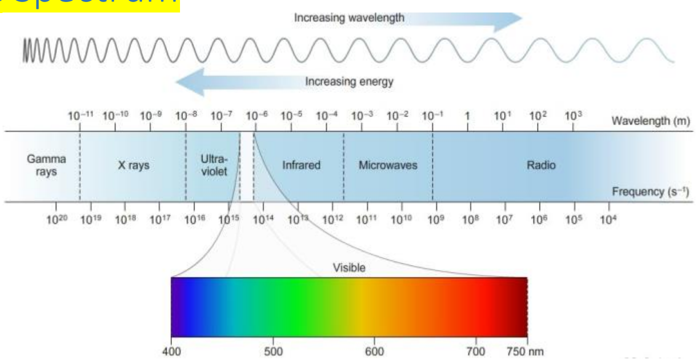
<u>Light and Optics</u>

Electromagnetic Spectrum



Electromagnetic Waves

- Are transverse waves due to the orthogonal oscillating electric and magnetic fields. The magnetic fields create electric fields which then creates another magnetic field. This reciprocating nature of the two fields is the basis of electromagnetic waves.
- <u>Electromagnetic Spectrum:</u> full range of frequencies and wavelength. (An angstrom is times 10 to the -10 meters).
- <u>Speed of Light:</u> All electromagnetic waves travel at the same speed in a vacuum (3.0 x 10^8). For MCAT, all waves can be approximated as moving at this speed. $c = f\lambda$

Colour and the Visible Spectrum

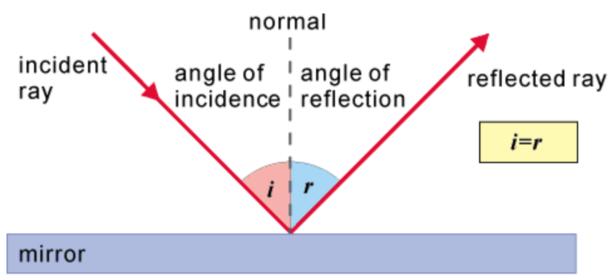
- **Visible Region** is the only part of the spectrum that is perceived as light to the human eye. In the 400-700 nm range.
- Colour of an object depends on what colour is reflected by it.
- **Blackbody** is an ideal absorber of all wavelengths of light.

Geometrical Optics

- <u>Rectilinear Propagation</u> is when light travels through the same medium. Travels in a straight line.

Reflection

- Rebounding of incident light at the boundary of a medium. These light waves are not absorbed into second medium, but reflected back into first medium.
- The normal is the perpendicular line from the surface, all angles are measured from this line

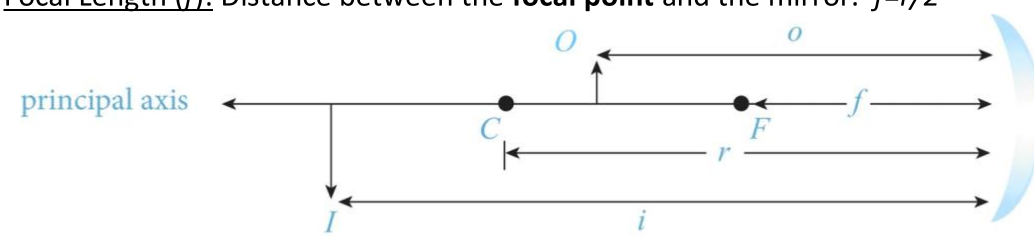


Plane Mirrors

- Real Image: Light actually converges at the position of the image. Can be projected onto a screen.
- Virtual Image: Light appears to be coming from the position of the image but does not actually converge there.
- Plane Mirrors: cause neither convergence nor divergence of reflected light rays. These always create virtual images that are the same distance behind the mirror as in front of it. Can also be thought of as spherical mirrors with infinite radius of curvature.

