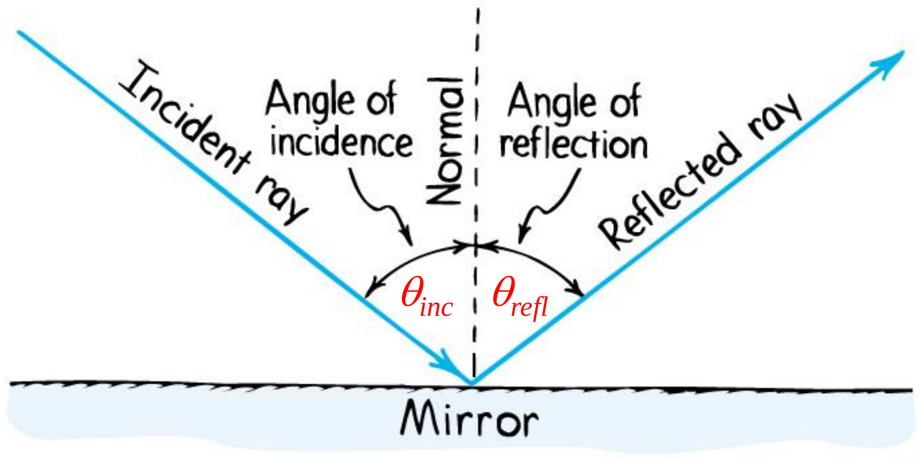
Chapter 28

Reflection & Refraction

Law of Reflection

Angle of incidence equals angle of reflection:

$$\theta_{inc} = \theta_{refl}$$

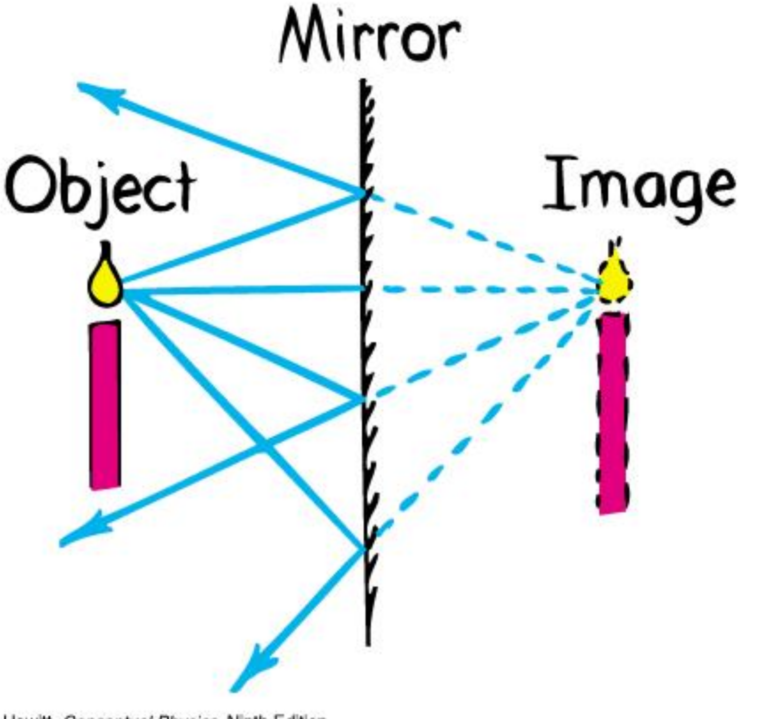


Note that the angles are measured with respect to the NORMAL (perpendicular) to the surface.

Mirrors: Make Use of Reflection

For a flat (plane) mirror:

- the image is as far behind the mirror as the object is in front of the mirror.
- The image is upright and the same size as the object.
- The image is "virtual" meaning that no light actually passes through the location of the image. (That is, the image is behind the mirror.)



Hewitt, *Conceptual Physics*, Ninth Edition.

