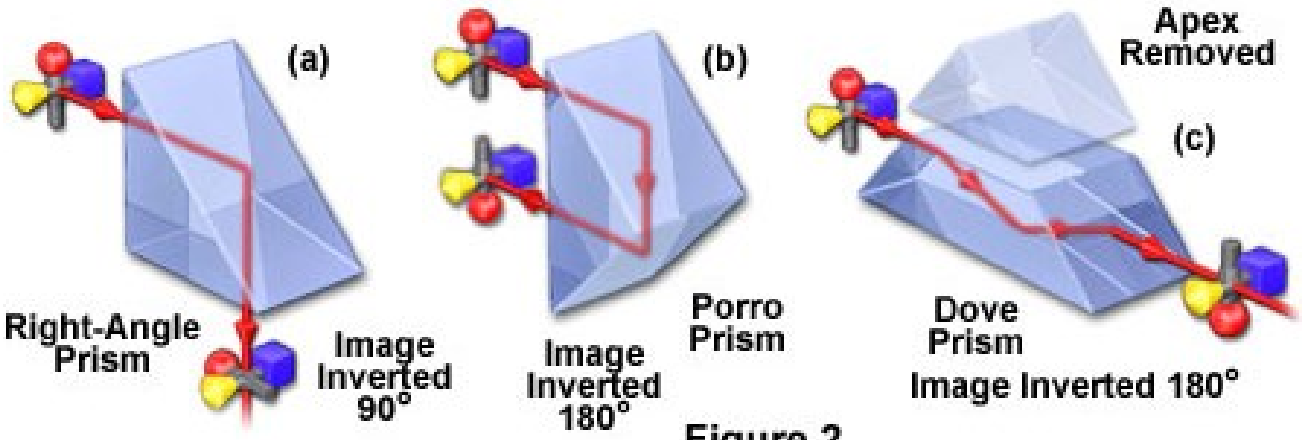
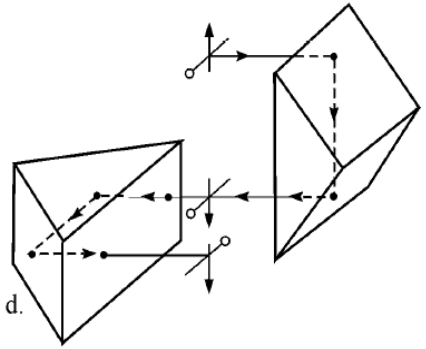


Figure 2



Prisms

- **Penta: (a)** Deviates the beam 90-degrees without deflection left-to-right or top-to-bottom.
- **Roof: (b)** Used in binoculars or when a right angle deflection of an image is required.
  - The image is deflected left-to-right not top-to-bottom.
- **Rhomboid: (c)** Creates an output beam that is displaced from and parallel to the input beam.
  - Does not change the direction of the beam, nor does it invert the image.

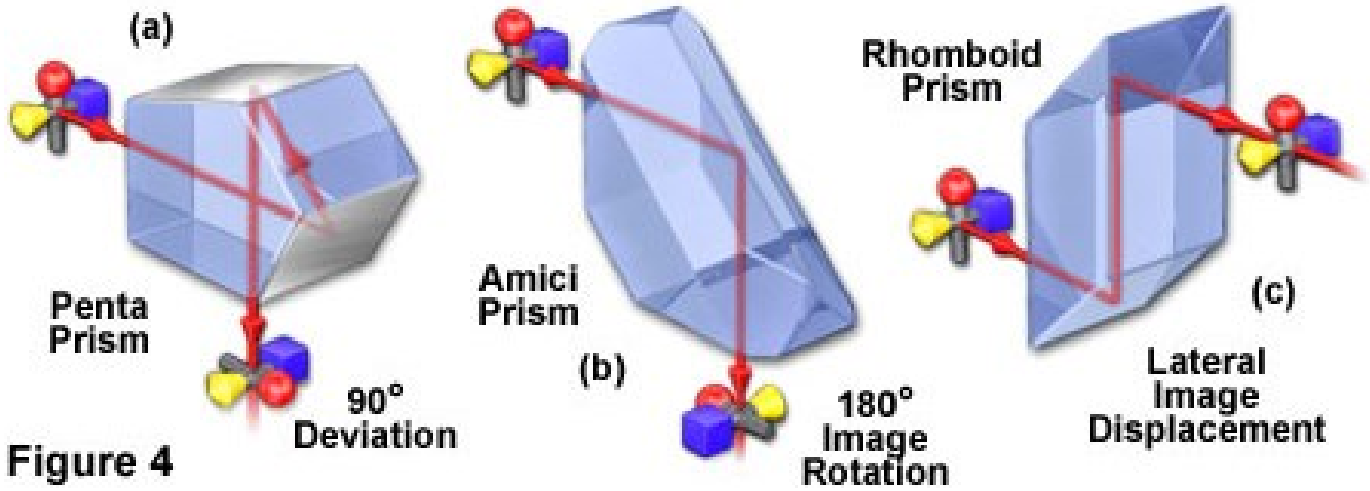
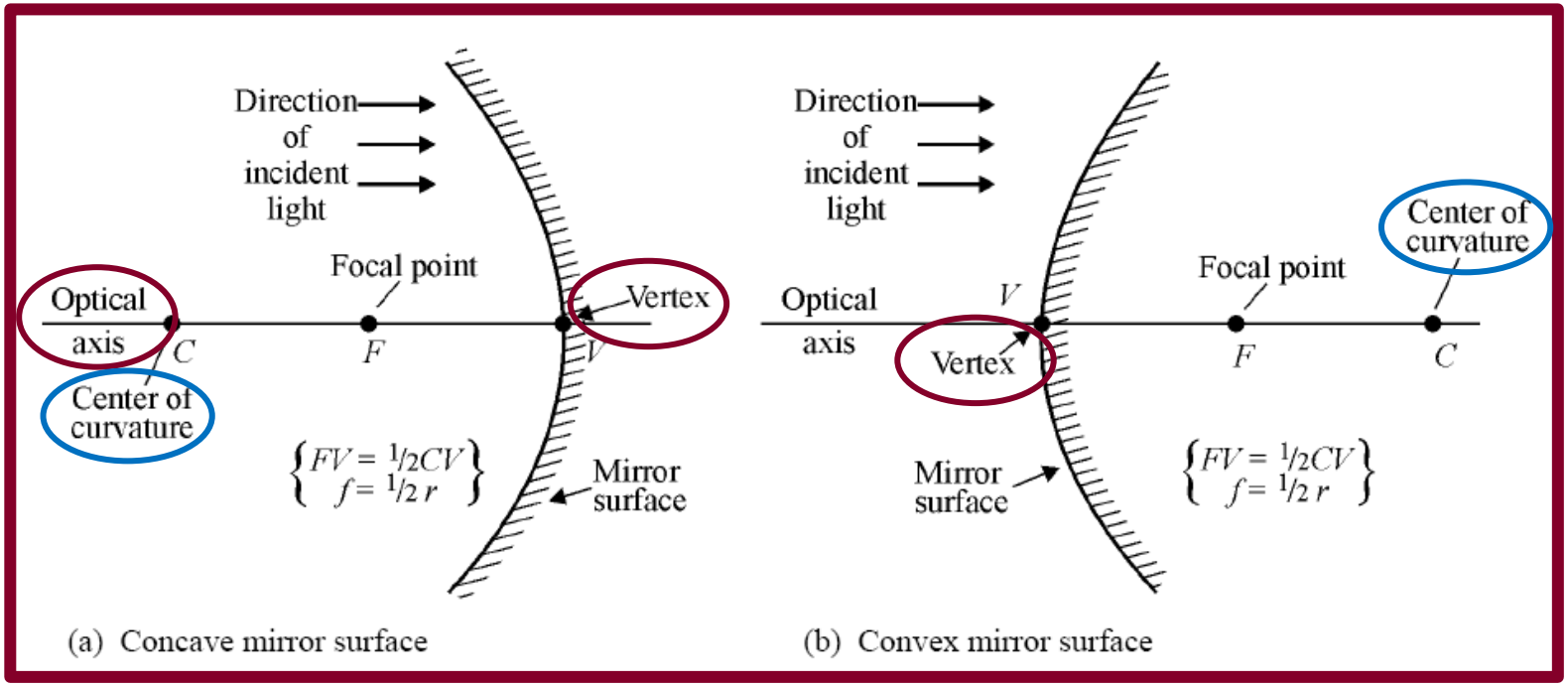


Figure 4

Spherical Mirrors

- Vertex is point where optical axis intersects the mirror.
- The mirror on the left is a concave, positive, converging mirror.
  - The center of curvature (*C*) is on the left.
- The mirror on the right is a convex, negative, diverging mirror.
  - The center of curvature (*C*) is on the right.



