Unit 4 Wave and Optics

4–24 Waves

Waves Terminology: Waves transport **Energy**, *E*. V**ibrating / oscillating** objects create waves. Waves must travel in a **medium**, except electromagnetic waves, which can travel in a vacuum. **Frequency,** *f*, is the number of vibrations/oscillations, cycles, or revolutions each second. **Period**, *T*, is the time for one complete vibration/oscillation. **Wavelength**, λ, is the length of a single wave, measured from a point on one wave to the exact same point on the next wave. Period is also the time that it takes one wavelength to pass. **Amplitude**, *A*, is the maximum displacement from the equilibrium position (not the top to bottom distance). The positive amplitude peaks are known as **crests**, while the negative regions are known as **troughs**.

Transverse waves: Look like the traditional sin waves, shown in Fig 24.1. The vibrating particles, that cause the wave, oscillate in a perpendicular to the wave direction.

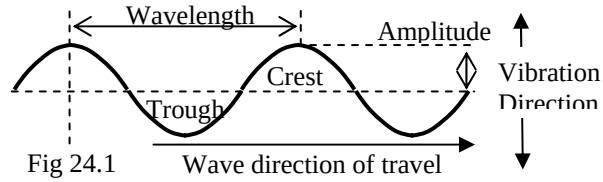


Fig 24.1

Longitudinal Waves: Compression, or **Shock Waves** where particles vibrate in a direction parallel to wave direction. Longitudinal waves have **compressions** and **rarefactions**, similar to crests and troughs. All waves have the above characteristics, and all waves can be diagrammed as a **Sinusoidal Function**. A **pulse** is a single wave. A **continuous wave** is a series of equal pulses.

Standing wave: Created when a continuous wave strikes a barrier and reflects back upon itself. *Any wave hitting a **hard boundary** reflects with a **180° phase change***. **In phase waves** have the same wavelength and speed. Their crests line up with each other. They are in step with each other. A 180° phase change means that the crests of one wave are lined up with the troughs of another. The reflected wave collides with the next incoming wave and superimpose, creating a standing wave. **Nodes** do not move at all, while **antinodes** are points of maximum amplitude. A wavelength is composed of two antinodes.

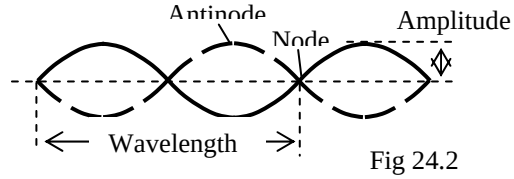


Fig 24.2

Wave speed depends on the medium: $\boxed{v = f\lambda}$ depends on the elasticity of the medium. Sound travels faster in metal than in water and faster in water than in air. Light is unusual, it is fastest in a vacuum, slows slightly in air, and moves slowest in denser mediums. ***As long as the medium does not change wave speed is constant***. If speed is constant and frequency doubles, what happens to wavelength? It is cut in half. Frequency and wavelength have an inverse relationship. The equation $\boxed{v = d/t}$ also applies to sound and light waves. You can time the distance to lightening by counting the seconds between flash and thunder. When timing sound that makes a round trip (echo or sonar), divide the final answer by 2.

Interference: When two or more waves meet, their amplitudes add.

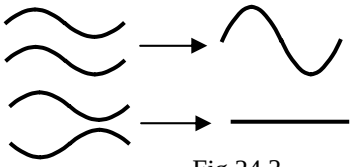


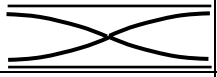
Fig 24.3

Constructive Interference: If the waves are in phase they will add constructively creating a wave with larger amplitude.

Destructive Interference: If the waves are out of phase they will add destructively creating a wave with smaller or even zero amplitude. The waves shown to the left have the same amplitude and wavelength. But, two waves could have different speeds, wavelengths, amplitudes, or phases and add with any combination of these. Therefore a host of complex new wave forms can be generated. Music is one such example.

Sound: The speed of sound in air at 25° C is 343 m/s (often rounded to 340 m/s). The speed of sound changes with temperature since the density and elasticity of air change as temperatures fluctuate. **Pitch** is frequency and **loudness** is amplitude

Resonance: Natural frequency of vibration, and the basis of musical instruments. Resonance is employed to create louder and richer sounds from string and tube musical devices. We will only consider the mathematical application of the fundamental resonant frequency, the frequency associated with the smallest possible fraction of a wavelength that will fit in a string or tube. Multiples of the fundamental frequencies wavelength would also work, and are known as overtones. We will not work with the overtones.

Strings ½ wavelength	**Open Tubes** ½ wavelength 	**Closed Tubes** ¼ wavelength
$v = f\lambda$ and $\lambda = 2L$ $\boxed{v = f2L}$	$v = f\lambda$ and $\lambda = 2L$ $\boxed{v = f2L}$	$v = f\lambda$ and $\lambda = 4L$ $\boxed{v = f4L}$

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Electromagnetic Radiation (Light): Travels in packets of energy, called **Photons**. A vibrating charge, surrounded by both an electric and a magnetic field creates electromagnetic waves. Once created the oscillating electric and magnetic field, which are perpendicular to each other, can self sustain each other and as a result can travel through the vacuum of empty space. We see only visible light, which is a very small portion of the entire electromagnetic spectrum. The entire spectrum from weakest to strongest is:

Radio Waves **Microwaves** **Infrared (IR)** **Visible** **Ultraviolet (UV)** **X-Rays** **Gamma Rays**

Low energy, low frequency, long wavelength High energy, high frequency, short wavelength

Visible light follows ***ROY G BIV*** from low energy to high energy. ***<u>So Blue light has higher energy than red light</u>***.

