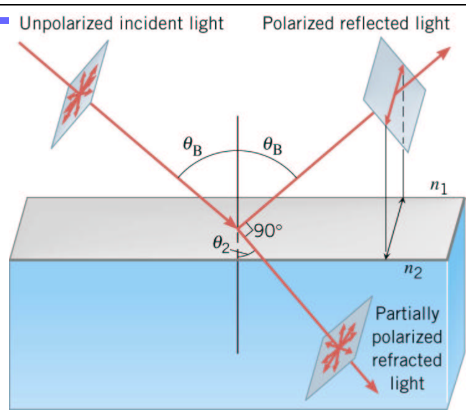
1 – Polarization and the Reflection and Refraction of Light

- The most common technique to produce polarized light is to use a material that only allows for the transmission of a certain component of the electric field.
- Polarization can also be achieved by reflection and refraction. When unpolarized light is reflected from a nonmetallic surface, it may be completely polarized, partially polarized, or unpolarized depending on the angle of incidence.
- If the angle of incidence is 0°, the reflected beam is unpolarized.
- For a particular angle of incidence, the **Brewster angle**, the angle between the reflected and refracted beam is 90°, the reflected beam is completely polarized with its electric field vector parallel to the surface and the refracted beam is partially polarized.



- The **Brewster angle** θ_B can be determined as follows. Since $\theta_2 = 90^\circ - \theta_B$, $\sin\theta_2 = \cos\theta_B$. From Snell's law one then finds:

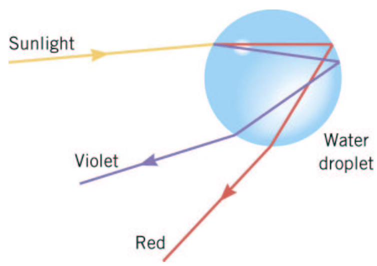
$$\frac{n_2}{n_1} = \frac{\sin\theta_B}{\sin\theta_2} = \frac{\sin\theta_B}{\cos\theta_B}$$

or

$$\boxed{\frac{n_2}{n_1} = \tan\theta_B} \quad (1)$$

2 – Dispersion of Light and Prisms

- In anything but vacuum, the index of refraction depends on the wavelength of light. This phenomenon is called **dispersion**.
- Snell's law then implies that different wavelengths are bent at different angles when incident on a refracting material.
- The index of refraction decreases with increasing wavelength. This means that blue light ($\lambda \approx 470$ nm) or violet light ($\lambda \approx 410$ nm) bends more than red light ($\lambda \approx 650$ nm). Application: **Prisms, Rainbow**:



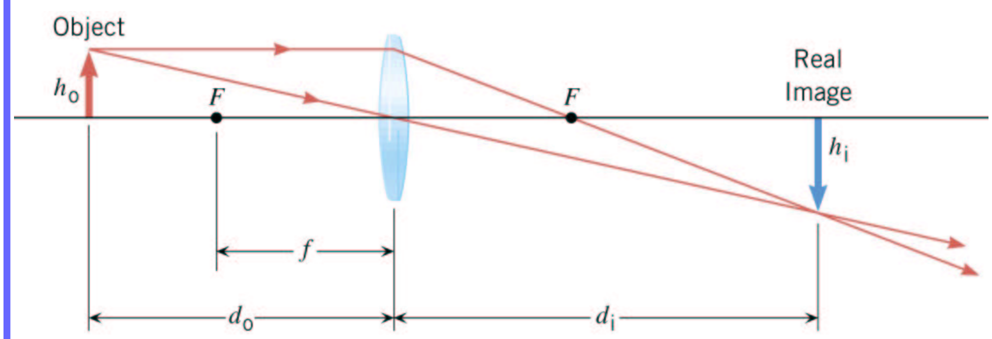
The Refraction of Light

3 – Images formed by Refraction: Lenses

- A **thin lens** consists of a piece of glass or plastic, ground so that each of its refracting surfaces is a segment of a sphere or a plane.
- *The thin lens approximation:* the thickness of the lens is assumed to be negligible.
- Lenses are commonly used in optical instruments such as cameras, telescopes and microscopes.
- There are **converging** and **diverging** lenses.
- The **focal point** for a converging lens is defined as the point where a group of rays parallel to the axis of the lens pass through after being converged by the lens.
- The distance from F to the lens is called the **focal length**, f.
- A diverging lens causes incident parallel rays to diverge after exiting the lens.

The Refraction of Light

- Consider a ray of light passing through the center of a thin lens:



$$\tan\alpha = \frac{h_o}{d_o} = -\frac{h_i}{d_i}$$

From this we find the magnification (Note: $d_i > 0, d_o > 0$):

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \qquad (2)$$

The Refraction of Light

- Moreover:

$$\tan\theta = \frac{h_o}{f} = -\frac{h_i}{d_i - f}$$

and thus (with $h_i/h_o = -d_i/d_o$) (**thin-lens equation**)

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad (3)$$

- Sign conventions for lenses:
  - → $f > 0$ for a converging and $f < 0$ for a diverging lens
  - → $d_o > 0$: object left of the lens (real)
    $d_o < 0$: object right of the lens (virtual)
  - → $d_i > 0$: image right of the lens (real)
    $d_i < 0$: image left of the lens (virtual)

The Refraction of Light

- Ray diagrams are convenient for determining the image formed by a thin lens, or a system of thin lenses. To locate the image of a converging thin lens, three rays are drawn:

Ray 1 is drawn parallel to the principal axis.