Spherical Mirrors

- **Parallel** rays are light rays coming from a very distant source (such as the sun) or as part of a collimated laser beam.
- The *law of reflection* requires that the ray be reflected so as to pass through a focal point *F* in front of a concave mirror (Figure 4-17a) or be reflected **to appear** to come from a focal point *F* behind a convex mirror (Figure 4-17b).
- A line drawn from the center of curvature *C* to **any point** on the mirror such as *P* is a *normal* line and bisects the angle between the incident and reflected rays, as shown.

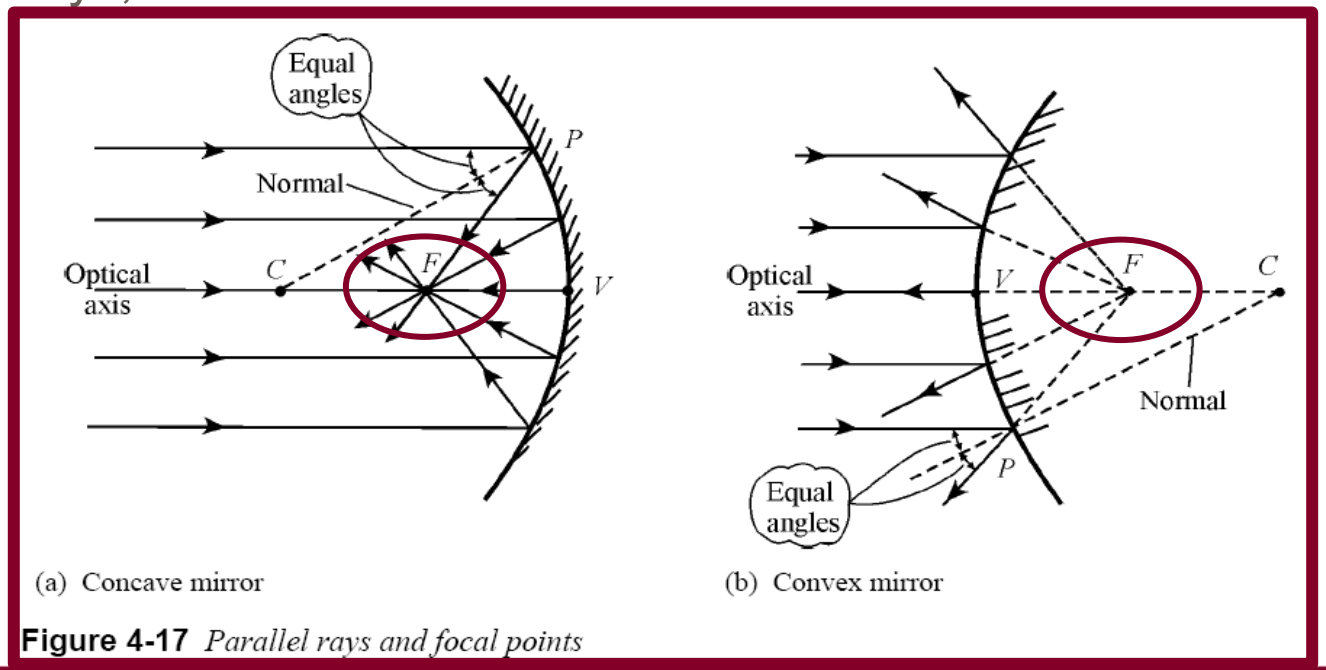


Figure 4-17 *Parallel rays and focal points*

Lenses, Convex/Converging/Positive

- Have positive spherical (curve outward) surfaces.
- Center-thickness is greater than edge-thickness.
- Focus light to a pre-defined point based on surface curvature.
- Biconvex: both surfaces are positive.
  - Utilized when the object being imaged is **much closer** to the lens.
- Plano-convex: one surface remains flat while the second has a positive curve.
  - Applied when the object being imaged is **far away** from the lens.
- Positive Meniscus: both sides curve in the same direction, center-thickness **>** edge-thickness.
  - Designed to minimize spherical aberration & to shorten the focal length of an optical system.

Note the parallel/collimated light ray entering from the left.

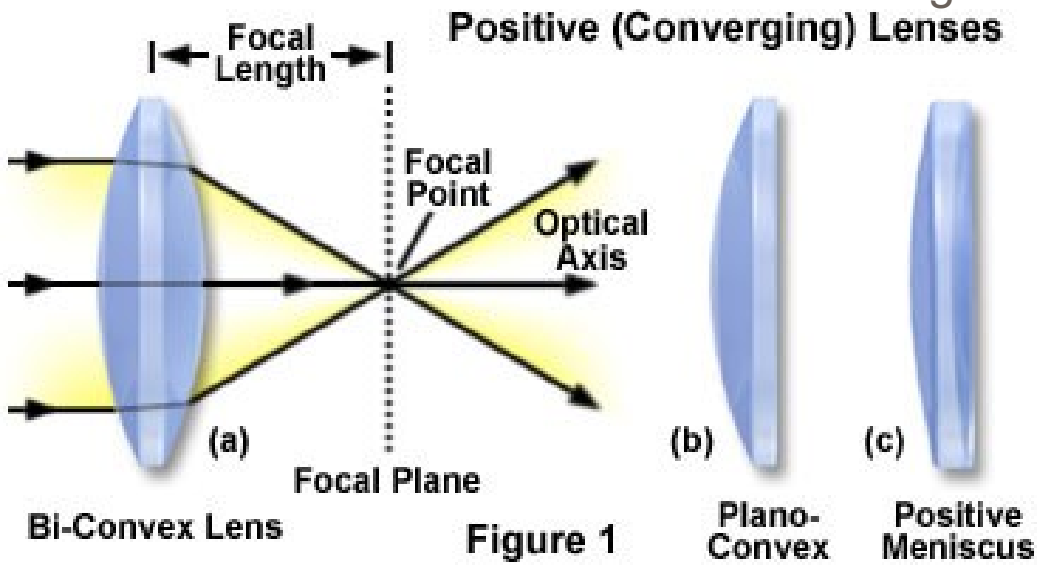


Figure 1

Lenses, Concave/Diverging/Negative

- Have negative spherical (curve inward) surfaces
- Center-thickness is less than edge-thickness
- Diverge (disperse) light from pre-defined point based on surface curvature
- Bi-Concave: both surfaces are negative.
  - Utilized to expand & collimate a laser beam.
- Plano Concave: one surface remains flat while the second has a negative curve.
  - Applied to reduce spherical aberration, coma and distortion
- Negative Meniscus: both sides curve in the same direction, center-thickness < edge-thickness.
  - Used to reduce or eliminate spherical aberration or increase resolution in optical systems.

