Applied Physics

(PHC-103/104)

Lecture 12

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What is Wave?

"A movement that carries energy and information from one place to another"

- Waves are a big part of physics. They help us send and receive information.
- Think of it like sending data over the internet - it's like a wave of information that travels from one place to another.
- Engineers work to improve how we send and receive these waves, and it's a very important job.

Types of Waves

Waves are of three main types:

1. ***Mechanical waves.*** These waves are most familiar because we encounter them almost constantly; common examples include water waves, sound waves, and seismic waves. All these waves have two central features: They are governed by Newton's laws, and they can exist only within a material medium, such as water, air, and rock.
2. ***Electromagnetic waves.*** These waves are less familiar, but you use them constantly; common examples include visible and ultraviolet light, radio and television waves, microwaves, x rays, and radar waves. These waves require no material medium to exist. Light waves from stars, for example, travel through the vacuum of space to reach us. All electromagnetic waves travel through a vacuum at the same speed $c = 299\,792\,458$ m/s.
3. ***Matter waves.*** Although these waves are commonly used in modern technology, they are probably very unfamiliar to you. These waves are associated with electrons, protons, and other fundamental particles, and even atoms and molecules. Because we commonly think of these particles as constituting matter, such waves are called matter waves.

Properties of Waves

1. **Amplitude:** This is the height of the wave. It shows how much energy the wave is carrying.

2. **Wavelength:** This is the distance between two identical points on the wave, like the distance between two peaks.

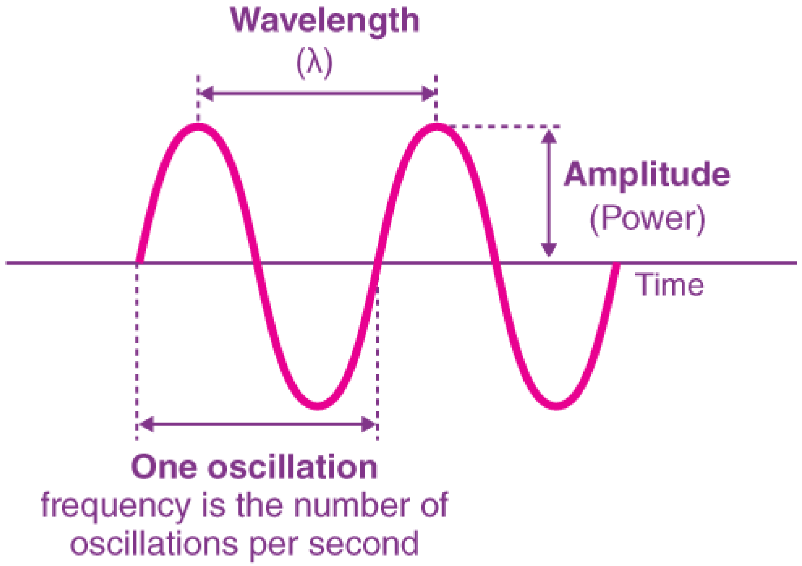
3. **Period:** This is the time it takes for a wave to complete one full cycle.

4. **Frequency:** This is how many waves pass a certain point in a certain amount of time. The unit of frequency is hertz (Hz)

$$\text{frequency} = 1 / \text{period}$$

5. **Speed:** This is how fast a wave travels.

$$\text{Wave Speed} = \text{Distance} / \text{Time}$$



Wave Speed and Wavelength

The speed of a wave is related to its wavelength and frequency by the following equation:

$$v = \lambda f$$

where v is the wave speed, λ is the wavelength, and f is the frequency.

This equation shows that the speed of a wave is equal to the product of its wavelength and frequency. Since the speed of a wave is constant in a given medium, an increase in frequency will result in a decrease in wavelength, and vice versa.

Frequency and Velocity Relationship

The frequency of a wave is related to its velocity by the following equation:

$$v = \lambda f$$

Since the velocity of a wave is constant in a given medium, an increase in frequency will result in a decrease in wavelength.

This means that the velocity of a wave is independent of its frequency.

In other words, if the frequency of a wave is increased, its velocity will remain the same, but its wavelength will decrease. This is because the wave is still traveling at the same speed, but it is completing more cycles in a given amount of time.

What is Interference?

- Interference is what happens when two or more waves meet each other. Depending on the overlapping waves' alignment of peaks and troughs, they might add up, or they can partially or entirely cancel each other.