Curved Mirrors

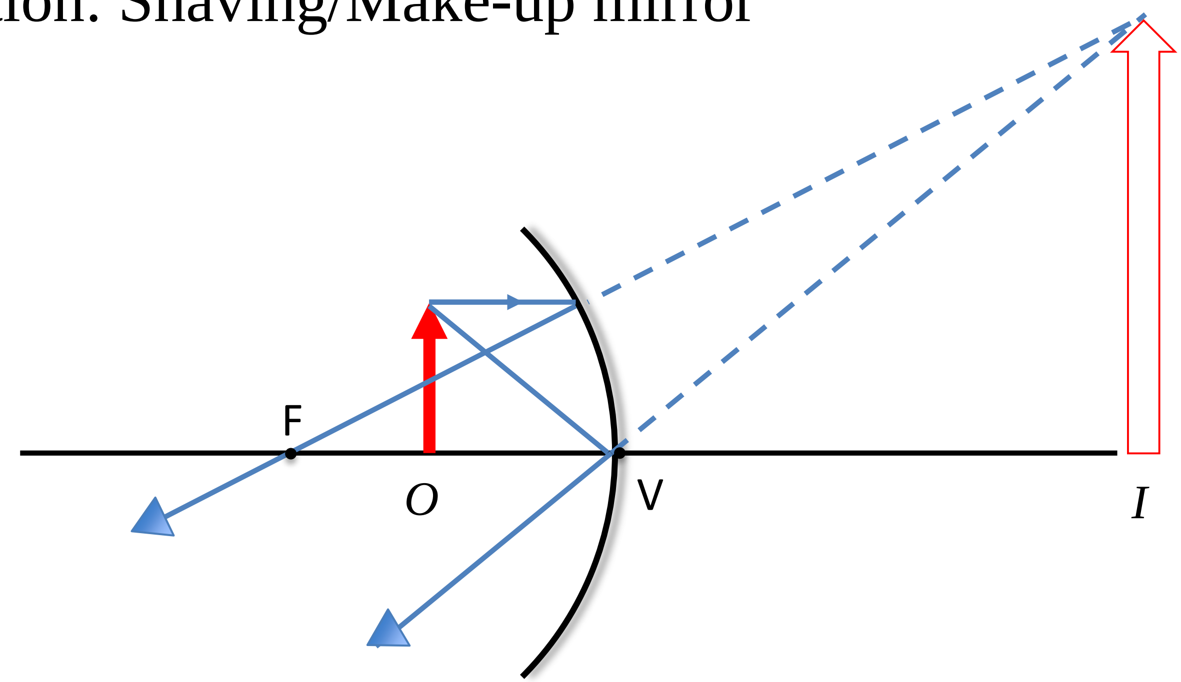
- Concave mirrors: Enlarged upright images form behind mirror (if object is with the focal length). Inverted images form in front of mirror (if object is beyond the focal length) and can be larger or smaller than the object.

- Convex mirrors: Upright image is always behind mirror and closer than object is in front. Image is always smaller than the object.

Concave Mirrors…

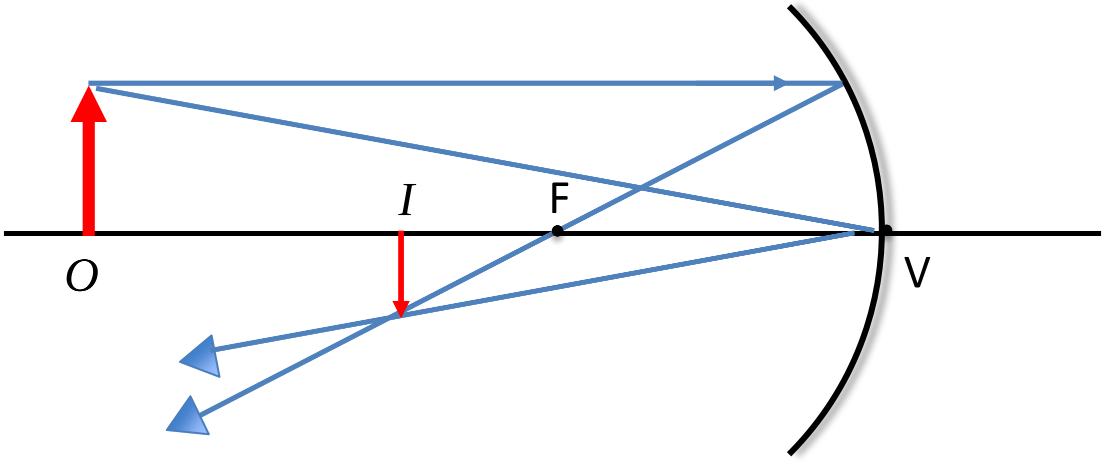
…form enlarged upright images behind mirror if object is within the mirror's focal length. That is, the images are enlarged, upright, and virtual.

