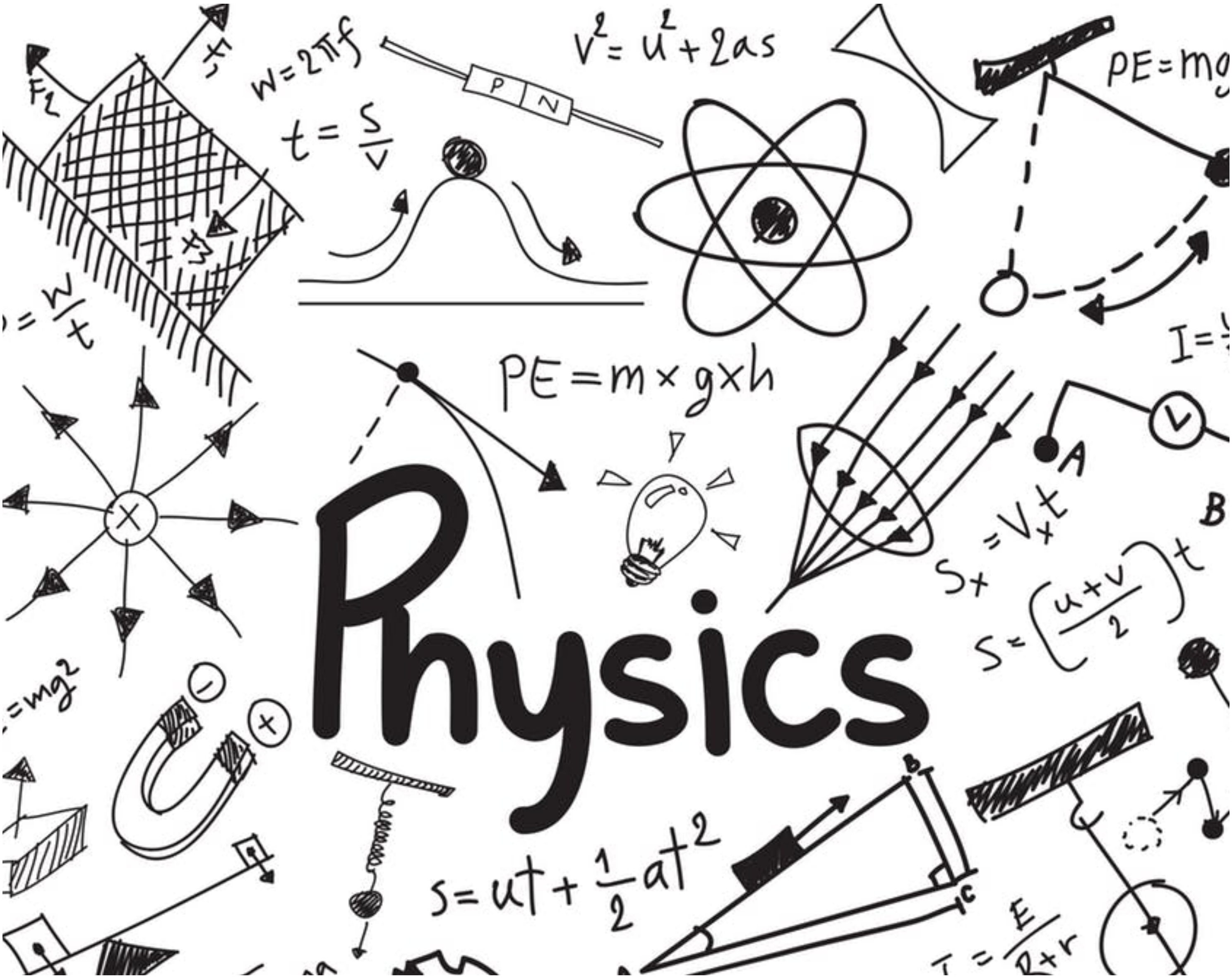
Light as a Wave

by Rain Lee



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“Light as a Wave”

a report by Rain Lee

A comprehensive discussion on the long debated subject - is light a wave phenomena?