Note the parallel/collimated light ray entering from the left.

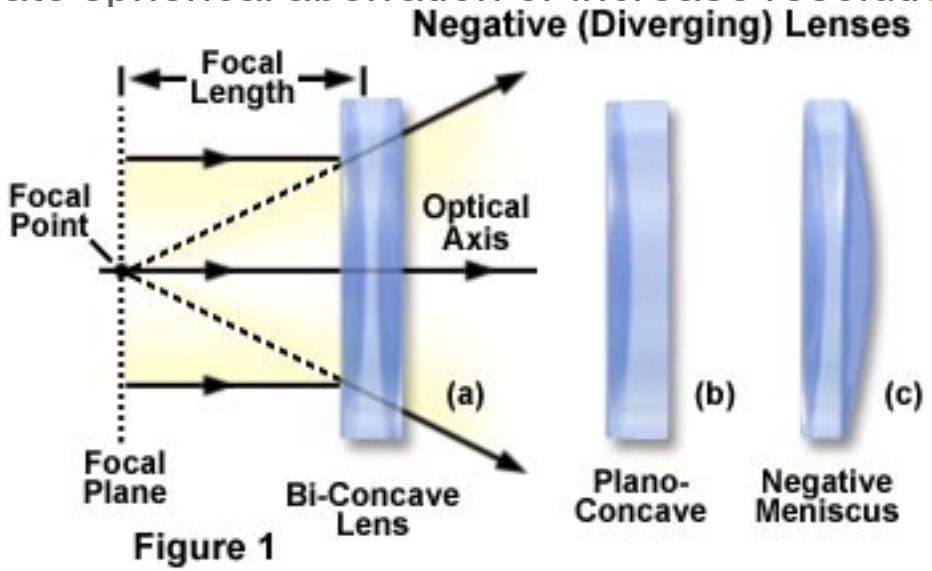
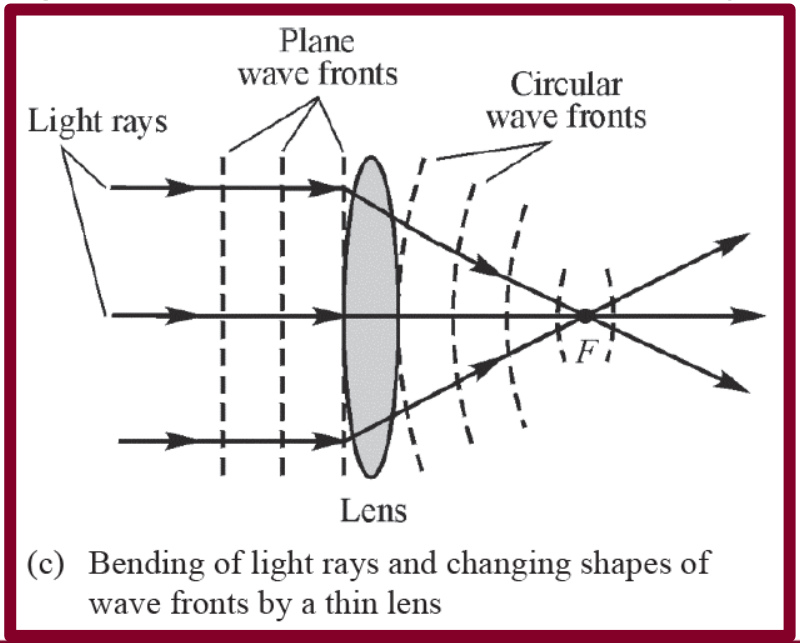


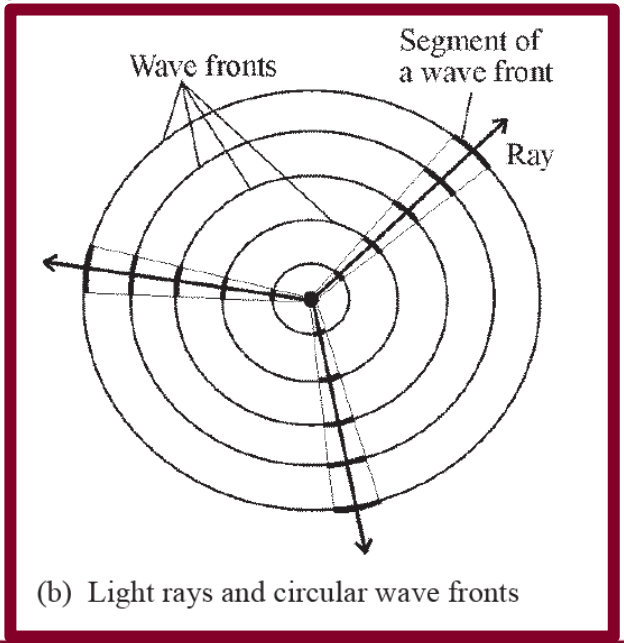
Figure 1

Mod #5: Wave Motion & Wave Fronts

- Geometrical or ray optics *cannot* account for the light patterns produced on a screen beyond objects such as a 100μm diameter human hair, or through small openings, such as a 50μm pinhole
- Therefore, we now move from the *propagation* of light energy along a straight-line to one that includes the *spreading* of light energy; a fundamental behavior of all wave motion.
- The figures below show *electromagnetic* wave fronts moving in conjunction with a laser beam/ray and (c) how a lens manipulates both.



