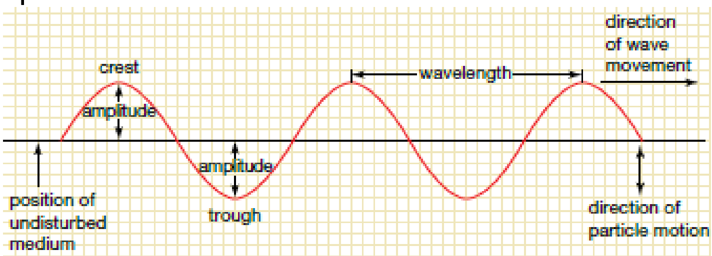
1. What is wave.

Wave is the transmission of energy and oscillations (disturbance) without the net transfer of matter.

2. Waves could be longitudinal and transverse.

In *longitudinal* wave oscillations are along the direction of the wave propagation (sound), in *transversal* – perpendicular (light).

3. Key features of waves: amplitude, wavelength, period, frequency and speed.



Amplitude is the maximum displacement from the equilibrium, measured from the equilibrium position to the top of a crest or the bottom of a trough.

Frequency is number of complete waves produced in 1 second (number of complete waves passing through the point in 1 second). Denoted as ***f***, measured in Hertz (Hz). 1 Hz = 1 complete wave/1 second. 1 Hz = 1 s^{-1}

Period is the time taken to produce 1 complete wave (time taken by one complete wave to pass through the point). Denoted as ***T***, measured in seconds.

$$f = \frac{1}{T} \quad T = \frac{1}{f}$$

Wavelength is the length of one complete wave (distance travelled by wave in one period, distance between successive corresponding parts of a periodic wave, distance between successive crests or troughs in transverse wave or distance between two successive compressions or rarefactions in the longitudinal wave). Denoted as λ, measured in meters.

Speed of the wave is the distance travelled in one second, denoted as v.

4. Wave equation.

$$v = \lambda f \quad f = \frac{v}{\lambda} \quad \lambda = \frac{v}{f} \quad v = \frac{\lambda}{T}$$

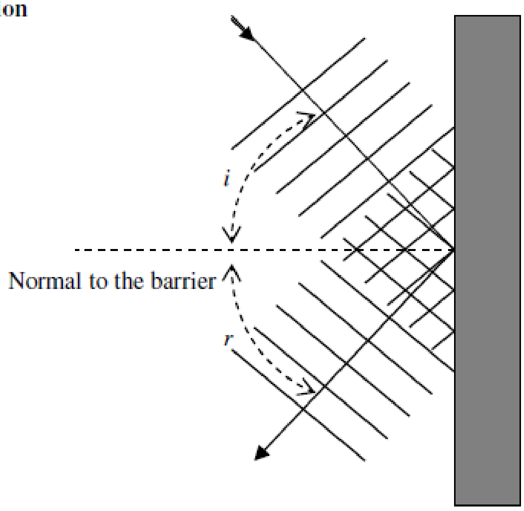
5. Ray model of light.

The fact that light usually travels in straight lines has led to the Ray Model of Light. In a ray model of light, light is represented as straight lines called rays, which show the direction that light travels. Ray is an idealized model of light, obtained by choosing a line that is perpendicular to the wavefronts of the actual light, and that points in the direction of energy flow. Single ray can be considered as a narrow beam of light. Example – shadow.

6. Reflection of light.

When light is reflected from smooth surface (mirror) we have specular reflection.

Reflection

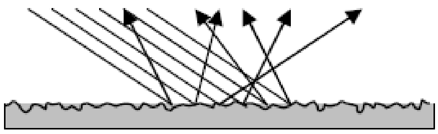


Wavelength, frequency and speed remain the same after reflection.

Angles of incidence and reflection are equal, $\angle i = \angle r$. This is known as the **law of reflection**.

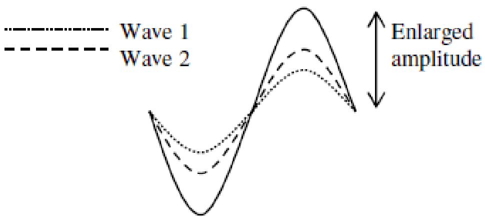
If light is reflected from non-smooth surface we will have diffuse reflection.

Diffuse reflection of a parallel beam of light



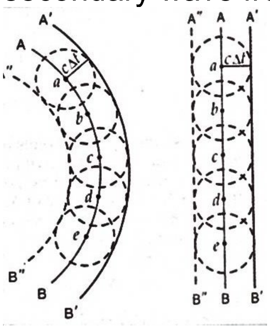
7. Interference.