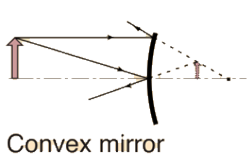
Spherical Mirrors

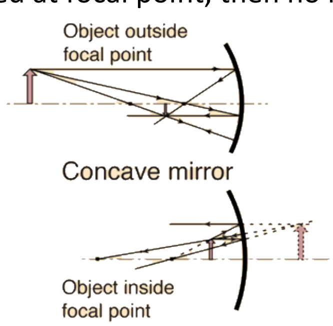
- Center of Curvature: point on the optical axis located at a distance equal to the **radius of curvature** (r) from the vertex of the mirror. Would be center of sphere.
- Concave Surface: center of curvature and radius are located in front of the mirror. These are called **converging mirrors**
- Convex Surface: center of curvature and radius are located behind the mirror. These are called **diverging mirrors**
- Focal Length (f): Distance between the **focal point** and the mirror. $f=r/2$



$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i} = \frac{2}{r}$$

- Image Distance: if $i > 0$ then image is a real image since image is in front of mirror. Opposite for a virtual image.
- Magnification: $m = -{}^{i}/_{o}$
- Ray Diagrams: Need to draw three rays for proper diagram
  - Axis: Ray strikes the mirror parallel to the axis passing normal through center of mirror
  - Focal Point: Ray goes through focal point and hits mirror then travels parallel to normal
  - Intersection: Ray strikes mirror at intersection with axis and is reflected back with the same angle.
- If object is placed at focal point, then no image appears (i=infinity)





Symbol	Positive	Negative
o	Object is in front of mirror	Object is behind mirror (extremely rare)
i	Image is in front of mirror (real)	Image is behind mirror (virtual)
r	Mirror is concave (converging)	Mirror is convex (diverging)
f	Mirror is concave (converging)	Mirror is convex (diverging)
m	Image is upright (erect)	Image is inverted

Refraction

- The bending of light as it passes form one medium to another and changes speed.

Snell's Law

- When light is in any medium except a vacuum, its speed is less, the **index of refraction** is then given by: $n = \frac{c}{v}$
- Refracted rays of light obey Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
  - When light enters a medium with a higher index, it bends towards the normal. Opposite for when light enters a medium with a lower index.

Total Internal Reflection

- **The critical angle** is when theta 2 is equal to 90 degrees.
  - The refracted light rays pass along the interface between the two media. Only occurs when going form a higher index medium to a lower index medium.

$$\theta_c = \sin^{-1} \frac{n_2}{n_1}$$

- **Total Internal Reflection** is when all the light incident is reflected back into the original medium. This happens when the angle of incidence is larger than the critical angle.

Lenses

Lenses refract light, and there are two surfaces that affect the path of light

Thin Spherical Lenses

- Lenses generally have negligible thickness, since light can travel from either side, they have two focal points. For thin lenses, the length of these focal points are the same, so it is as if there is only one focal point.
- Converging lenses are always thicker at the center, while diverging lenses are always thinner at the center. Same equation as those for mirrors apply.

Real Lenses

- The focal length can be derived from the **lensmaker's equation:**

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) r_1 \; is\; radius\; of\; curvature\; of\; the\; first\; lens\; surface$$

Sign Convention for Lenses

Symbol	Positive	Negative
o	Object is on same side of lens as light source	Object is on opposite side of lens from light source (extremely rare)
i	Image is on opposite side of lens from light source (real)	Image is on same side of lens as light source (virtual)
r	Lens is convex (converging)	Lens is concave (diverging)
f	Lens is convex (converging)	Lens is concave (diverging)
m	Image is upright (erect)	Image is inverted

The real side is where light actually goes. So for lenses, a real image will be one which is on the opposite side of the lens since lenses are meant to refract light, not reflect it.

Convex Lens is converging like a concave mirror so they have similar properties.

Power

- Power is measured in **diopters** and f needs to be in meters: $P = {}^{1}/_{f}$

- Hyperopia: farsightedness and is corrected by using converging lenses (convex)
- Myopia: nearsightedness and is corrected by diverging light away.

Multiple Lens Systems

Can be added as if in series with each other:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \cdots + \frac{1}{f_n} \qquad P = P_1 + P_2 + \cdots + P_n$$

- The magnification is also amplified since the image of one lens becomes the object of another lens: $m = m_1 + m_2 + \cdots + m_n$

Spherical Aberration

- The blurring of the periphery of an image as a result of inadequate reflection of parallel beams at the edge of a mirror, or inadequate refraction of parallel beams at the edge of a lens.
- Causes an area of multiple images which causes things to seem blurry

Dispersion

- Various length of light separate from each other
- The smaller the wavelength, the more the light ray will be bent.
- Implies that the index of refraction is dependent on the wavelength of the material.

Chromatic Aberration

- A dispersive effect within a spherical lens.
- Some lenses may cause a significant splitting of white light which results in a rainbow halo around images.