(c) Bending of light rays and changing shapes of wave fronts by a thin lens



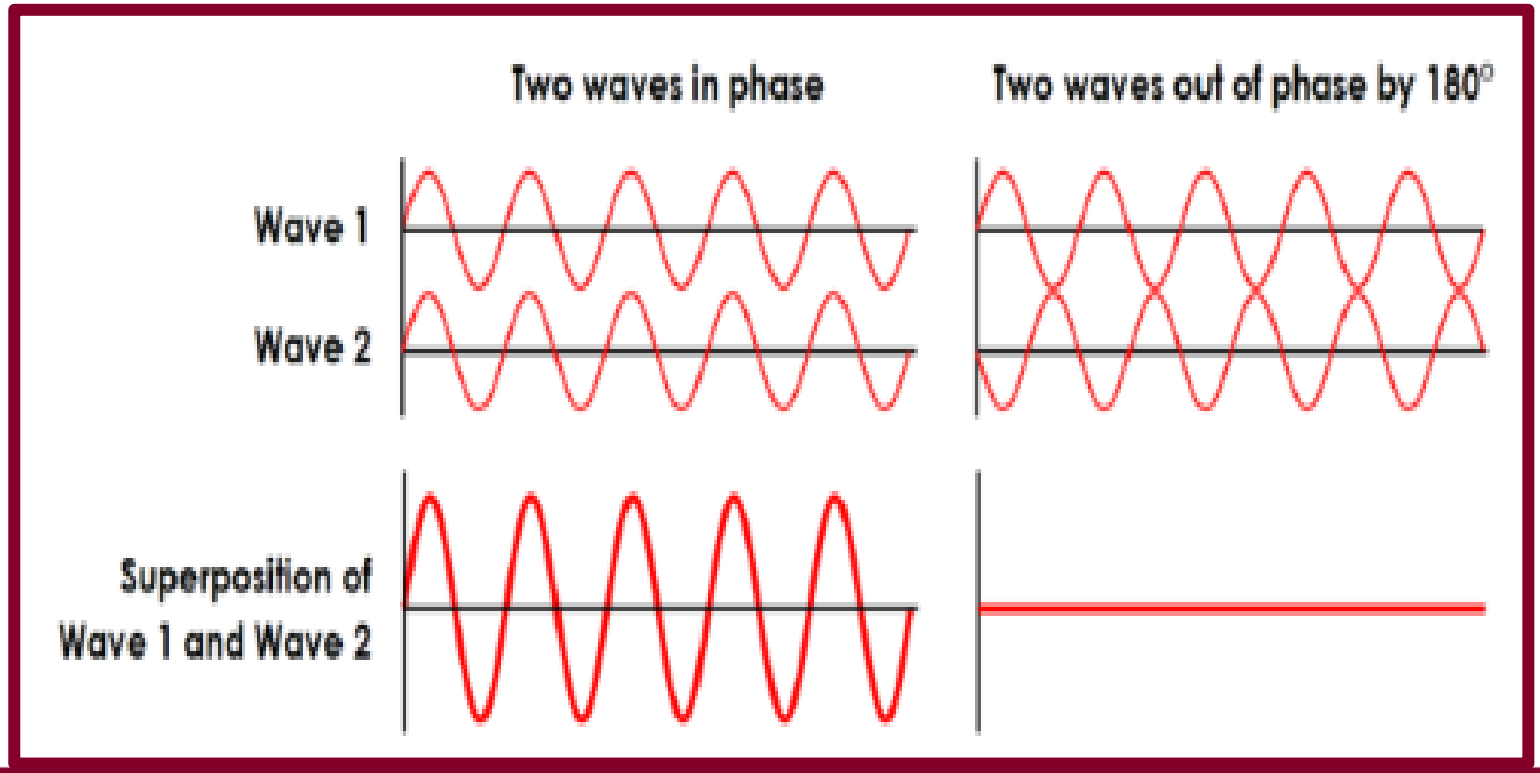
(b) Light rays and circular wave fronts

Wave Motion & Wave Fronts

- This picture shows water wave motion travelling radially outward from center.
- These wave motions are mostly up and down or *transverse* vibrations, propagating in a direction *perpendicular* to the vibrations as wave fronts.
- A *wave front* is defined as a series of adjacent points along which all motions of the wave are identical.

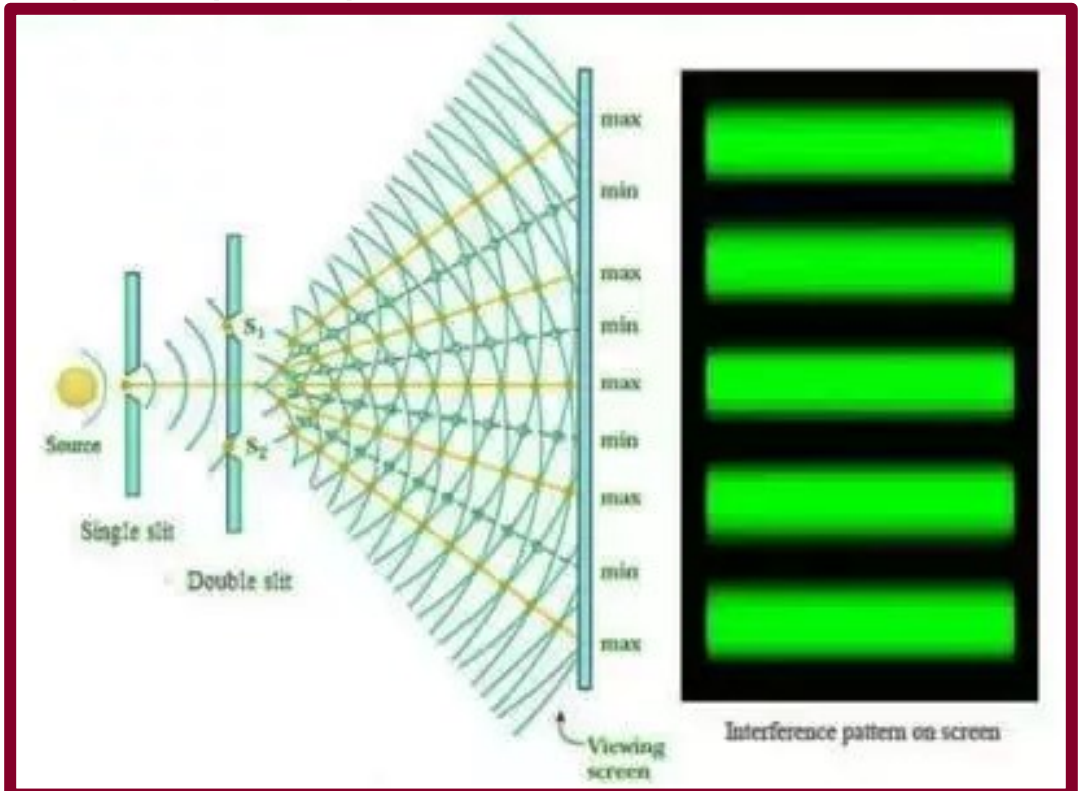
Principle of Superposition

- When two or more waves move simultaneously through a region of space, each wave proceeds independently.
- The result of superposition of 2 - waves when they are in phase (constructive interference) and when they are 180° out of phase (destructive interference.