Two waves interfere when they cross or overlap each other. If they are in phase (crests meeting crests and troughs meeting trough), **constructive interference** is said to occur resulting in a wave with larger amplitude.

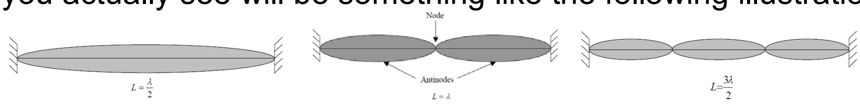


If they are half of a wavelength out of phase (crests meeting troughs), **destructive interference** occurs resulting in the destruction of both waves.

8. Huygens' principle.
Light travels in the form of wave fronts and each point on the wave front acts as a new point source of light from which fresh light waves called secondary wavelets travel in all directions with the same speed. The interference of all the secondary wavelets gives the new position of wave front [called secondary wave front] at an instant.



9. Standing wave on a string.
If a string is tied between two fixed supports, pulled tightly and sharply plucked at one end, a pulse will travel from one end of the string to the other. The pulse is reflected from where it is tied to the support. If the initial pulse has a positive (up) displacement and is traveling to the right, then the reflected pulse will have a negative (down) displacement and be traveling to the left. If a series of pulses is put on the string by an oscillator, there will be a train of positive pulses traveling to the right and a train of negative pulses traveling to the left. When these pulses meet they will interfere. Standing waves on a string are a result of traveling waves interfering both destructively and constructively. The nodes (places of zero amplitude) are due to destructive interference, and the antinodes (places of maximum amplitude) are due to constructive interference. When a standing wave appears, the nodes and antinodes are fixed in place.
The wavelengths of the standing waves are fixed by the length of the string. As both ends are fixed, there must be a node at each end of the string. As the standing waves on the string are sinusoidal, the allowed number of waves on the string will be an integral number of half wavelengths, or: $\frac{n\lambda}{2} = L$, where n is a positive integer, λ the wavelength, and L the length of the string. What you actually see will be something like the following illustrations.

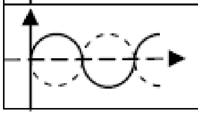


For a stretched string, the frequency of vibration (standing wave) depends on the tension, the length and the type of string used. If these quantities remain constant, only vibrations of certain frequencies are possible. These frequencies are integral multiples of the lowest one. The lowest frequency of vibration is called the **fundamental frequency**. Other modes of vibrations are possible at higher frequencies.

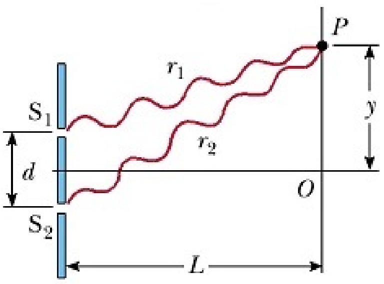
Modes	Overtones	λ	$f = v/\lambda$	Harmonics
	Fundamental	$2L$	$1\left(\frac{v}{2L}\right)$	First har.
	First o'tone	L	$2\left(\frac{v}{2L}\right)$	Second har.
	Second o'tone	$\frac{2L}{3}$	$3\left(\frac{v}{2L}\right)$	Third har.

v is the speed of the *travelling wave in the stretched string*.

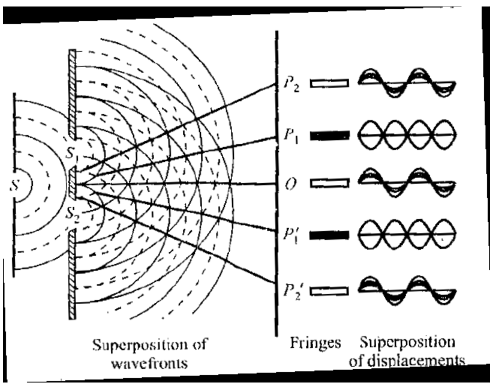
10. Standing wave on a string fixed at one end.

Modes	Overtones	λ	$f = v/\lambda$	Harmonics
	Fundamental	$4L$	$1\left(\frac{v}{4L}\right)$	First har.
	First o'tone	$\frac{4L}{3}$	$3\left(\frac{v}{4L}\right)$	Third har.
	Second o'tone	$\frac{4L}{5}$	$5\left(\frac{v}{4L}\right)$	Fifth har.

