Physics 105

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ACADEMY

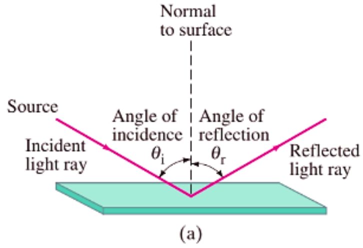
Chapter -23-
(Light: Geometric Optics)

❖ Section (23.1): The Ray Model of light

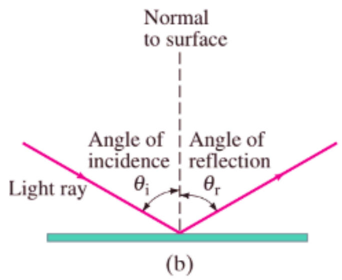
- The Ray Mode: light travels in straight-line called light rays paths in uniform ***transparent media*** like air and glass, Because these explanations involve straight-line rays at ***various angles***, this subject is referred to as geometric optics
  - ➢ The speed of light in vacuum is (**$c = 3*10^8$ m/s**)

❖ Section (23.2): Reflection

- The figure illustrates a beam of light striking a flat surface. In this context:
  - ➢ The angle of incidence (θ_i) is defined as the *angle* between the incoming ray (or wave) and the normal (the line perpendicular) to the surface.
  - ➢ The angle of reflection (θ_r) is defined as the *angle* between the reflected ray and the normal.



(a)



(b)

- According to the ***law of reflection***, these two angles are always equal:

$$\boldsymbol{\theta_r = \theta_i}$$

- Additionally, it is ***important to note*** that the incident ray, the normal, and the reflected ray all lie within the ***same plane***.

❖ Section (23.4): Index of Refraction

- When a wave moves from one medium, where its speed is v_1, to another medium with a different speed v_2 (**where $v_2 \neq v_1$**), its ***direction*** of motion generally changes. This change in direction is known as refraction.
- The speed of light varies depending on the medium it travels through. For instance, in a vacuum, the speed of light is **$c = 3.00\times10^8$**. However, when light travels through water, its speed ***decreases*** by a factor of **1.33.** In general, the speed of light in a medium, denoted as v, is related to the medium's index of refraction n, which is defined as follows:

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

- The index of refraction is defined as the ***ratio*** of the speed of light in a vacuum to the speed of light in a specific *material*.
- It is always greater than or equal to 1.

TABLE 23–1 Indices of Refraction†

Material	$n = \frac{c}{v}$
Vacuum	1.0000
Air (at STP)	1.0003
Water	1.33
Ethyl alcohol	1.36
Glass	
Fused quartz	1.46
Crown glass	1.52
Light flint	1.58
Plastic	
Acrylic, Lucite, CR-39	1.50
Polycarbonate	1.59
"High-index"	1.6–1.7
Sodium chloride	1.53
Diamond	2.42

† λ = 589 nm.

✓ ***Example:*** How much time does it take for light to travel 1.20 m in water? (where **n** for water = 1.33)

✓ ***Solution:***

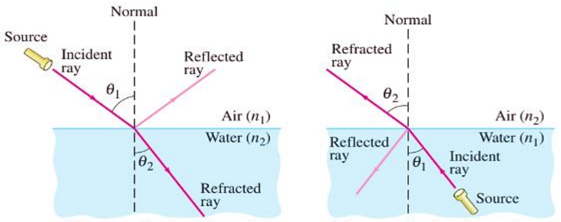
n for water = 1.33 , c = 3 *10^8 m/s

$v = \frac{c}{n} = \frac{3*10^8}{1.33}$ = 2.25 * 10^8 m/s

$v = \frac{d}{t}$ so the time equal

$t = \frac{d}{v} = \frac{1.2}{2.25*10^8}$ = 0.533 *10^{-8}

❖ Section (23.5): **Refraction: Snell´s Law**



(a) $n_2 > n_1$: Ray bends toward ⊥ (b) $n_1 > n_2$: Ray bends away from ⊥

- Returning to the *direction of propagation*, consider light traveling with speed $v_1 = \frac{c}{n_1}$ in one medium and with speed $v_2 = \frac{c}{n_2}$ in another medium.