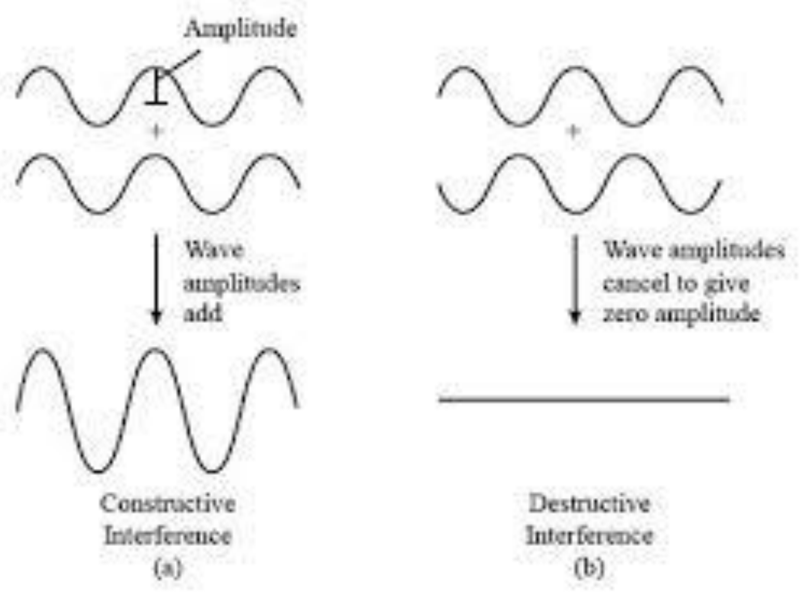
- As per the interference definition, it is defined as

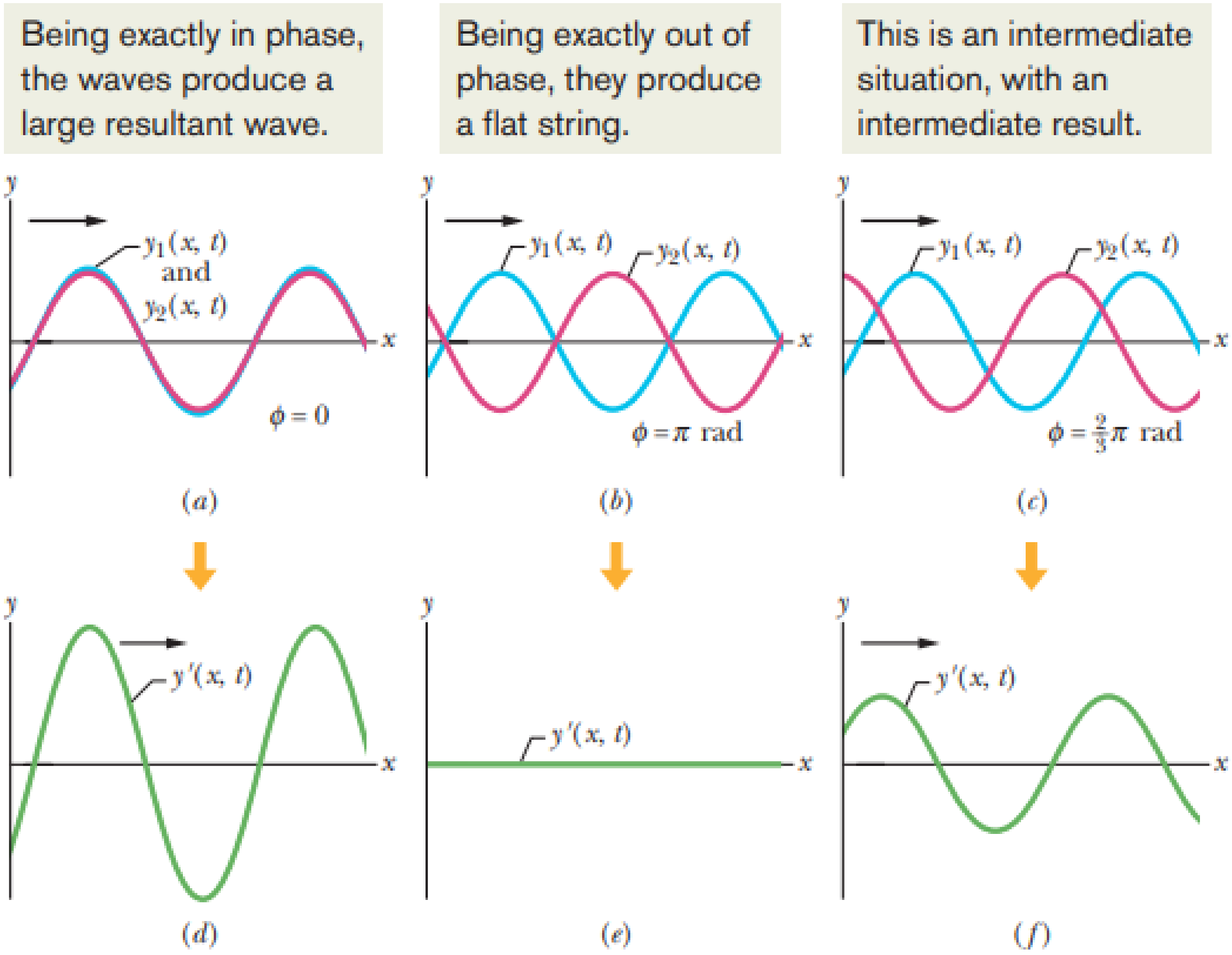
"The phenomenon in which two or more waves superpose to form a resultant wave of greater, lower or the same amplitude."