11. Interference of the waves from 2 sources.



Construction for analyzing the double-slit interference pattern. A bright fringe, or intensity maximum, is observed at *O*.

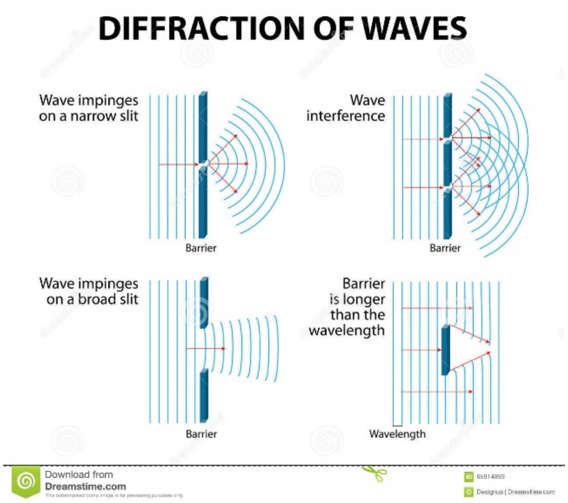


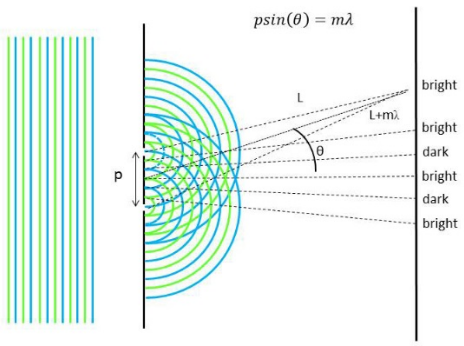
Consider any point P on screen, path difference between the waves reaching at P from S1 and S2 is given as, $Path\ Difference\ (PD) = S_2P - S_1P$
Condition for the maximum (constructive interference) is
$PD = n\lambda$, so PD = whole number of wavelength. Central maximum corresponds to n=0 (PD=0), first to n=1 (PD=λ) and so on.
Condition for the minimum (destructive interference) is
$PD = \frac{2n-1}{2}\lambda$, so first minimum corresponds to PD=λ/2, second to PD=3λ/2, third to PD=5λ/2 and so on.

12. Spacing between bands.
If L is distance to the screen, d is the separation of the sources (distance between openings), x is separation between the bands

$$x = \frac{\lambda L}{d}$$

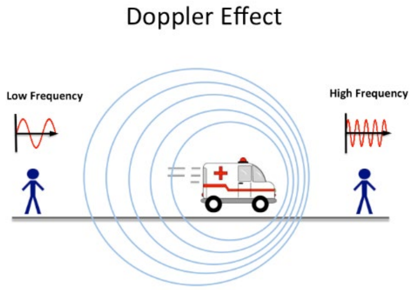
13. Diffraction.
Diffraction is the bending of wave as it passes around the edge of an object. The amount of bending depends on the relative size of the wavelength to the size of the opening. If the opening is much larger or smaller than the wavelength, the bending will be almost unnoticeable. However, if the two are closer in size or equal, the amount of bending is considerable.





When waves diffract through a gap of width *w* in a barrier, the ratio $\frac{\lambda}{w}$
Is important. As the value of this ratio increases, so, too, does the amount of diffraction that occurs.

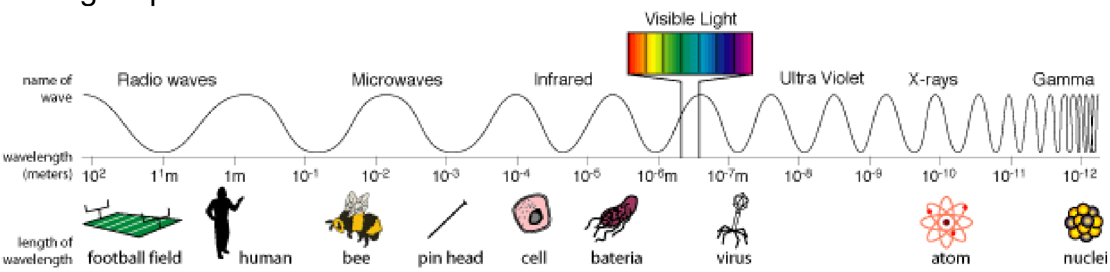
14. The Doppler effect.



$$f' = \frac{v_{wave}}{v_{wave} \pm v_{source}} f_0$$

15. **Resonance** is the increase in the amplitude of oscillations of an object caused when a forced oscillation matches the object's natural frequency of vibration.