- The **r**elationship between the *directions of propagation* in these two media is given by **Snell's law**, which is expressed as:

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

  - Here, θ_1 represents the angle of incidence, and θ_2 denotes the angle of refraction.
  - If $n_1 < n_2$ Which leads to $\theta_2 < \theta_1$ (refracted light bends to wards normal)
  - If $n_1 > n_2$ Which leads to $\theta_2 > \theta_1$ (refracted light bends away from normal)

✓ ***Example***: A beam of light in air enters

I. water (n = 1.33) an angle of 60.0° relative to the normal.
II. diamond (n = 2.42) at an angle of 60.0° relative to the normal.

Find the angle of refraction for each case (where n for light = 1)

✓ ***Solution:***

I. To find θ of refraction of water use Snell's law:

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

$1 \sin(60^\circ) = 1.33\sin\theta_2$

$\theta_2 = \sin^{-1}(\frac{\sin(60°)}{1.33}$

$\theta_2 = 40.62^\circ$

II . To find θ of refraction of diamond use Snell's law :

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

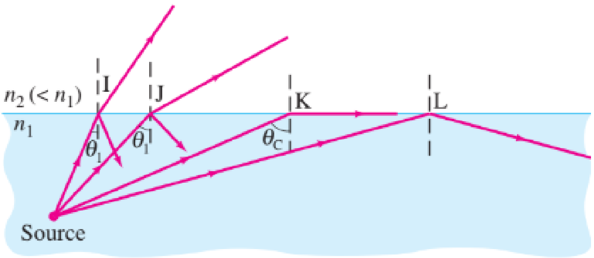
$1 \sin(60^\circ) = 2.42\sin\theta_2$

$\theta_2 = \sin^{-1}(\frac{\sin(60°)}{2.42})$

$\theta_2 = 20.96^\circ$

- Apparent depth: it refers to the ***phenomenon*** where an object seems to be nearer to the water's surface than its true depth.

❖ Section (23.6): **Total Internal Reflection; Fiber Optics**



- Sometimes, ***refraction*** can "trap" a light ray, stopping it from exiting the material.
  - ➢ The critical angle: is the ***angle*** of incidence beyond which light traveling from a denser medium to a less dense medium is completely reflected back into the denser medium, rather than refracted.
- This occurs when the angle of incidence causes the refracted ray to lie along the boundary between the two media.

$$\boldsymbol{sin\theta_c = \frac{n_2}{n_1}}$$

- When ***light*** passes from one material into a second material where the index of refraction is less (say, from water into air), the refracted light ray bends away from the normal, as for rays **I** and **J** in figure At a particular incident angle, the angle of refraction will be 90°, and the refracted ray would skim the surface (ray **K**).
- For case **I** and **J** part of the ray is reflected and part is reflected since $\mathbf{n_1 > n_2}$ Which leads to refracted light is bent away from the normal.
  - ➢ From Snell's law:

$$\boldsymbol{n_1 sin\theta_1 = n_2 sin\theta_2}$$

At $\theta_1 = \theta_c$, and the $\theta_2 = 90^\circ$

Sin $\theta_c = \frac{n_2}{n_1}$ (1)

If $\boldsymbol{\theta_1} > \boldsymbol{\theta_c}$ that's leads to $\mathbf{sin\theta_1} > \boldsymbol{\frac{n_2}{n_1}}$

But in Snell's law $\frac{n_1}{n_2} sin\theta_1 = sin\theta_2$,sin θ_2 >1 which cannot happen since sin $\theta \leq 1$

For $\boldsymbol{\theta_1 > \theta_c}$ no light is refracted and all light is reflected this is called ***total internal reflection***

  - ➢ Total internal reflection: is a **phenomenon** that occurs when a light ray traveling from a denser medium to a less dense medium hits the boundary at **an angle greater than the critical angle**.
  - ➢ Instead of refracting into the second medium, the light is completely reflected back into the original, denser medium. This effect is key in technologies like ***fiber optics*** and ***prisms***.

✓ ***Example:*** Consider a sample of glass whose index of refraction is n = 1.65.
Find the critical angle for total internal reflection for light traveling from this glass to

I. air (n = 1.00).
II. water (n = 1.33)

✓ ***Solution:***

I . $sin\theta_c = \frac{n_2}{n_1}$ so the θ_c for air equal

$\theta_c = \sin^{-1}(\frac{1}{1.65})$

$\theta_c = 37.30^\circ$

II. $sin\theta_c = \frac{n_2}{n_1}$ so the θ_c for water equal

$\theta_c = \sin^{-1}(\frac{1.33}{1.65})$

$\theta_c = 53.71^\circ$

- **Fiber Optics; Medical Instruments:**
  - Total internal reflection is the principle behind fiber optics. Glass and plastic fibers as thin as a few micrometers in diameter are commonly used. A bundle of such slender transparent fibers is called a light pipe or fiber-optic cable.