To see light, the waves must be aimed straight into our eyes to excite the photoreceptors at the back of our eyes. The colors we see are the waves of light that reflected off of an object. The colors that are not present are the ones that passed through the object or were absorbed by the object. Grass absorbs red and blue light needed for photosynthesis, and it reflects the unnecessary green wavelengths.

Law of Reflection: $\boxed{\theta_i = \theta_r}$. All optical angles are measured in relation to a normal line. A normal is a line perpendicular to the surface (Force Normal is perpendicular to the surface). When a surface is curved the normal is perpendicular to a tangent to the curved surface. It is diagrammed as a dashed line.

Ray, smooth surface Parallel rays, smooth surface Rough surface, ***Diffuse*** reflection

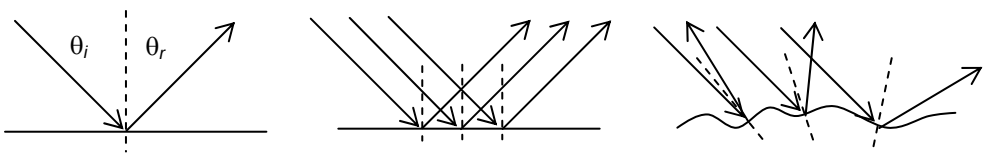

Fig 24.4

On a smooth surface such as a mirror the incident parallel rays of light reflect parallel, and the image formed is identical to the object. But on a rough surface the incident parallel rays are sent in all directions and the image will be **diffuse** (fuzzy).

Transmitting Light: *EM* waves not only travel in vacuums, but that is where they are fastest. The speed of light in a vacuum, *c*, is $\boxed{c = 3\times10^8\ m/s}$. The ***Index of refraction***, $\boxed{n = \frac{c}{v}}$ was devised as a comparison value. It compares the speed of light in a medium a the known speed in a vacuum. The index of refraction for light in a vacuum is 1.00, and the index can never be less than one. The index of refraction for air is 1.0003, which rounds to $\boxed{n_{air} = 1.00}$.

Refraction: The bending of light as it changes mediums. The ***speed changes, but the frequency does not***, $\boxed{v = f\lambda}$ ***so the wavelength changes*** causing the path of the light to bend. ***<u>Less to more, bends toward</u>***.

Less dense to more dense	Light slows	Frequency same	Wavelength shortens	Bends toward normal
More dense to less dense	Light faster	Frequency same	Wavelength lengthens	Bends away from normal

Snell's Law: $\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$ Given the speed in one or both mediums, the indices of refraction or angles can be determined. With three pieces of information the fourth can be determined mathematically. Fig 24.5 shows light moving from a less dense medium to a more dense medium. n_1 and θ_1 go with the incident medium while n_2 and θ_2 go with the refracted medium. Blue light with its higher energy, higher frequency, and lower wavelength bends more than red light. It will bend more toward the normal (less to more), and it will bend more away from the normal as well (more to less).

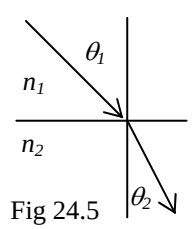

Fig 24.5

Total Internal Reflection: A special case of Snell's Law. If the incident angle is of a certain size it will result in a 90° angle of refraction. This incident angle is called the critical angle $\boxed{\theta_c}$. At incident angles equal to or larger than the critical angle the light reflects back into the substance. So the light at the critical angle or greater is totally internally reflected. Medium 1 contains the incident ray so θ_1 is the critical angle and θ_2 is 90°. This only works when you go from a dense to less dense medium.

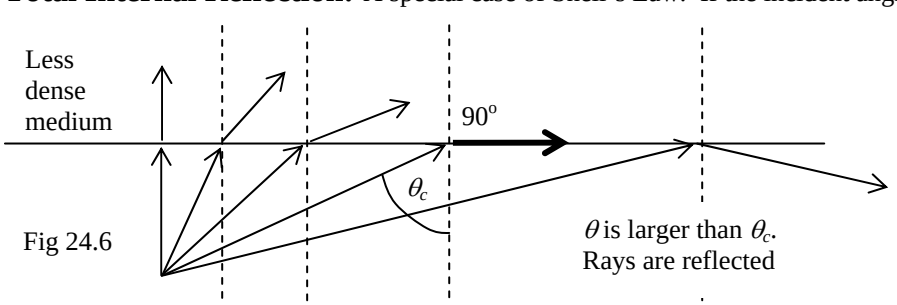

Fig 24.6

$n_1 \sin\theta_c = n_2 \sin 90^o$ $n_1 \sin\theta_c = n_2$ $\boxed{\sin\theta_c = \frac{n_2}{n_1}}$

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