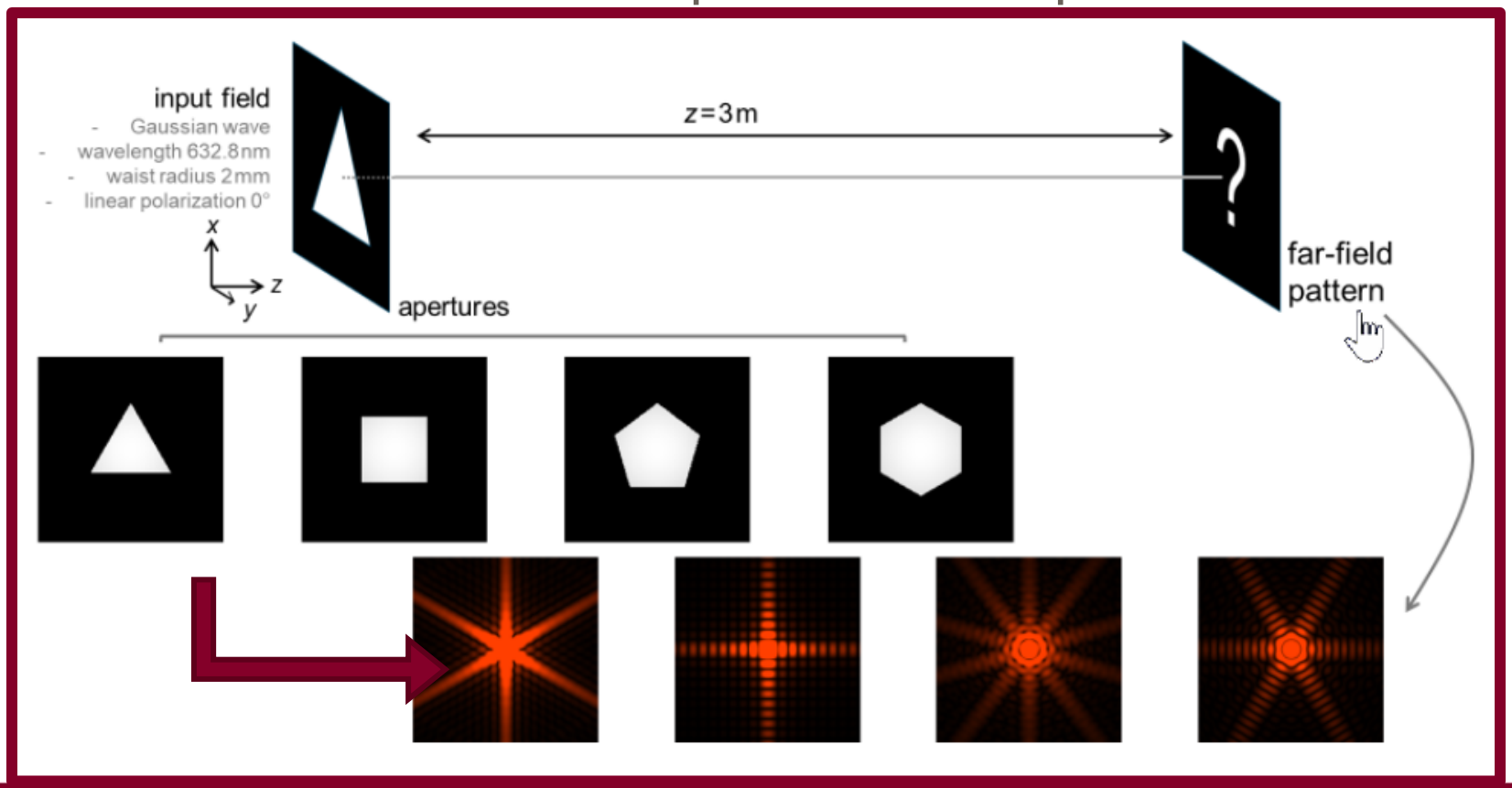
Interference

- It is possible to show the interference of overlapping light waves coming from two nearby coherent sources.
- The *solid* circles represent crests (max), the *dashed* circles, troughs (min).



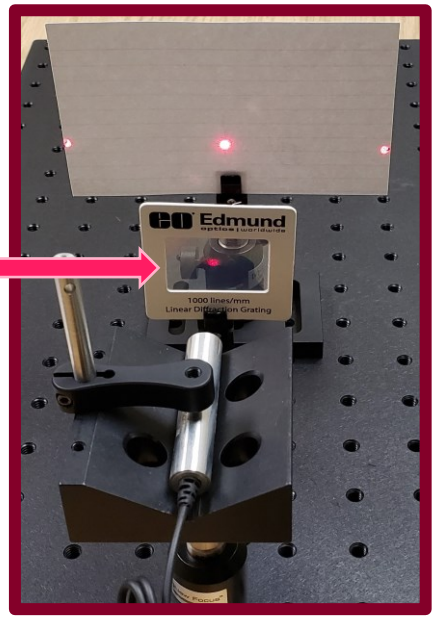
Diffraction

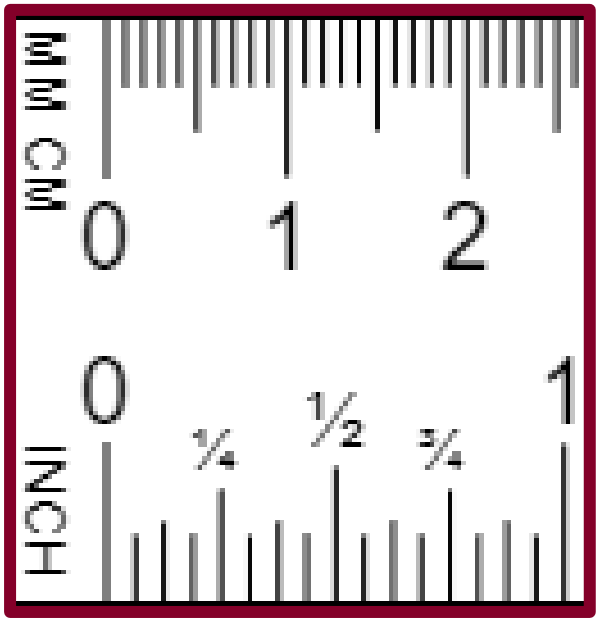
- The ability of light to bend around corners is fundamental to both interference (2 - coherent light sources) and diffraction (1 - coherent light source).
- Each obstacle creates a unique diffraction pattern.



Diffraction Gratings

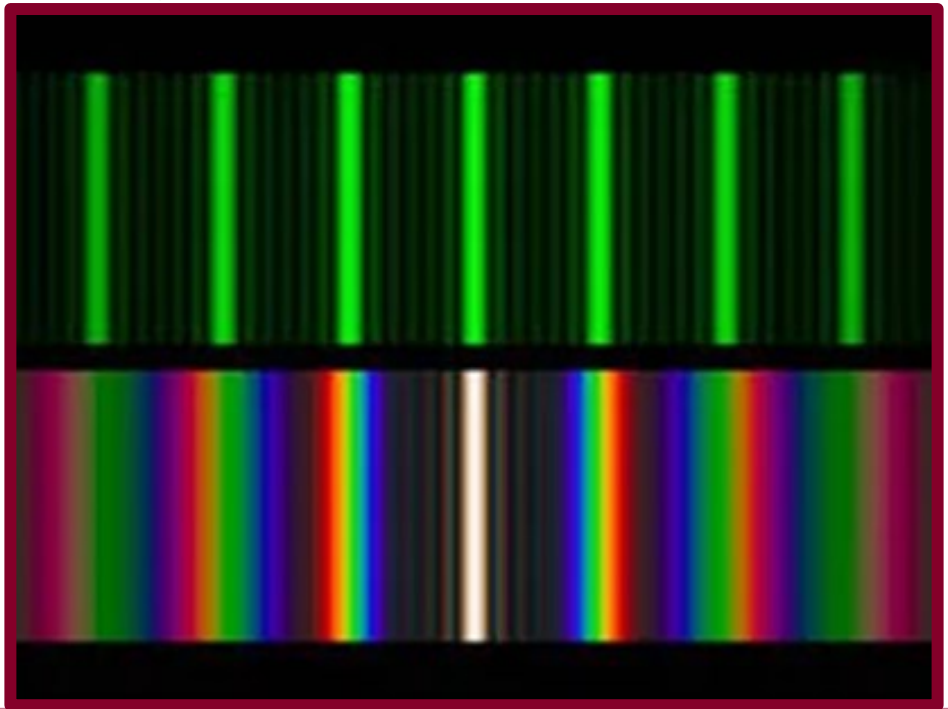
- An optical device with close, equidistant, and parallel lines for the purpose of resolving (diffracting) light into its spectral components.
- Transmission Grating: lines on or in a transmissive medium.
- Reflection Grating: lines on a reflective medium.
- The diffraction grating in the picture has 1000 lines/mm.