Diffraction

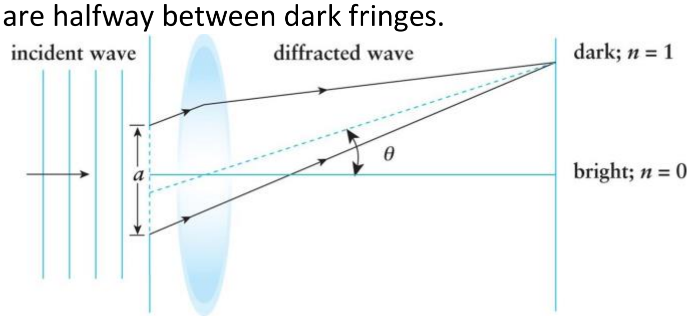
- The spreading out of light as it passes through a narrow opening or around an obstacle.

Single Slit

- When light passes through a narrow opening, with a width on the magnitude of the light's wavelength, the light waves seem to spread out.

Slit-Lens System

- If a lens is placed between the narrow slit and the screen, a pattern of bright central fringes with alternating dark and bright fringes on each side emerges.
- Central bright fringe is twice as wide as side bright fringes. As slit becomes narrower, the central fringe becomes wider.
- Location of the dark fringes (minima) is given by the following formula: $a * \sin\theta = n\lambda$
- Bright fringes are halfway between dark fringes.

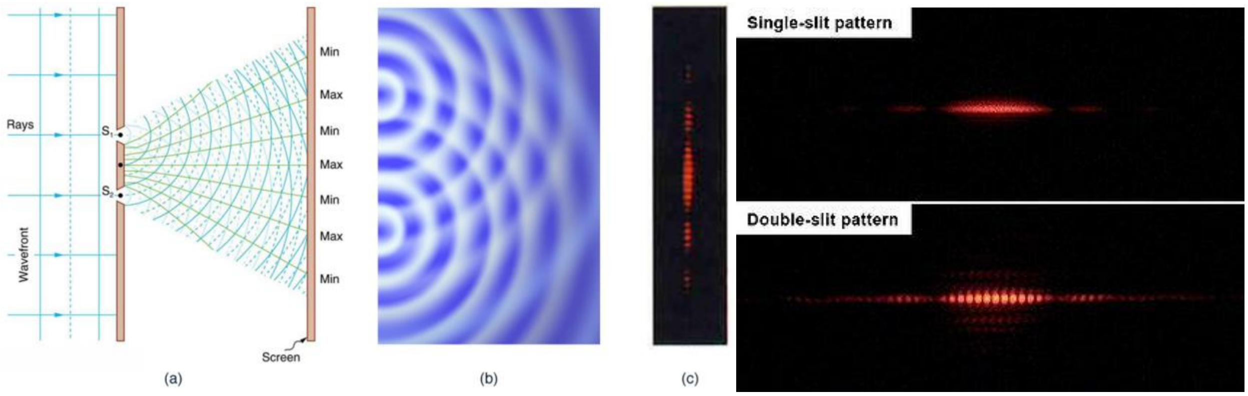


Multiple Slits

- When waves interact, the displacements can be added together in process called **interference**.
- Thomas Young showed that the diffracted rays of light emerging from two parallel slits interfered with one another. A central experiment used to prove that light was a wave.
- The position of dark fringes are positions where destructive interference occurs, this position can be located by using the following equation:

$$d * \sin\theta = (n + 0.5)\lambda, d\ is\ the\ distance\ between\ the\ two\ slits.$$

- Diffraction Gratings: multiple slits arranged into patterns which can create colorful patterns.



X-Ray Diffraction

- Uses the bending of light rays to create a model of molecules.
- Can be combined with protein crystallography during protein analysis.

Polarization

- Plane-Polarized Light: light in which the electric fields of all the waves are oriented in the same direction, plane of the electric field identifies the plane of polarization.
  - Unpolarized light has a random orientation of its electric field vectors
  - Used in the classification of stereoisomers, a compound will cause plane-polarized light to rotate CW or CCW by a given number of degrees, which is relative to its concentration (called the **specific rotation**).
- **Polarizers** only allow the portion of light through that is parallel to the axis of the polarizer.
  - Second polarizer can be added to further alter how much light goes through. If axis is aligned perpendicular to first polarizer, then no light will pass through.
- Circular Polarization: Light has a uniform amplitude, but a continuously changing direction, which causes a helical orientation in the propagating wave.
  - Rarely seen (mainly in highly specialized pigments)
  - Average electrical field vectors and magnetic field vectors lie perpendicular to each other
  - The maxima fall on the outer border of the helix.