constructive vs destructive Interference?

- If the crest of a wave meets the crest of another wave of the same frequency at the same point, then the resultant amplitude is the sum of individual amplitudes – this is known as constructive interference.

- Similarly, suppose a wave's crest meets another wave's trough. In that case, the resultant amplitude is equal to the difference in the individual amplitudes – this is known as destructive interference.




Being exactly in phase, the waves produce a large resultant wave.
Being exactly out of phase, they produce a flat string.
This is an intermediate situation, with an intermediate result.
y
x
$y_1(x, t)$ and $y_2(x, t)$
$\phi = 0$
(a)
$y_1(x, t)$
$y_2(x, t)$
$\phi = \pi$ rad
(b)
$y_1(x, t)$
$y_2(x, t)$
$\phi = \frac{2}{3}\pi$ rad
(c)
$y'(x, t)$
(d)
$y'(x, t)$
(e)
$y'(x, t)$
(f)

1. Two waves of equal amplitude (A = 2 cm) and wavelength (λ = 5 cm) are traveling in the same direction. They are in phase with each other, meaning that their peaks and troughs align. What is the resulting amplitude of the combined wave?

2. Two waves have amplitudes $A1=6$ units and $A2=4$ units, but they are completely out of phase. What is the amplitude of the resultant wave?

3. Two waves, each with an amplitude of $A1=5$ units and $A2=12$ units, interfere at a phase difference of $60\circ$. What is the amplitude of the resultant wave?

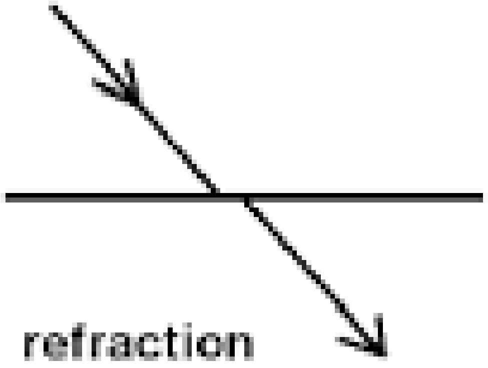
4. Two waves with equal amplitudes $A1=A2=10$ units interfere at a phase difference of $90\circ$. What is the amplitude of the resultant wave?

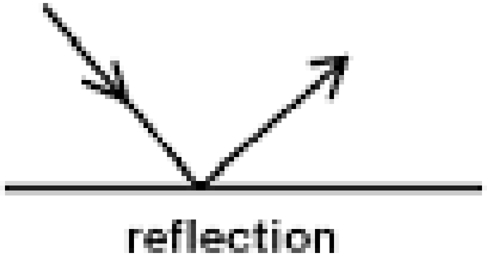
Difference between Reflection and Refraction

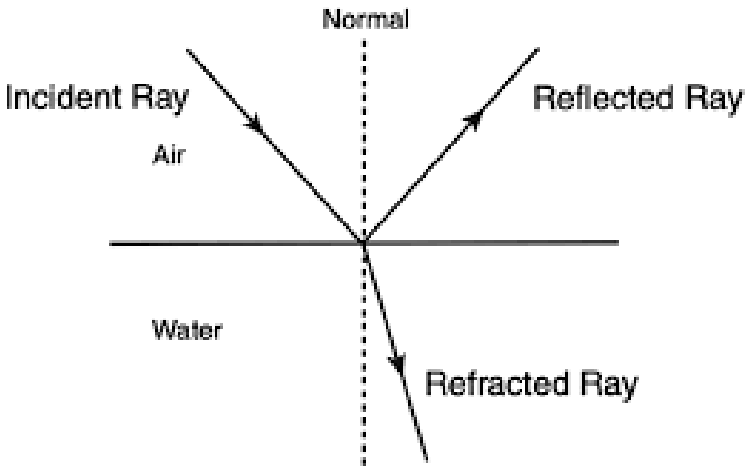
- Reflection is simply the property of a light that rebounds after hitting a surface.