16. Light spectrum.



17. **Refraction** is the bending of a ray when it passes at an angle from one medium into another in which its speed is different.

Refractive index or **index** of **refraction** n of a material is the ratio of the speed of light in the vacuum to that in another medium.

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

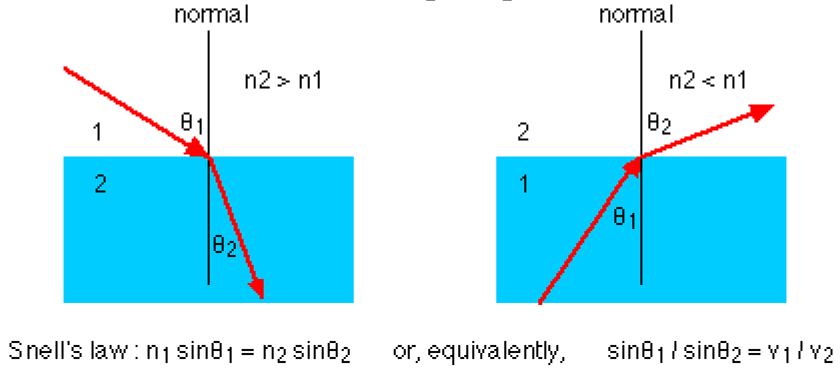
When light travels from one medium to another, the speed changes, as does the wavelength. The index of refraction can also be stated in terms of wavelength:

$n = \frac{\lambda}{\lambda_m}$ where λ is the wavelength in vacuum, λ_m is the wavelength in the medium. Although the speed changes and wavelength changes, the frequency of the light will be constant.

18. Snell's law.

When light pass from medium with refractive index n_1 into the medium with refractive index n_2 it will bend according to Snell's law

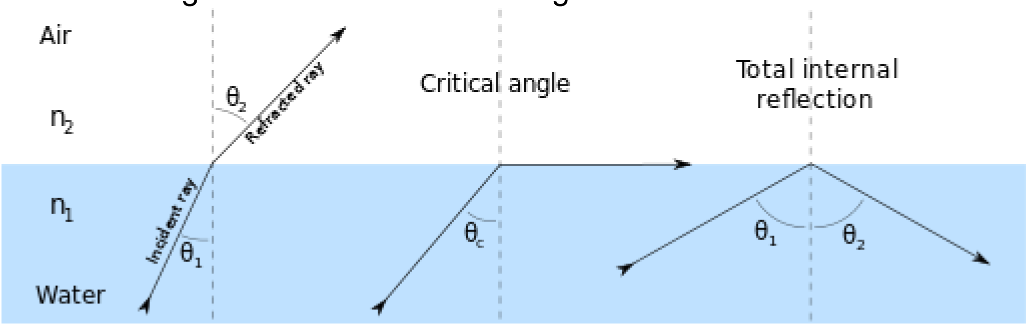
$n_1 \sin\theta_1 = n_2 \sin\theta_2$ or $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$



So when light pass from less optically dense medium into more optically dense medium it will bend towards the normal, if vice versa – away.

19. Total internal reflection.

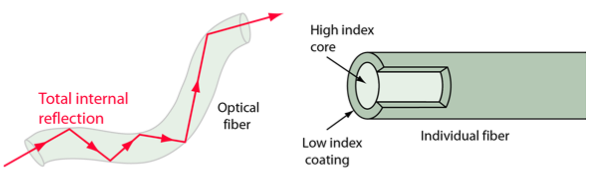
Total internal reflection is complete reflection of a ray of light within a medium such as water or glass from the surrounding surfaces back into the medium. The phenomenon occurs if the angle of incidence is greater than a certain limiting angle, called the critical angle. In general, total internal reflection takes place at the boundary between two transparent media when a ray of light in a medium of higher refractive index approaches the other medium at an angle of incidence greater than the critical angle.