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<u>What are the evidences that support light is a wave phenomena?</u>

by Rain Lee

<u>Introduction</u>

Throughout history, many people have tried to categorize light as waves or particles. British physicist, Sir Isaac Newton (1643-1727) believed light was made up of particles. He realised that light had frequency like properties when he used a prism to split sunlight into its component colours. Across the English Channel, Dutch physicist Christiaan Huygens did not agree, and argued that light was made up of waves, by questioning, “Why would light shining through a pin hole or slit will spread out rather than going in a straight line, if it was made up of particles?” London-based scientist, Thomas Young (1773-1829) performed an experiment to study the interference of light waves by shining light through a screen with two slits equally separated, the light emerging from the two slits, spread out according to Huygen's principle. Eventually the two wave fronts will overlap with each other, if a screen was placed at the point of the overlapping waves, you would see the production of light and dark fringes/lines. His principle, known as Young’s Principle is widely used today. French physicist and civil engineer, Augustin Fresnel supported his principle with a thesis. On the contrary, award winning scientist, Albert Einstein (1879-1955) believed that light itself is made up of particles (photons), and visible light was the result of photons flowing through mediums such as air and water. This is highly debatable, because light has properties of absorption, reflection and it can be transmitted via a medium. It can be scattered, refracted, polarised, diffracted and at different frequencies on the electromagnetic spectrum, the human eyes perceive different colours. Waves of light, which are essentially the path that light travels along in air or water, also possess these properties.

On the other hand, if we were to say that light was made up of waves, there would be many situations that are contradictory towards this statement. For example, when we are exposed to the ultraviolet rays of the sun’s light, we get sunburns. However, under the light of a heat lamp, which uses infrared rays, you don’t get sunburns. Yes, you sweat, but there is no molecular deterioration of your skin cells caused by the energy of the waves even after hours. The greater the energy, the larger the frequency and the shorter (smaller) the wavelength. Infrared and ultraviolet rays are both near to each other on the electromagnetic spectrum. No doubt they are not visible light, but their properties are distinct. It is no doubt, that the wavelength of a wave in the sea, no matter how small, is bound to erode the rocks or sand. It is simply a matter of time. In the electromagnetic spectrum, this is not always the case. The light waves can either be constructive or destructive, which increases or decreases the intensity, depending on the alignment of the trough and crest of the same wavelengths.

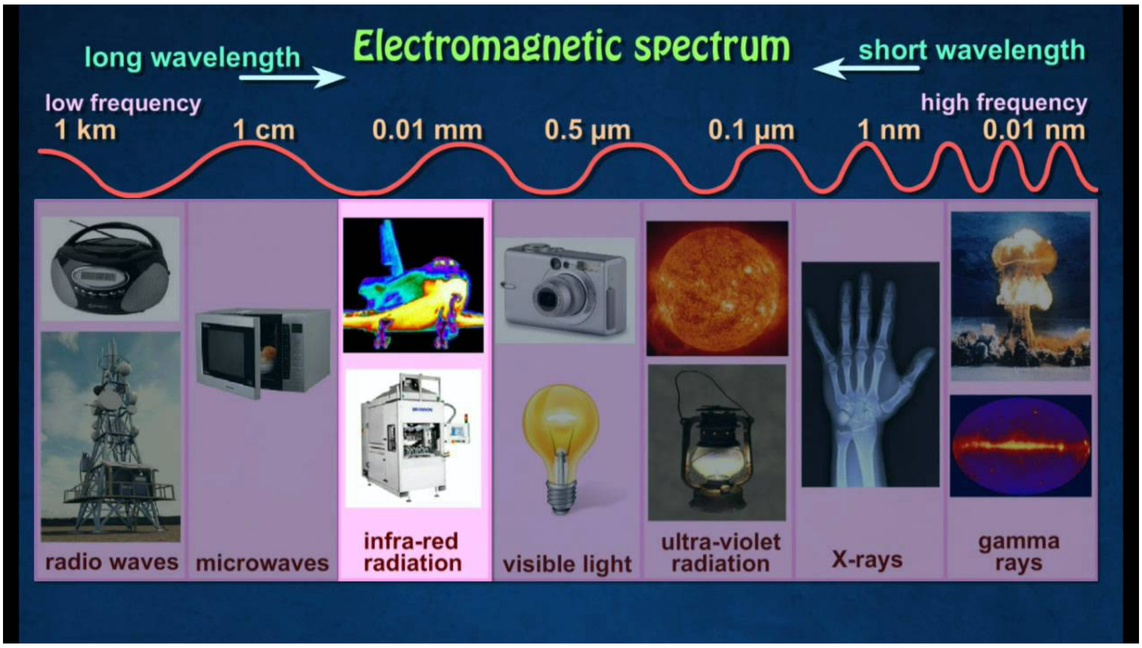

Fig 1.1 Applications of Electromagnetic Spectrum

To this day, the question of whether light is a wave or made up of small particles, called photons (the smallest *known* energy quantity), with a velocity of 299,792,458 m/s (the speed of light) remains. The question still exists because scientists have found evidence of light being both composed of photons and waves. What has baffled some scientists even more is that some properties can be classified as neither photon nor wave composition of light