- When the light that passes through a surface undergoes some changes in appearance, whenever it usually passes through a medium, this phenomenon is usually referred to as refraction.

- The two different types of lights that are typically involved in this are the incident ray and the reflected ray. Light energy is incredible and has many uses to it.







Difference between Reflection and Refraction	
Reflection	**Refraction**
This phenomenon usually occurs in mirrors.	This phenomenon usually occurs in lenses.
Reflection can simply be defined as the bouncing back of light when it strikes the medium on a plane.	Refraction can be defined as the process of the shift of light when it passes through a medium leading to the bending of light.
The light entering the medium returns to the same medium.	The light entering the medium travels from one medium to another.
Considering the light waves, they bounce from the plane and change direction.	During refraction, the light waves pass through the surface while simultaneously changing both direction and medium.
The angle of incidence of the light is equal to the angle of reflection.	The angle of incidence is not equal to the angle of refraction.

Laws of Reflection

- We know that light is a form of energy which can undergo various phenomena like refraction, reflection, and interference.

- Law of reflection is defined as:

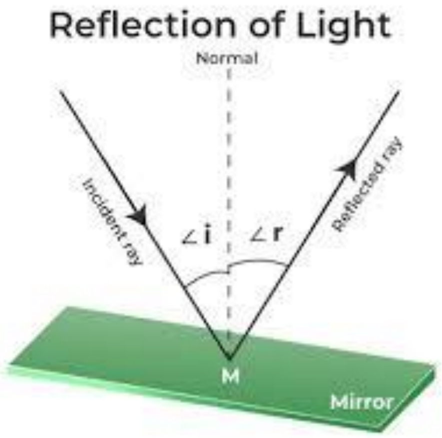
i. The principle when the light rays fall on the smooth surface, the angle of reflection is equal to the angle of incidence,

ii. Also, the incident ray, the reflected ray, and the normal to the surface all lie in the same plane.

Or

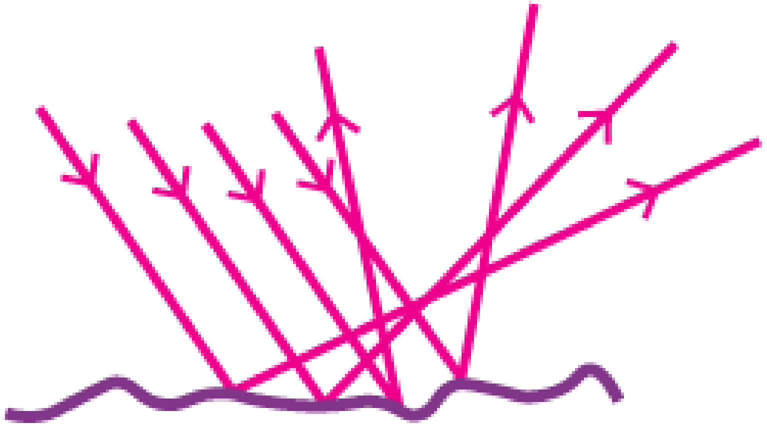
Laws of Reflection:

1. Angle of Incidence = Angle of Reflection
   $\theta_i = \theta_r$, where θ_i is the angle of incidence and θ_r is the angle of reflection.
2. The Incident Ray, Reflected Ray, and Normal lie in the same plane.