Application: Shaving/Make-up mirror



Concave Mirrors…

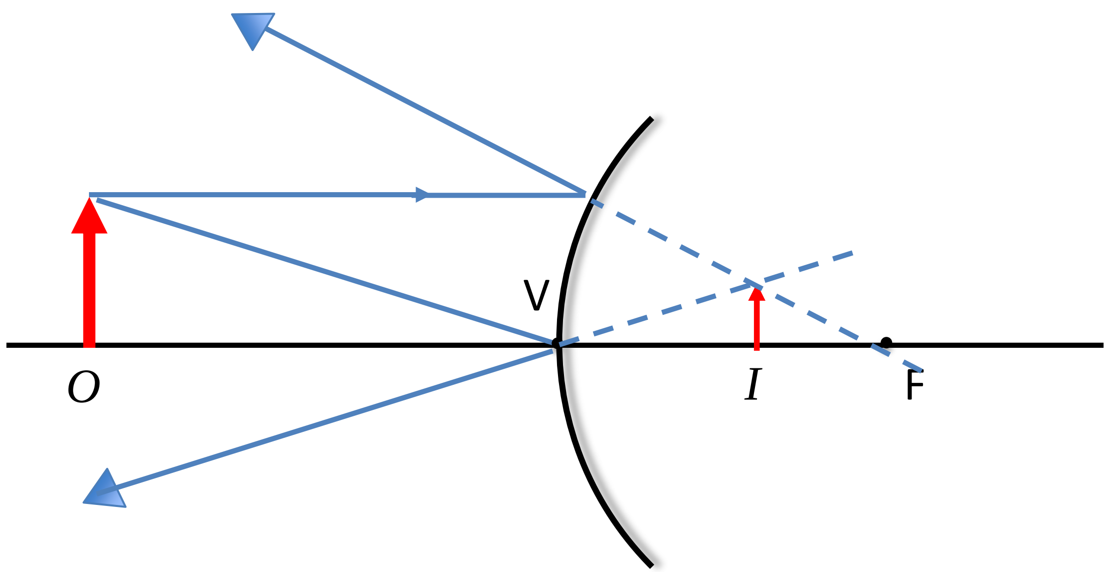
…form inverted images in front of the mirror if the object is beyond the the focal length. The images can be larger or smaller depending on how far beyond the focal length the object is placed. (Shown below is a smaller inverted real image.)



Convex Mirrors…

…always form smaller upright images in behind the mirror regardless of the location of the object. The images will be smaller, upright, and virtual.

Application: Security/Surveillance Mirror



Index of Refraction, *n*

(a.k.a. refractive index or "optical density")

$$n = \frac{c}{v}$$

where *c* = speed of light in vacuum and *v* = speed of light in material.

Note that $n \geq 1$, (since $c > v$).

Example:

Calculate the speed of light in water ($n_{water} = 1.33$).

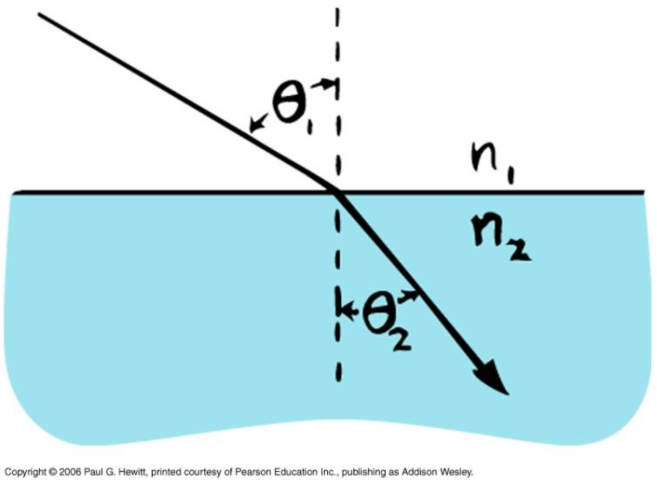
Solve the equation for *v*: $v = \frac{c}{n} = \frac{3\times10^8 \frac{\mathrm{m}}{\mathrm{s}}}{1.33} = 2.0 \times 10^8 \frac{\mathrm{m}}{\mathrm{s}}$.

Thus, in water, light travels at about 2/3 its speed in vacuum.

(Note that the larger the *n*, the slower light travels in that material.)