- Fiber - optic cables are use in:

I. Communication:
  - ✓ This allows for extremely fast and high-capacity data transmission. Optical fibers can accommodate over 100 distinct wavelengths, with each one capable of carrying more than 10 gigabits of data per second.

II. Medicine:
  - ✓ The ability of optical fibers to transmit light along curved paths has been effectively utilized in various medical fields. Notably, devices called endoscopes enable physicians to examine the inside of the body by guiding a flexible tube containing optical fibers into the area of interest. For instance, a type of endoscope known as a bronchoscope can be inserted through the nose or throat, navigated through the bronchial tubes, and eventually positioned in the lungs. Once there, the bronchoscope delivers light via one set of fibers and transmits an image back to the physician through another set. In some cases***, the bronchoscope*** can even be used to collect small tissue samples for further analysis. Similarly, ***the colonoscope*** is used to examine the colon, making it a vital tool in the fight against colon cancer.

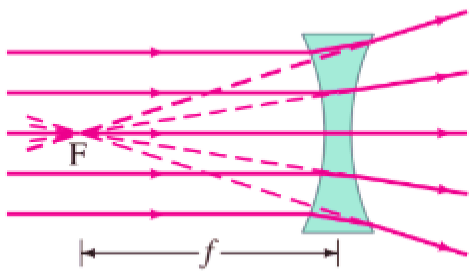
❖ Section (23.7): Thin Lenses; Ray Tracing

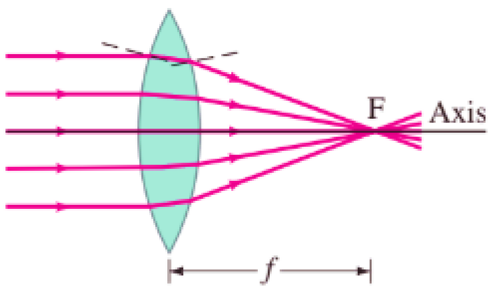
- A Lens: is a transparent optical device, typically made of glass or plastic, that bends or refracts light to ***converge*** or ***diverge*** it. Lenses are commonly used in various devices like microscope, and telescopes to focus light and form images.

- There are **two** primary types of lenses:

  I. Convex (converging) lenses: which focus light rays by bringing them together. These lenses take *parallel rays* of light and converge them at a focal point.
  - ✓ Convex lenses are thicker in the ***center*** compared to the edges.

  II. Concave (diverging) lenses: which ***cause light rays*** to spread apart. These lenses make *parallel rays* diverge as if they are originating from a point source.
  - ✓ Concave lenses are thinner in the ***center*** *than at the edges.*





Convex lens

- The P ray—or parallel ray—approaches the lens parallel to its axis. The P ray is bent so that it passes through the focal point of a convex lens .
- The F ray (focal-point ray) is directed through the focal point and then toward the lens. The lens bends this ray so that it travels parallel to the axis, which is essentially the reverse of how a parallel ray (P ray) is handled.
- The behavior of a convex lens is more varied, as the type of image it produces depends on the object's position. For instance, if the object is located beyond the focal point the image will be inverted, appear on the opposite side of the lens, and light will pass through it, resulting in a real image, which may be either reduced or enlarged in size. Conversely, if the object is placed between the lens and the focal point , the image will be virtual ,upright, and enlarged .

Concave lens

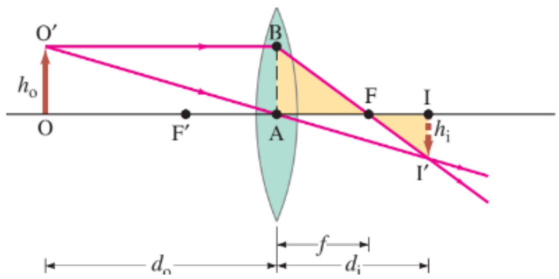
- The P ray—or parallel ray— approaches the lens parallel to its axis and, when extended backward, appears to originate from the focal point on the same side of the lens.
- The F ray (focal-point ray) is directed toward the focal point on the opposite side of the lens. However, before reaching that point, the ray passes through the lens and is bent to travel parallel to the axis.
- In a concave lens, the image is upright and smaller in size. Additionally, the image is virtual because it appears on the same side of the lens as the object.