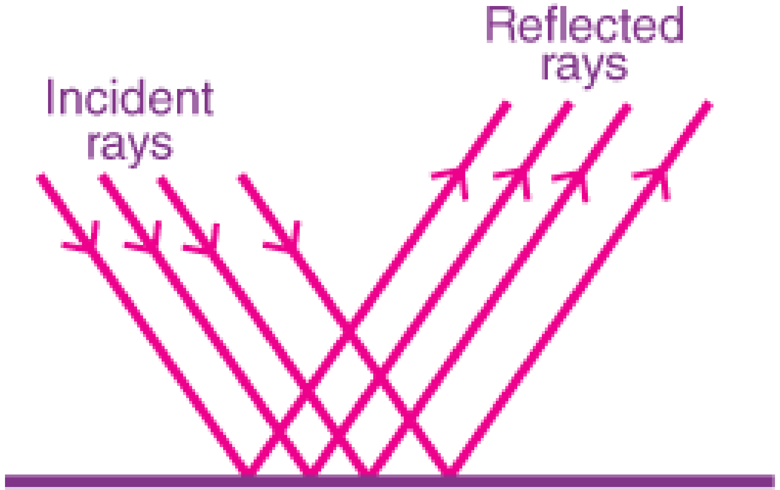


Differences between Regular and Irregular Reflection

S. N o.	Regular Reflection	Irregular Reflection
1	It occurs when all the reflected rays from a given smooth surface are parallel to the parallel incident rays.	It occurs when for a given set of parallel incident rays, the reflected rays do not remain parallel to each other.
2	This occurs from smooth surfaces like a mirror, silver spoon, etc.	This occurs from rough surfaces like wood, table, door, book, etc.
3	The image is formed and seen.	It helps to see objects. No images or blurry images can be seen.



Diffuse reflection from
rough surfaces



Regular reflection from
smooth surfaces

Laws of Refraction

1. **Snell's Law:**

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

where:

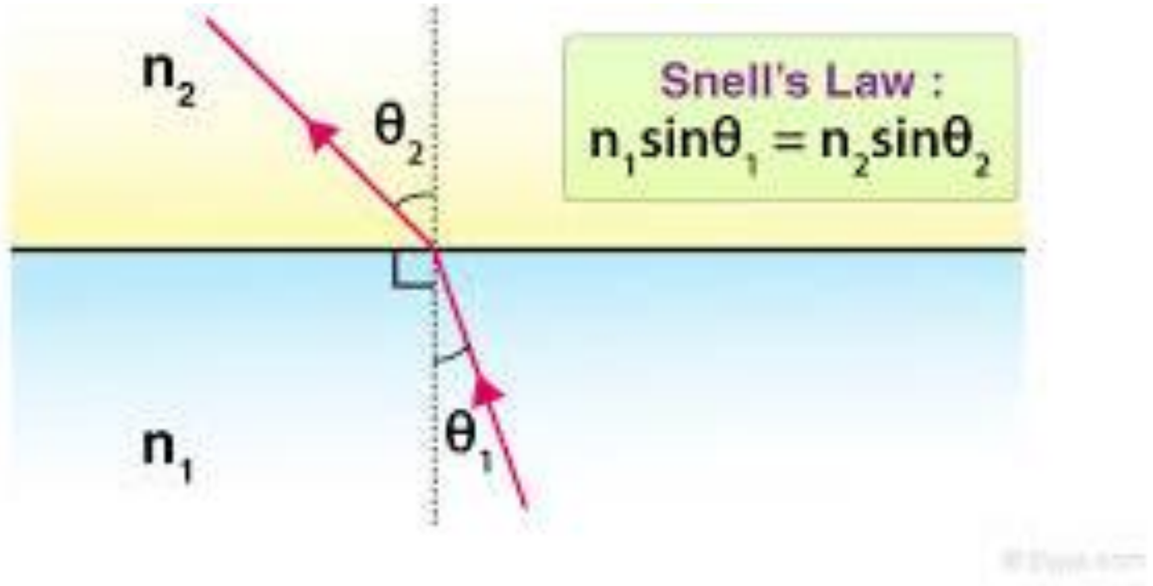
- θ_1: Angle of incidence
- θ_2: Angle of refraction
- v_1, v_2: Speed of light in respective media
- n_1, n_2: Refractive indices of the two media.

2. **The Incident Ray, Refracted Ray, and Normal lie in the same plane.**

Laws of refraction state that:

i. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant. This is also known as Snell's law of refraction

ii. The incident ray refracted ray, and the normal to the interface of two media at the point of incidence all lie on the same plane.



1. **Refractive Index (n):**
    - $n = \frac{c}{v}$, where c is the speed of light in a vacuum, and v is the speed of light in the medium.
    - Higher n: Denser medium (e.g., glass, water).
      Lower n: Rarer medium (e.g., air).
2. **Bending of Light:**
    - Light bends **toward the normal** when it enters a denser medium ($n_2 > n_1$).
    - Light bends **away from the normal** when it enters a rarer medium ($n_2 < n_1$).
3. **Critical Angle and Total Internal Reflection (TIR):**
    - When light moves from a denser to a rarer medium, there exists a **critical angle** (θ_c) where the angle of refraction becomes 90°. Beyond this angle, **total internal reflection** occurs.
    - Critical angle formula: $\sin\theta_c = \frac{n_2}{n_1}$, where $n_2 < n_1$.