After being refracted, it passes through one of the focal points.

Ray 2 is drawn through F, and emerges parallel to the principal axis.

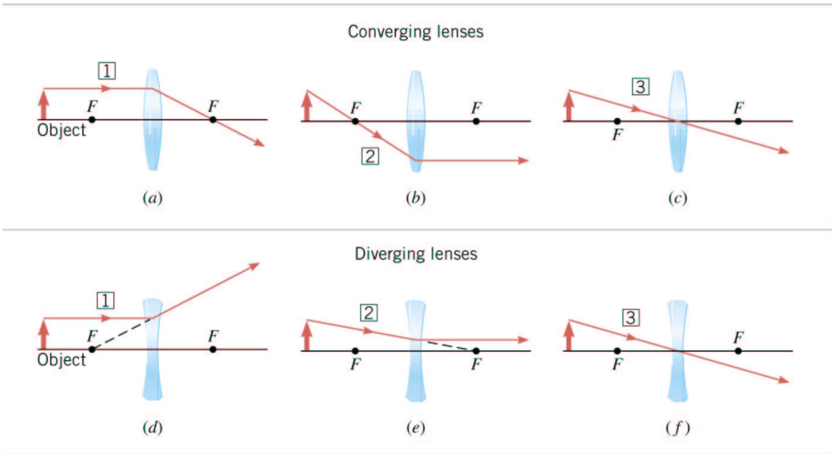
Ray 3 is drawn through the center of the lens

and continues in a straight line.

- The point of intersection of *any two* of the rays can be used to locate the image. The third ray serves as a check on the construction.
- A similar construction is used to locate the image formed by a diverging lens.

The Refraction of Light

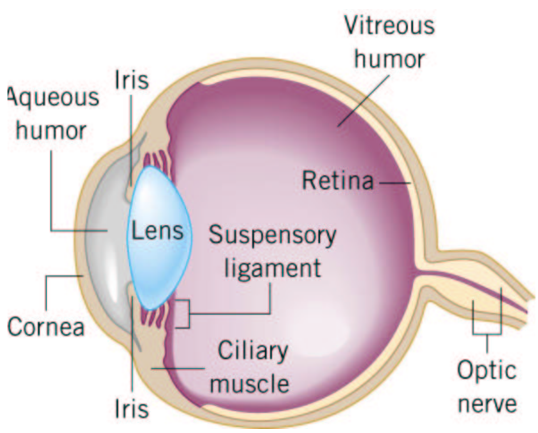
- For a converging lens with the object outside the front focal point, *ie.* $d_o > f$, the image is real and inverted.
- For a converging lens with the object inside the front focal point, *ie.* $d_o < f$, the image is virtual and upright.
- For a diverging lens, the image is virtual and upright.



- **combination of thin lenses:** first, the image of the first lens is calculated as though the 2nd lens were absent. The light then approaches the 2nd lens as if it had come from the image formed by the 1st lens. **The image formed by the 1st lens is treated as the object for the 2nd lens**.
- If the image formed by the 1st lens is virtual, it is treated as a virtual object for the 2nd lens ($d_o < 0$).
- The same procedure can be extended to three or more lenses.
- The overall magnification is the product of the magnifications of the separate lenses.

The Refraction of Light

4 – The Human Eye



- Light entering the eye is focused by the cornea-lens system onto the back surface of the eye (retina) which consists of a large number of sensitive receptors.
- When stimulated by light, they send impulses via the optic nerve to the brain.

- The eye focuses on a given object by varying the shape of the lens and thus its focal length (**accommodation**).
- The smallest distance for which the lens will produce a sharp image on the retina is called the **near point**. It increases with age: from $d_o = 25\ cm$ for people in their twenties and $d_o = 5\ m$ or more at age 60.
- The largest distance for which the lens will produce a sharp image on the retina is called the **far point**. For people with normal vision the far point is nearly at infinity ($d_o = \infty$).
- **Farsightedness:** the image of a distant object is produced behind the retina. Distant objects appear clear, but near objects are blurred. Converging contact lenses are used to correct for farsightedness. Assume the near point of a farsighted person is $d_i = -210$ cm away from the eye, ie the converging lens should produce a (virtual) image 210 cm left of the lens. If this person wants to read a book that is

$d_o = 25$ cm away, the needed focal length of the lens is obtained from the thin-lens equation.

- **Nearsightedness:** either the eye is longer than normal, or the maximum focal length of the lens is too small. Light is focused in front of the retina. Close objects appear clear, but distant objects are blurred. Diverging contact lenses are used to correct for nearsightedness. Assume the far point of a person is $d_i = -519$ cm away from the eye, ie the diverging lens should produce a (virtual) image 519 cm left of the lens. For a nearsighted person to have a normal far point, ie $d_o = \infty$, the needed focal length is obtained from the thin-lens equation: $1/f = 1/\infty + 1/d_i = -1/(519cm) \Rightarrow f = -519cm$.
- The strength of glasses or contact lenses is usually measured in diopters: The **refractive power** of a lens in diopters equals the inverse of the focal length in meters.