Law of Refraction (Snell's Law)

Don't panic, but the law of refraction involves (gasp!) a trig function!



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where n_1 and n_2 are the refractive indices of the material for the incoming light and the outgoing light, respectively, and θ_1 and θ_2 are the angles of incidence and refraction, respectively.

Qualitatively, for $n_2 > n_1$, the light ray bends toward the normal.

For $n_2 < n_1$, the light ray bends away from the normal (just reverse the arrows of the light rays in the figure above.

Lenses: Make Use of Refraction

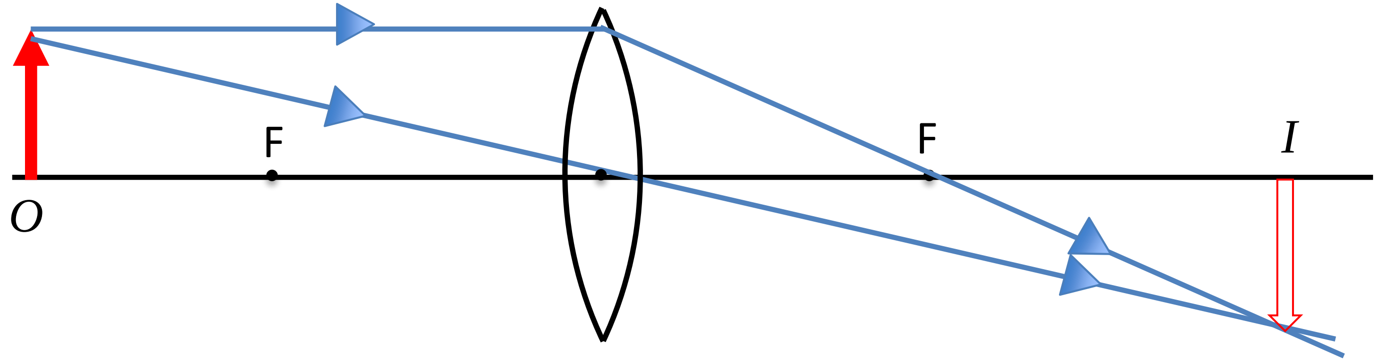
- Convex lenses: Enlarged upright images form on same side as the object lens (if object is within the focal length). Inverted images form on other side of lens (if object is beyond the focal length) and can be larger or smaller than the object.

- Concave lenses: Upright image is always on the same side of the lens as the object and is closer to the lens. Image is always smaller than the object.

Note that the concave lens behave like a convex mirror and a convex lens behaves like a concave mirror except that the light refracts through instead of reflecting back.

Convex Lenses…

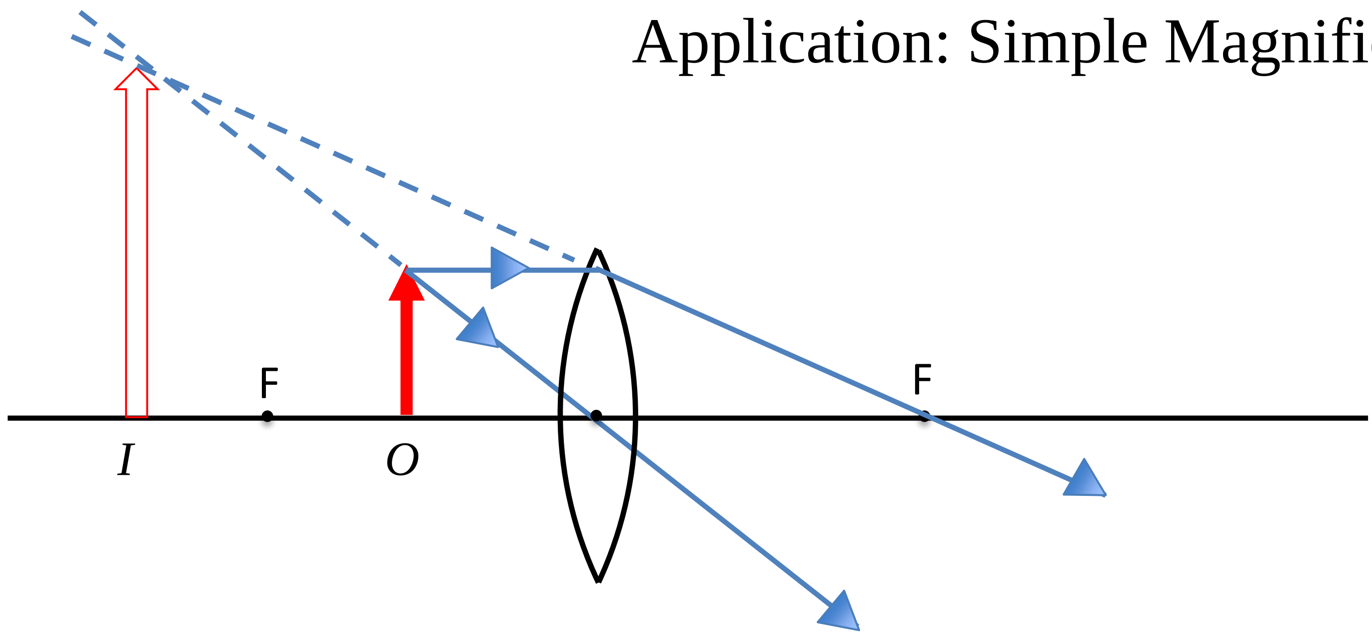
…form inverted images in behind the lens if the object is beyond the the focal length. The images can be larger or smaller depending on how far beyond the focal length the object is placed. (Shown below is a larger inverted real image.)