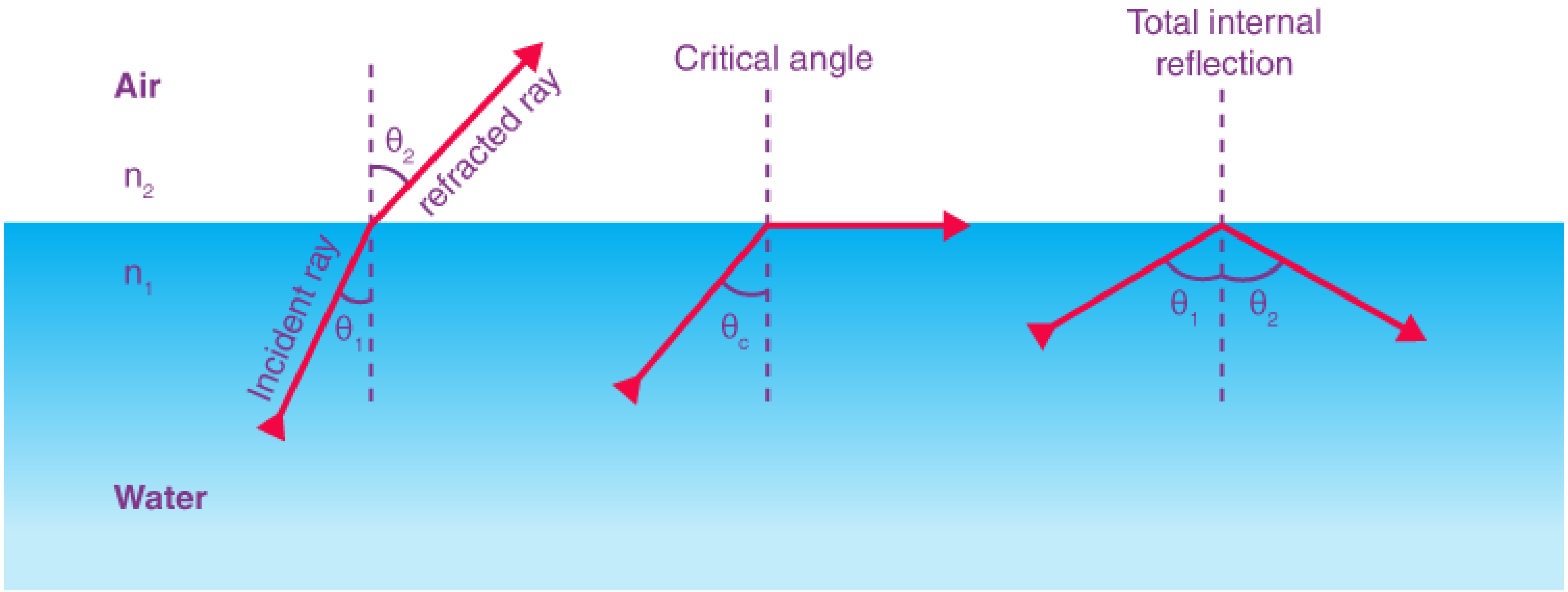
What is Total Internal Reflection?

Total internal reflection is defined as:

The phenomenon which occurs when the light rays travel from a more optically denser medium to a less optically denser medium.

- Consider the following situation. A ray of light passes from a medium of water to that of air.
- Light ray will be refracted at the junction separating the two media.
- Since it passes from a medium of a higher refractive index to that having a lower refractive index, the refracted light ray bends away from the normal.
- At a specific angle of incidence, the incident ray of light is refracted in such a way that it passes along the surface of the water.
- This particular angle of incidence is called the critical angle.
- Here the angle of refraction is 90 degrees.

- When the angle of incidence is greater than the critical angle, the incident ray is reflected back to the medium. We call this phenomenon total internal reflection.



Formula of Total Internal Reflection

Total internal reflection	$\frac{n_1}{n_2} = \frac{sinr}{sini}$
Critical angle, θ	$sin\theta = \frac{n_2}{n_1}$

Notations Used In The Total Internal Reflection Formula And Critical Angle

- r is the angle of refraction
- i is the angle of incidence
- n_1 is the refractive index in medium 1
- n_2 is the refractive index in medium 2
- θ is the critical angle

What are the Conditions of Total Internal Reflection?

Following are the two conditions of total internal reflection:

- The light ray moves from a more dense medium to a less dense medium.
- The angle of incidence must be greater than the critical angle.