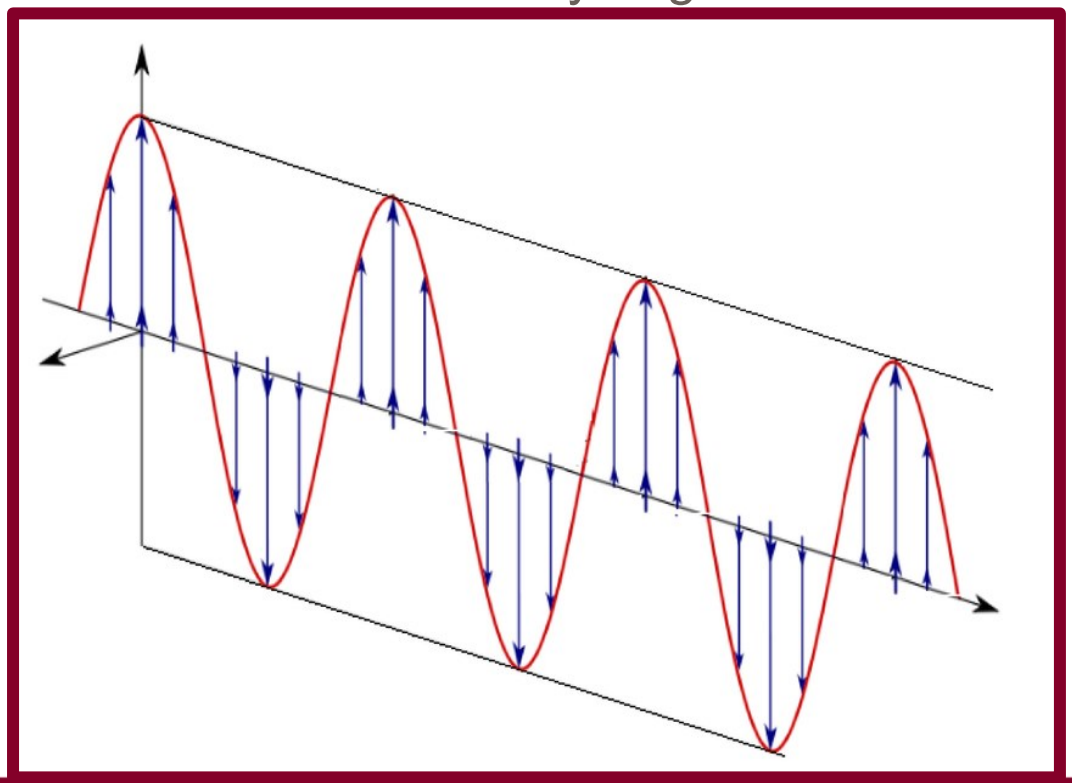
Diffraction Gratings

- Graphic compares a green light diffraction pattern with one of white light.
- Green light pattern corresponds to the location of the green-light fringe within the “rainbow” fringe.
- Notice the white light central fringe is white, with the composite color fringes to either side.
- The “rainbows” are oriented with the blue end towards the center because it is the shortest wavelength shown.



Polarization

- Polarization of light waves refers to the *transverse* direction of vibration of the ***electric field*** (E-field) vector of electromagnetic waves.
- *Transverse* means *E*-field vibrations *perpendicular* to the direction of wave propagation.
- If the electric field vector maintains that direction, the light is said to be *linearly polarized* and can be at any angle.



Mod #6: Four Basic Elements of a L.A.S.E.R.

- Light Amplification by Stimulated Emission of Radiation
- 1. Amplifying/Active/Gain Medium
- 2. Excitation Mechanism
- 3. High Reflectivity Mirror (HR)
- 4. Output Coupler (OC)
  - Mirror with less reflectivity than HR & where beam exits
  - HR & OC comprise the Feedback Mechanism or cavity

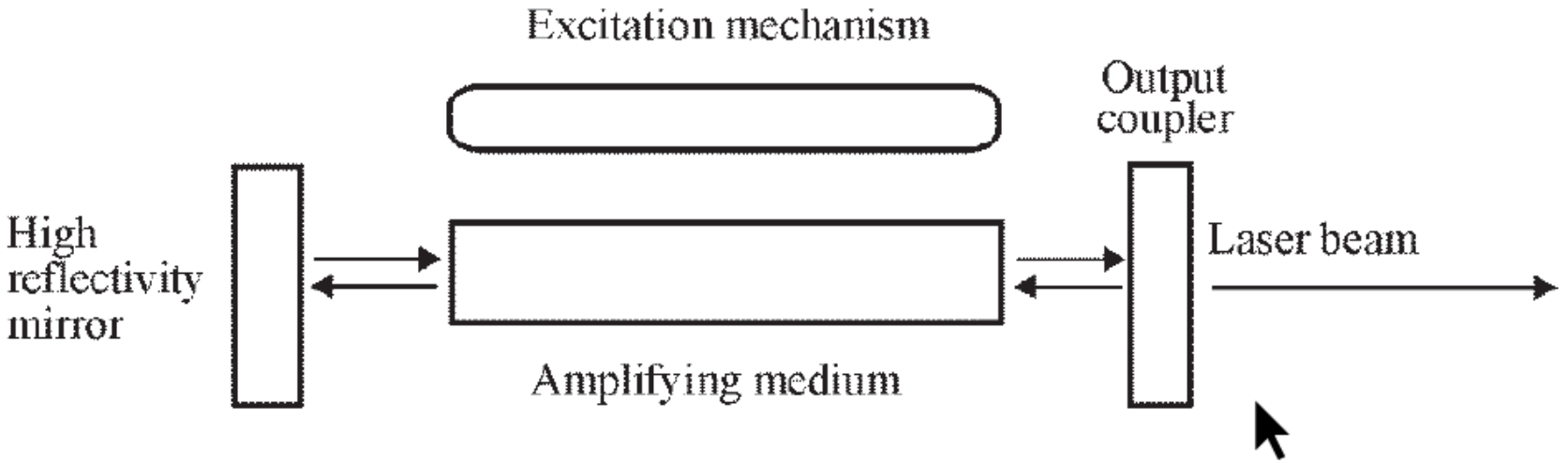


Figure 6-10 *Schematic diagram showing the basic structure of a laser*

Properties Related to Applications

Collimation or Least Diverged & Directionality:

- Used for
  - Reference beams in construction
  - Leveling and grading land
  - Alignment of pipe such as sewer pipe
  - Sending light over long distances without suffering significant divergence
  - Laser pointers

Monochromaticity:

- Most applications require a single narrow wavelength based on the material absorbing the wavelength

Properties Related to Applications

Coherence:

- Related to applications in holography

Intensity or Irradiance:

- One of the two most important parameters in using the laser for materials (organic or inorganic) processing
- The other important parameter is the laser wavelength per absorption
  - If it cannot be absorbed, it cannot be used for processing.

Properties Related to Applications

Divergence:

- Beam divergence relates to laser pointing and free space optical communications

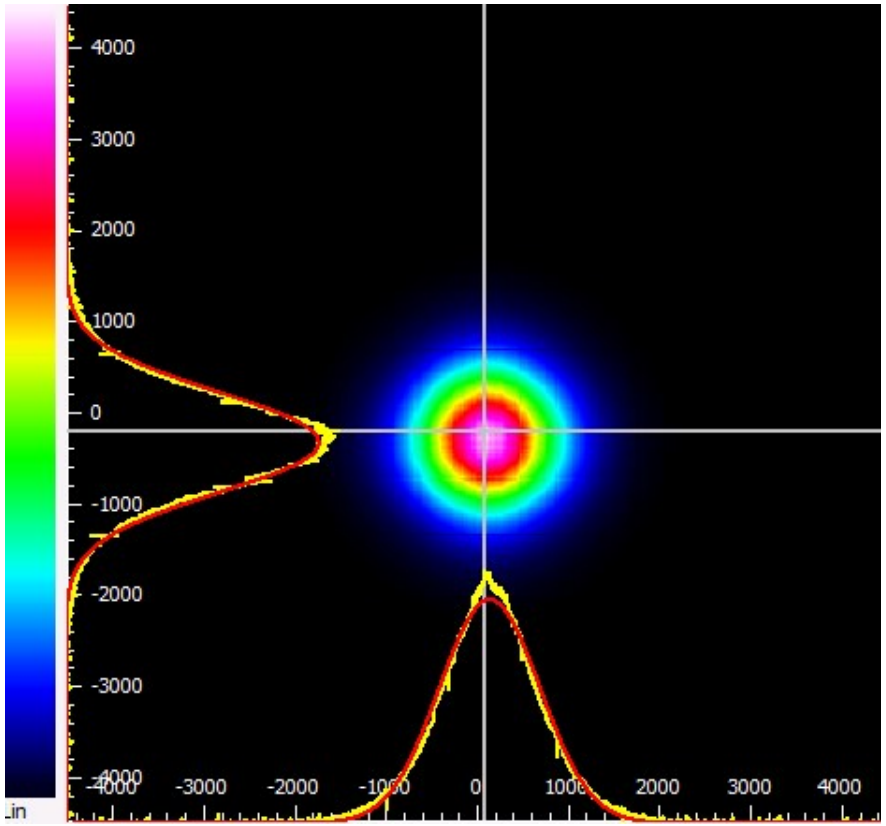
Focusability:

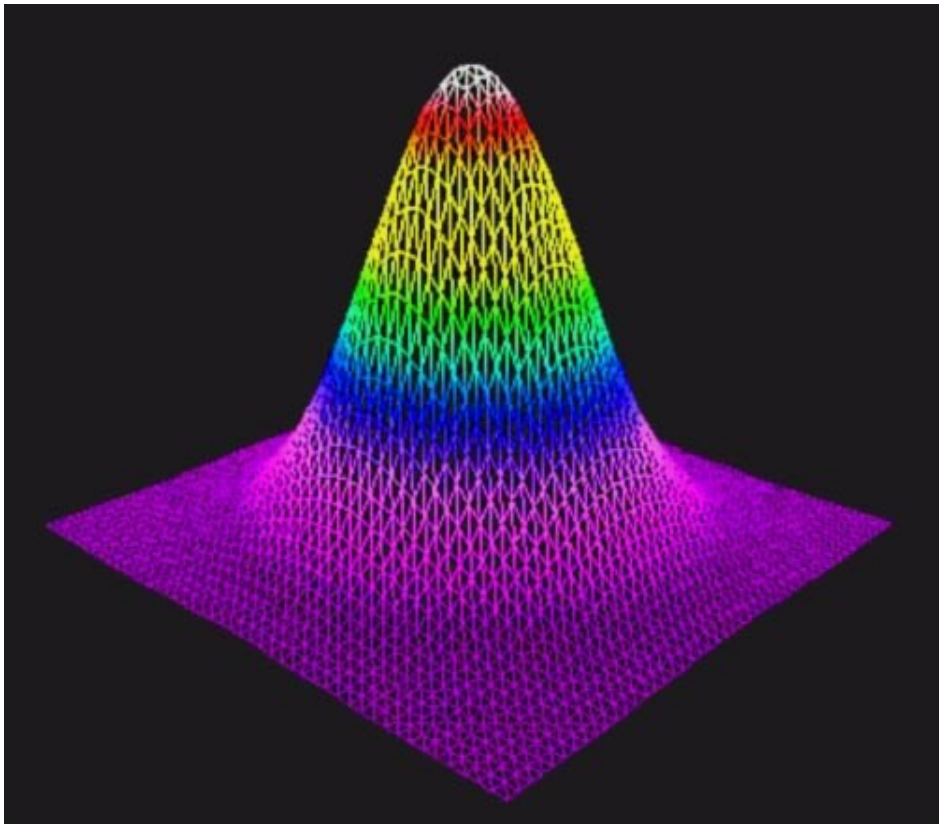
- Smallest diameter that can be obtained with a focused laser is approximately the dimension of the wavelength of the laser
- Almost all applications (pointing...not so much) of lasers involve their ability to be focused to a very small spot size

Laser Pumping Sources

- **Electron pumping:**
  - Used primarily in gaseous or semiconductor gain media
- **Optical pumping:**
  - Provided by either gas filled flashlamps or other lasers
- **Shape of laser beam per gain-medium and mirrors**
  - Active/Gain-medium to be of an elongated shape so gain, which is length dependent, will operate primarily in one direction
  - Mirrors are placed at both ends of the medium, forming a cavity/resonator redirecting the beam back and forth through the amplifier thereby allowing the beam to increase to saturation

Laser Beam Profile





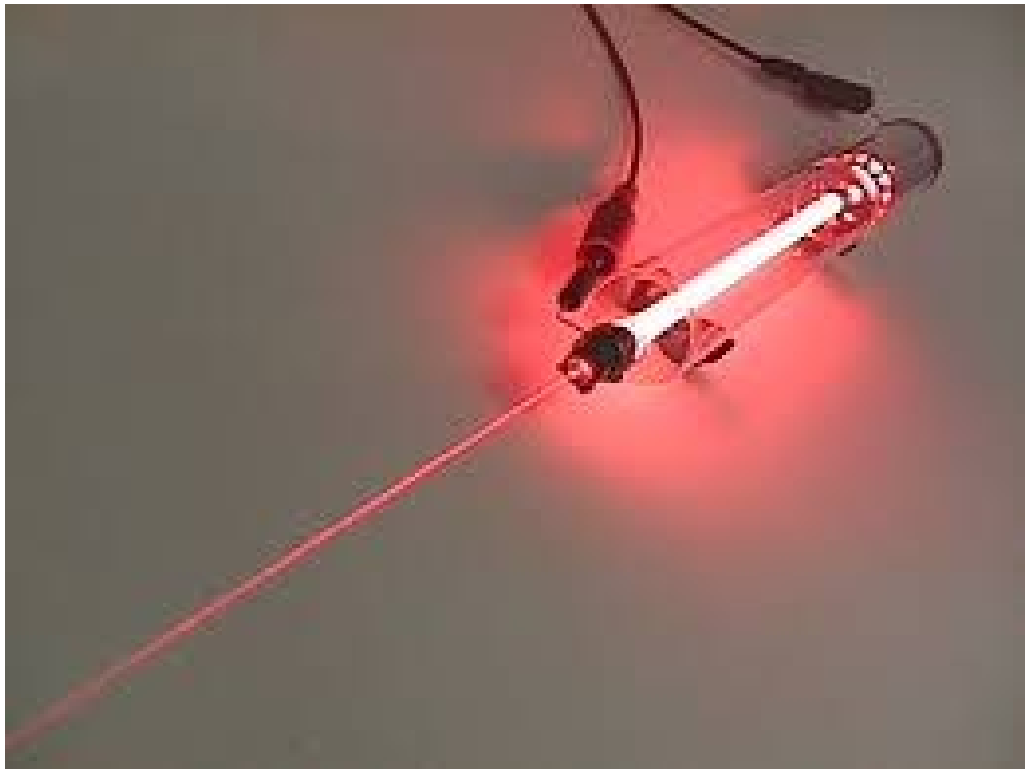
A diagram showing a Gaussian (normal distribution) laser beam with a TEM_{00} mode. The TEM_{00} (Transverse Electro Magnetic zero zero) mode is the one most qualified for laser processing.

Laser Beam Pulsing

- **Continuous Wave (CW)**
  - Beam is on all the time
- **Pulsing Device**
  - Can quickly switch a laser beam between the on/off states.
  - Accomplished with a shutter within the laser cavity/resonator, located between one of the mirrors and the end of the gain medium
    - Shutter can be of various types
  - With the purpose of switching the laser to generate short, intense pulses