Convex Lenses…

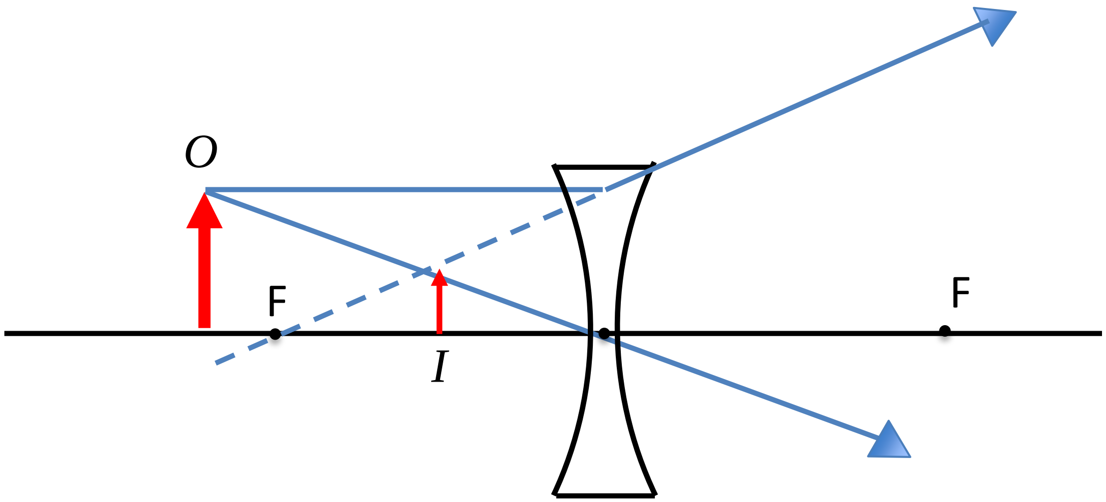
… form enlarged upright images on side of the lens as the object if object is within the mirror's focal length. That is, the images are enlarged, upright, and virtual.

Application: Simple Magnifier



Concave Lenses…

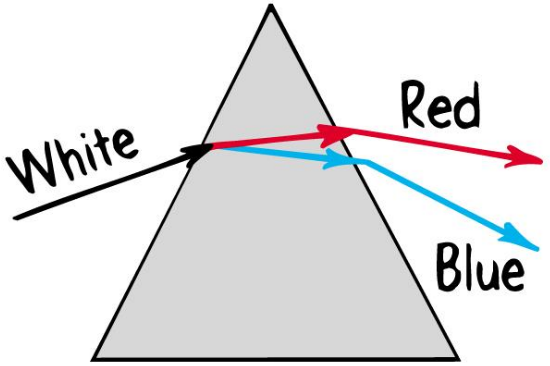
…always form smaller upright images on the same side of the lens as the object regardless of the location of the object. The images will be smaller, upright, and virtual.