1 A light ray strikes a plane mirror at an angle of incidence of 30°. What is the angle of reflection?

2 A light ray passes from air ($n_1 = 1.00$) into water ($n_2 = 1.33$) at an angle of incidence of 45°. Find the angle of refraction.

3 The critical angle for light passing from glass ($n_1 = 1.50$) to air ($n_2 = 1.00$) is to be calculated.

4 A light ray passes from air into a medium, reducing its speed from $3.0 \times 10^8 \mathrm{~m/s}$ to $2.0 \times 10^8 \mathrm{~m/s}$. Find the refractive index of the medium.

5 A light ray strikes the surface of a glass slab ($n = 1.5$) at an angle of incidence of 60°. Find:

1. The angle of reflection.
2. The angle of refraction.

6 A light ray passes from water into air with an angle of incidence of 50°.
If the refractive index of water is 1.33, what is the angle of refraction?

What is Diffraction?

Diffraction is the bending or spreading of light waves around obstacles or through small openings, which cannot be explained by simple ray optics. It is evidence that light behaves as a wave.

Wave Nature of Light and Diffraction

Evidence of Wave Nature:

Diffraction provides strong evidence that light is a wave because:

1. Particle theory cannot explain the bending of light around obstacles.
2. The interference and diffraction patterns depend on wavelength, a property associated with waves.

Comparison of Interference and Diffraction

Property	Interference	Diffraction
Source	Requires two coherent sources.	Requires a single source.

Young's Interference Experiment

In 1801, Thomas Young experimentally proved that light is a wave, contrary to what most other scientists then thought. He did so by demonstrating that light undergoes interference, as do water waves, sound waves, and waves of all other types. In addition, he was able to measure the average wavelength of sunlight; his value, 570 nm, is impressively close to the modern accepted value of 555 nm. We shall here examine Young's experiment as an example of the interference of light waves.

Figure 35-8 gives the basic arrangement of Young's experiment. Light from a distant monochromatic source illuminates slit S_0 in screen A. The emerging light then spreads via diffraction to illuminate two slits S_1 and S_2 in screen B. Diffraction of the light by these two slits sends overlapping circular waves into