Common Laser Types

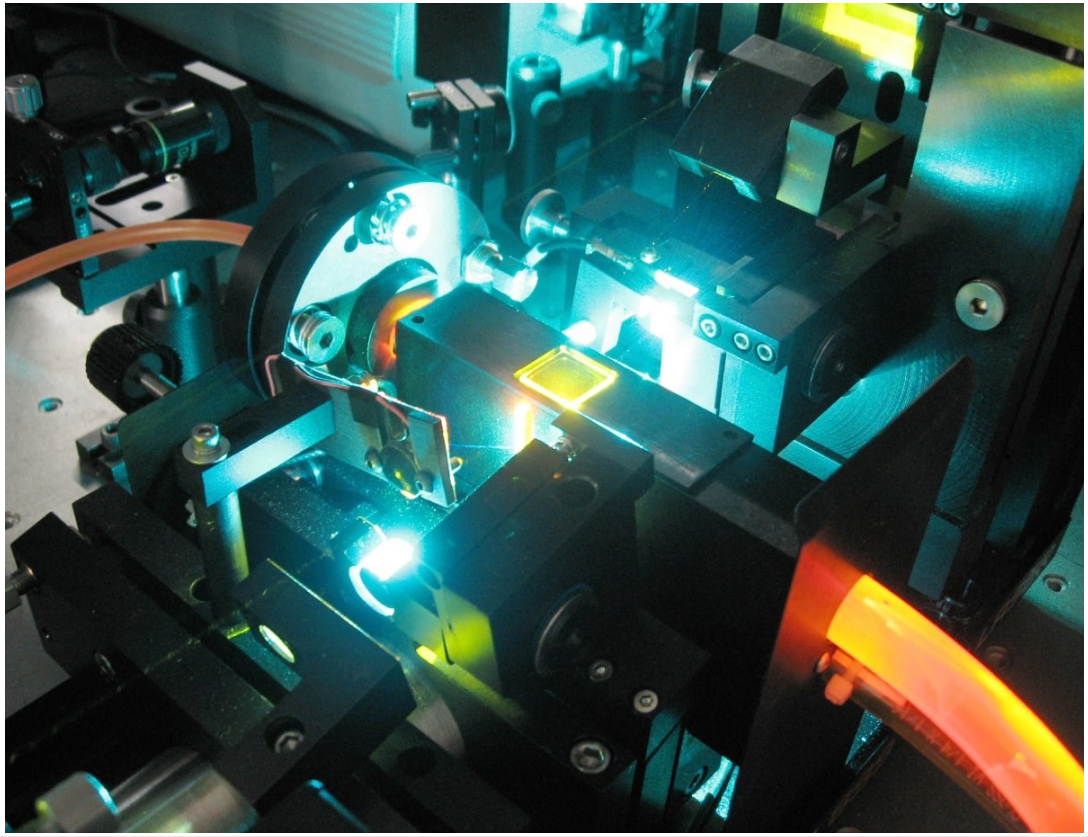
- **Gas Lasers**
  - Lasing is typically achieved by applying a voltage across a glass or ceramic tube that contains the gain medium which is either a low-pressure gas or gas mixture. Shown is a typical Helium Neon gas laser.



Common Laser Types

Liquid or Dye Lasers

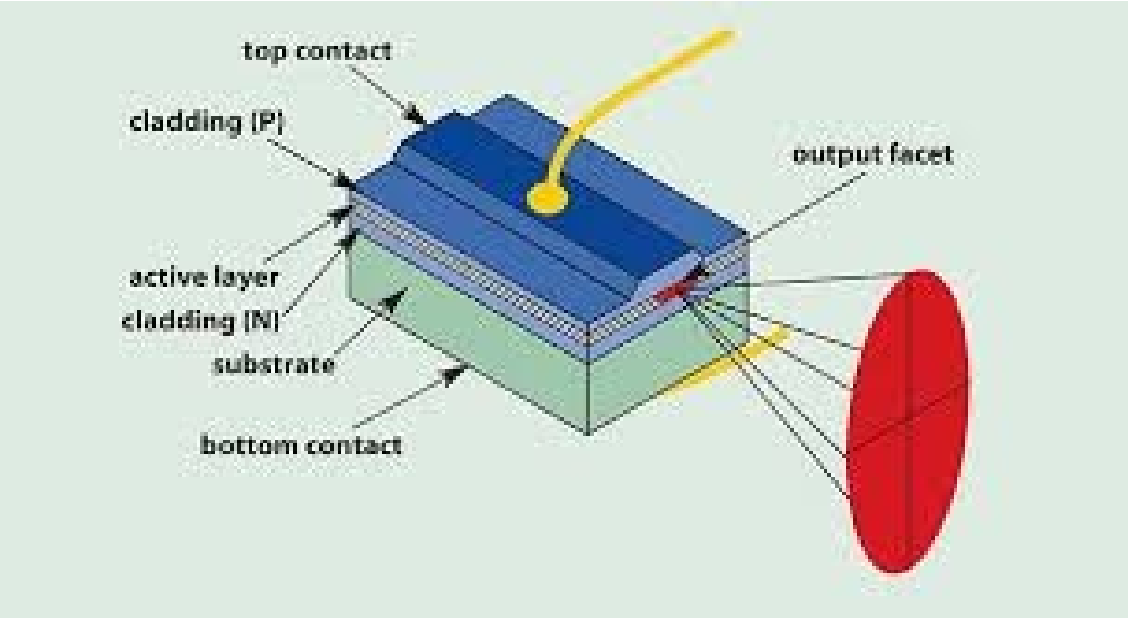
- Certain organic dye molecules can act as radiating species for lasing. The system is known as a liquid dye laser (yellow tube) which are optically pumped by either flashlamps or other lasers.



Common Laser Types

Semiconductor Lasers

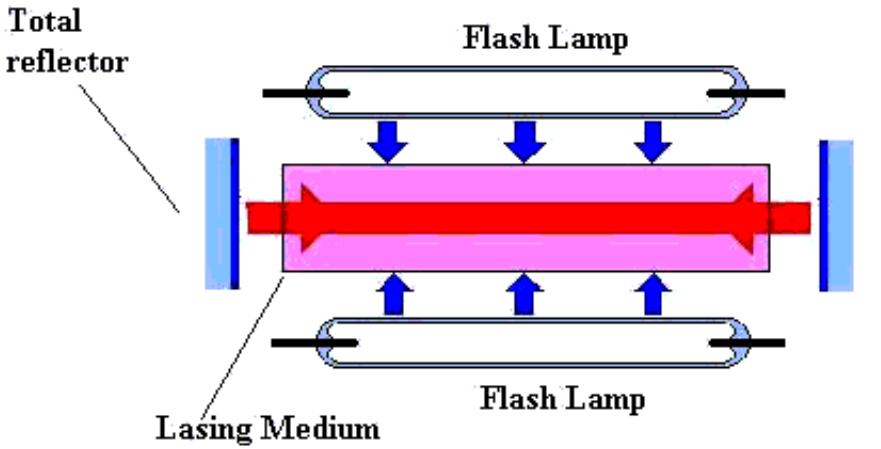
- Often referred to as a laser diode since it operates like an electronic diode. By injecting charge carriers into the region of space defined by the junction, recombination radiation (photons) can occur.

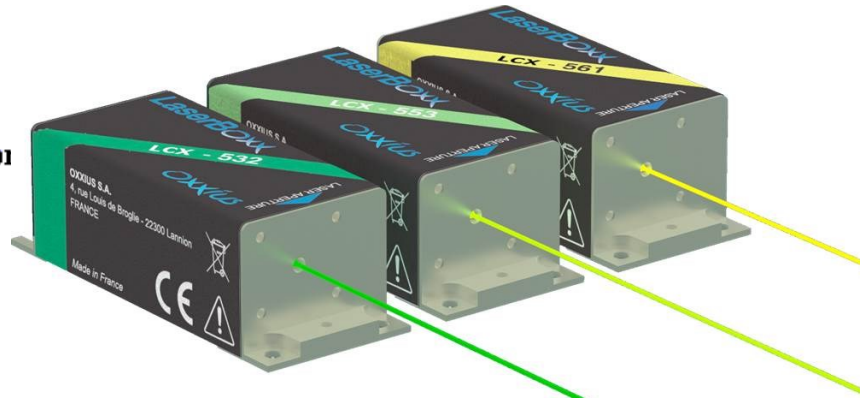


Common Laser Types

Solid-State Lasers

- Refers to a laser whose gain medium has an ion introduced as impurities in an optically transparent host material. Most common is the Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser. Nd is the impurity. YAG is the host material.





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Thank you for your attention.

Please email me your questions/comments or feel free to give me a call.

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