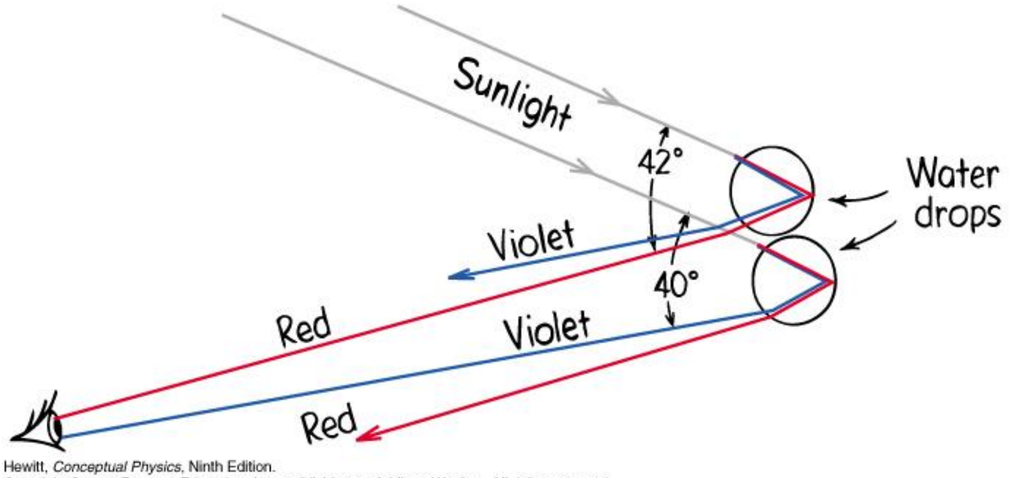


Dispersion

The index of refraction of a material is generally not a constant but actually depends on the frequency of the light. As a result, different frequencies will refract at different angles.

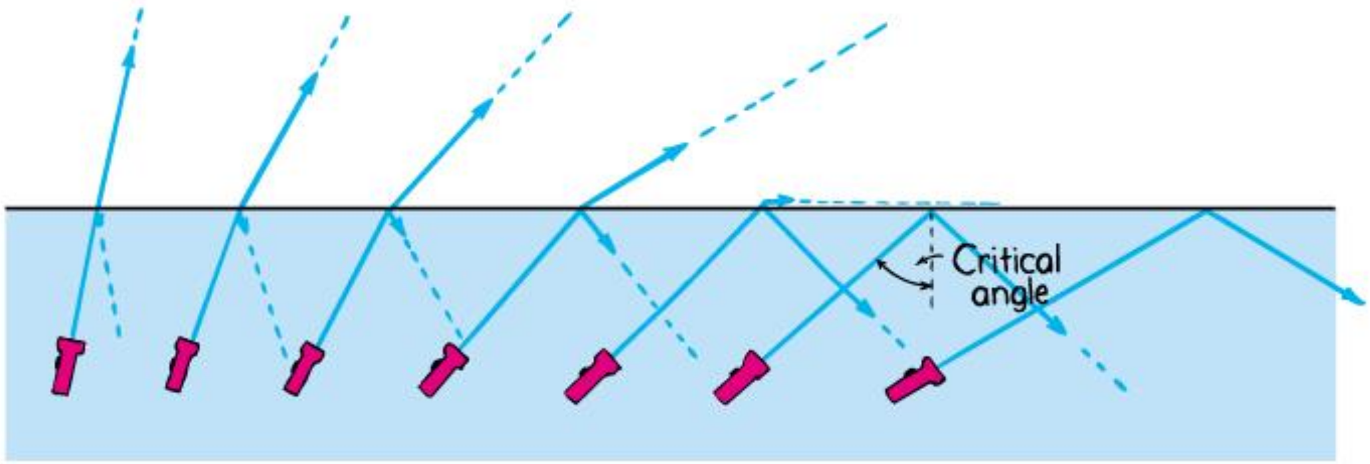
Example: In glass and in water, the *n* for red light is less than the *n* for blue and violet light. Since, red light bends less than blue light and violet, light, white light is dispersed in a rainbow.





Total Internal Reflection

When light goes from a material of higher *n* to one of lower *n*, the ray bends away from the normal. Once the refracted ray reaches 90º, any angle greater than this critical angle of incidence will result in the ray being 100% reflected back into the material. This is total internal reflection.



Hewitt, *Conceptual Physics*, Ninth Edition.

Image Aberrations (defects)

Spherical aberration:

- Light rays further from the symmetry axis do not focus in the same place.
- Affects both mirrors and lenses.

Chromatic aberration:

- Light rays of different color (frequency) do not focus in the same place (due to dispersion).
- Affects only lenses.