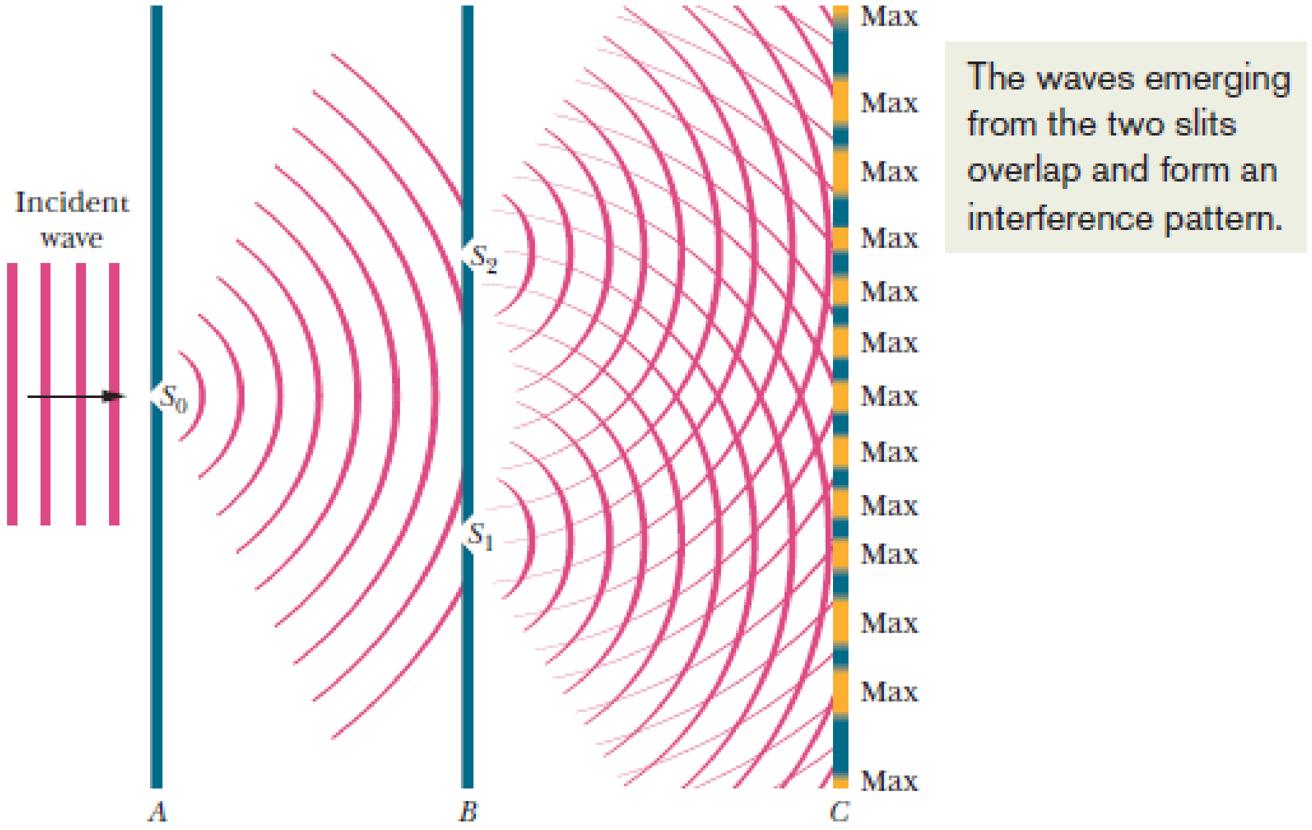
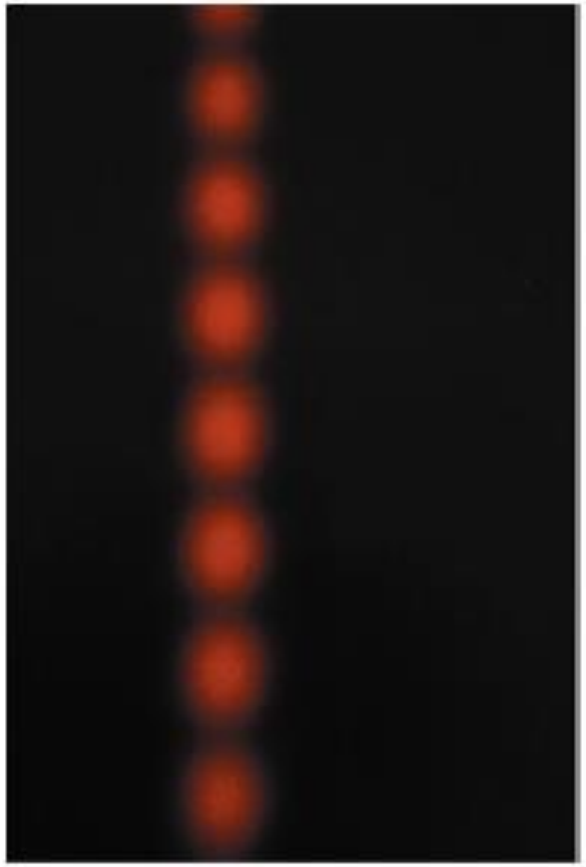


Figure 35-8 In Young's interference experiment, incident monochromatic light is diffracted by slit S_0, which then acts as a point source of light that emits semicircular wavefronts. As that light reaches screen B, it is diffracted by slits S_1 and S_2, which then act as two point sources of light. The light waves traveling from slits S_1 and S_2 overlap and undergo interference, forming an interference pattern of maxima and minima on viewing screen C. This figure is a cross section; the screens, slits, and interference pattern extend into and out of the page. Between screens B and C, the semicircular wavefronts centered on S_2 depict the waves that would be there if only S_2 were open. Similarly, those centered on S_1 depict waves that would be there if only S_1 were open.

the region beyond screen B, where the waves from one slit interfere with the waves from the other slit.

The "snapshot" of Fig. 35-8 depicts the interference of the overlapping waves. However, we cannot see evidence for the interference except where a viewing screen C intercepts the light. Where it does so, points of interference maxima form visible bright rows—called *bright bands, bright fringes,* or (loosely speaking) *maxima*—that extend across the screen (into and out of the page in Fig. 35-8). Dark regions—called *dark bands, dark fringes,* or (loosely speaking) *minima*—result from fully destructive interference and are visible between adjacent pairs of bright fringes. (*Maxima* and *minima* more properly refer to the center of a band.) The pattern of bright and dark fringes on the screen is called an **interference pattern.** Figure 35-9 is a photograph of part of the interference pattern that would be seen by an observer standing to the left of screen C in the arrangement of Fig. 35-8.



Courtesy Jearl Walker

Figure 35-9 A photograph of the interference pattern produced by the arrangement shown in Fig. 35-8, but with short slits. (The photograph is a front view of part of screen *C*.) The alternating maxima and minima are called *interference fringes* (because they resemble the decorative fringe sometimes used on clothing and rugs).