- The midpoint ray (M ray) goes through the middle of the lens, which is basically like a thin slab of glass. For ideal lenses, which are infinitely thin, the M ray continues in its original direction with negligible displacement after passing through the lens.

❖ Section (23.8): The Thin Lens Equation

- We will now derive an equation that connects the ***image distance*** to the *object distance* and the focal length of a thin lens.
- This thin-lens equation allows for **quicker** and **more accurate** determination of *image position* compared to ray tracing.
- The derivation can be based on Figure, which illustrates the image produced by a convex lens along with the P and M rays used to locate the image. Observe that the P ray forms two similar blue-shaded triangles on the right side of the lens in Figure (a). Since ***these triangles are similar***, it follows that

$$\frac{h_\circ}{f} = \frac{-h_i}{d_i - f}$$



- ➢ Where f is the focal length: is the distance from the lens to the focal point.
- ➢ We use $(-h_i)$ on the right side of the equation, because $(h_i)$is ***negative*** for an inverted image.
- ➢ Next, the (M) ray forms another pair of similar triangles, shown with pink shading in Figure 5 (b), from which we obtain the following:

$$\frac{h_\circ}{d_\circ} = \frac{-h_i}{d_i}$$

- **Combining** these *two relationships*, we obtain a result known as the **thin-lens equation**:

$$\frac{1}{d_\circ}+\frac{1}{d_i}=\frac{1}{f}$$

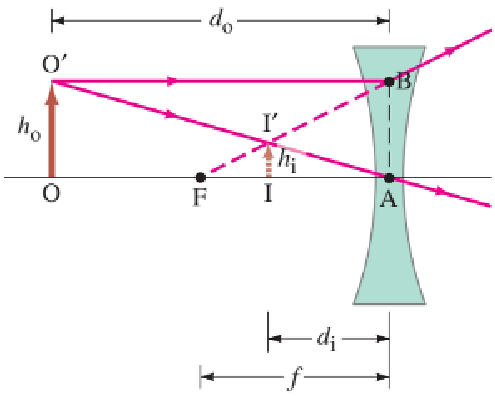
➢ Magnification of the image: is the ratio of the image height to object height

$$m=\frac{h_i}{h_\circ}$$

✓ ***Rearranging*** the Equation:

$$m=\frac{h_i}{h_\circ}=\frac{-d_i}{d_\circ}$$

- As previously mentioned, the sign of the magnification reveals the orientation of the image, while its magnitude shows how much the image size is enlarged or reduced compared to the object. The thin-lens equation, although originally derived for converging lenses, is applicable to both converging and diverging lenses in all cases if the following sign conventions are used:



- ***Focal Length***
  - ✓ f is positive for converging (convex) lenses.
  - ✓ f is negative for diverging (concave) lenses.
- ***Magnification***
  - ✓ m is positive for upright images (same orientation as object).
  - ✓ m is negative for inverted images (opposite orientation of object).
- ***Image Distance***
  - ✓ d_i is positive for real images (images on the opposite side of the lens from the object).
  - ✓ d_i is negative for virtual images (images on the same side of the lens as the object).
- ***Object Distance***
  - ✓ d_o is positive for real objects (from which light diverges).
  - ✓ d_o is negative for virtual objects (toward which light converges).

- The power: Ophthalmologists and optometrists use the reciprocal of the focal length to define the strength of eyeglass or contact lenses, rather than the **focal length itself**.

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

➢ The unit for lens power is the diopter (D), which is an inverse meter: **1 D = 1 m^{-1}**

✓ ***Example:*** An object is placed 12 cm in front of a diverging lens with a focal length of -7.9 cm. Find:

(a) The image distance

(b) The magnification

✓ ***Solution:***

(a) $\frac{1}{d_{\circ}} + \frac{1}{d_i} = \frac{1}{f}$

$\frac{1}{12*10^{-2}} + \frac{1}{d_i} = -\frac{1}{7.9*10^{-2}}$

$d_i = -0.0476$ m

(b) $m = \frac{-d_i}{d_{\circ}}$

$m = \frac{-(-0.0476)}{0.12}$

$m = 0.3966$

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