For critical angle of incidence angle of refraction will be 90°, so

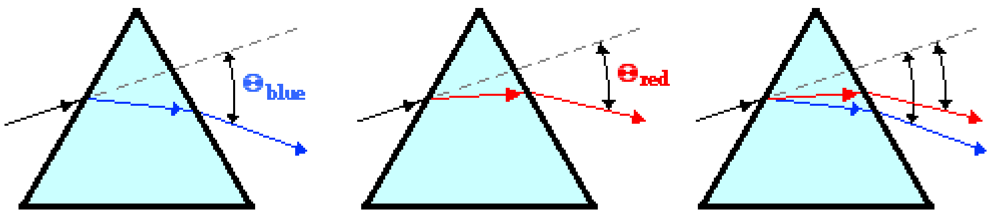
$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

20. Optical fiber



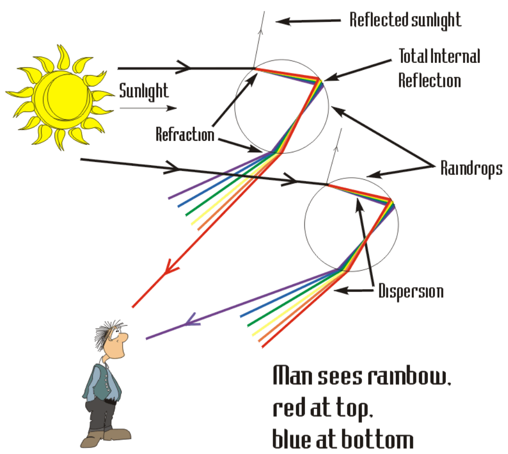
The field of fiber optics depends upon the total internal reflection of light rays traveling through tiny optical fibers. The fibers are so small that once the light is introduced into the fiber with an angle within the confines of the numerical aperture of the fiber, it will continue to reflect almost losslessly off the walls of the fiber and thus can travel long distances in the fiber. Bundles of such fibers can accomplish imaging of otherwise inaccessible areas.

21. Dispersion
Visible light, also known as white light, consists of a collection of component colors. These colors are often observed as light passes through a triangular prism. Upon passage through the prism, the white light is separated into its component colors - red, orange, yellow, green, blue and violet. The separation of visible light into its different colors is known as **dispersion**.

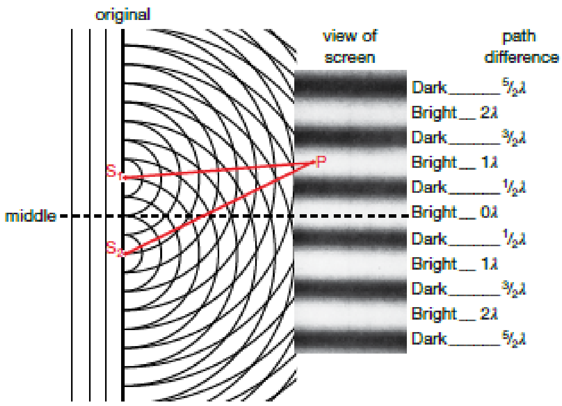


Blue light refracts more than red light due to the difference in wavelength. This causes blue light to deviate from its original path by a greater angle than the red light.

22. Rainbow

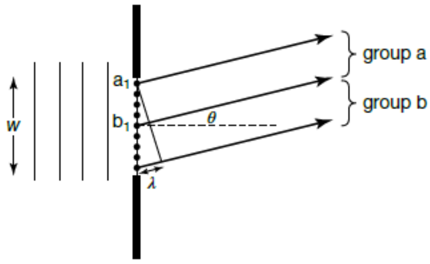


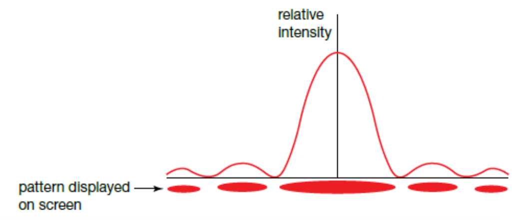
23. Young's experiment.
Two very different models of light were developed in the seventeenth century — one by Sir Isaac Newton (1642–1727) in England and the other by Christiaan Huygens (1627–1695) in Holland. Newton's model was described as a 'particle model'. In his model, light consists of a stream of tiny, mass-less particles he called corpuscles. The particles stream from a light source like water from a sprinkler.
Huygens proposed a wave model of light, where light travels in a similar way to sound and water waves (see number 8). See also 11 – 13.



Young's experiment proved that light is a wave as interference pattern on the screen with bright bands representing constructive interference and dark bands representing destructive interference can be created only by a wave as interference is an exclusive wave fenomena.

24. Single slit diffraction.





The angle of the minimum intensity (θ_{min}) can be related to wavelength (λ) and the slit's width (w) such that: $\sin\theta = \frac{\lambda}{w}$

25. Light as an electromagnetic wave.