Waves: Transverse and Longitudinal

We live in a world where we wireless gadgets and appliances such as satellite TV, wireless internet, mobile phones, wireless mouses, microwaves and tanning beds. These gadgets/appliances use various wave frequencies on the electromagnetic spectrum. The waves we encounter daily, are mechanical waves (which require a medium to travel through) and, in their simplest form, can be described as a disturbance in a medium which allows for the transfer of energy to happen. There are two categories of mechanical waves i.e. transverse and longitudinal waves.

Light and other types of electromagnetic radiation are transverse waves and the displacement of the medium particles is perpendicular to the direction of propagation of the wave (see Figure 1.2). A ripple on a pond and a wave on a string are some visual examples of transverse waves. Transverse waves cannot travel through a gas or a liquid because there are no mechanisms for driving motion perpendicular to the propagation of the wave. When a transverse wave travels horizontally through a medium, its particles vibrate upwards and downwards, which results in the wave looking like the graph of a sine function.Waves can be described by their amplitude, wavelength and frequency. The amplitude of the wave (height of the wave) proportionally points to the intensity of the wave, while a shorter wavelength means that the wave has more energy. Wavelength can be measured by finding the distance between two consecutive peaks or troughs. The formula, $v = f\lambda$ (Where v is the velocity of the wave in Hertz, f is the frequency of the wave and λ is the wavelength of the wave) defines how many waves pass a particular position over a certain time.

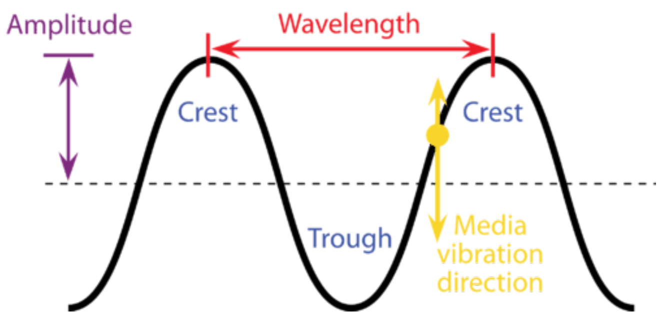

Figure 1.2 Transverse wave diagram

Sound waves and waves in a stretched spring are longitudinal waves, the displacement of the medium particles is parallel to the propagation of the wave. A wave in a “slinky spring” is a good visualization. Sound waves in air are longitudinal waves. Unlike transverse waves, they can travel through gases, solids and liquids. As longitudinal waves displace particles in a direction parallel to the propagation, a disturbance causes them to get squashed together (they vibrate by moving left and right), creating a region of high pressure known as a compression. Once the compression travels onwards in the horizontal direction, the particles behind it are comparatively more spaced out, resulting in a low pressure region, known as a rarefaction (see Figure 1.3). A longitudinal wave's wavelength can be measured by finding the distance between two consecutive compressions.

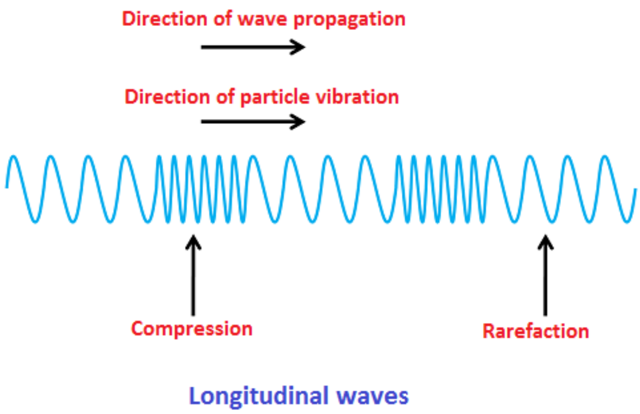

Figure 1.3 Longitudinal wave diagram

To summarise (See Figure 1.4): Transverse waves are always characterized by particle motion being perpendicular to wave motion. A longitudinal wave is a wave in which particles of the medium move in a direction parallel to the direction that the wave moves.

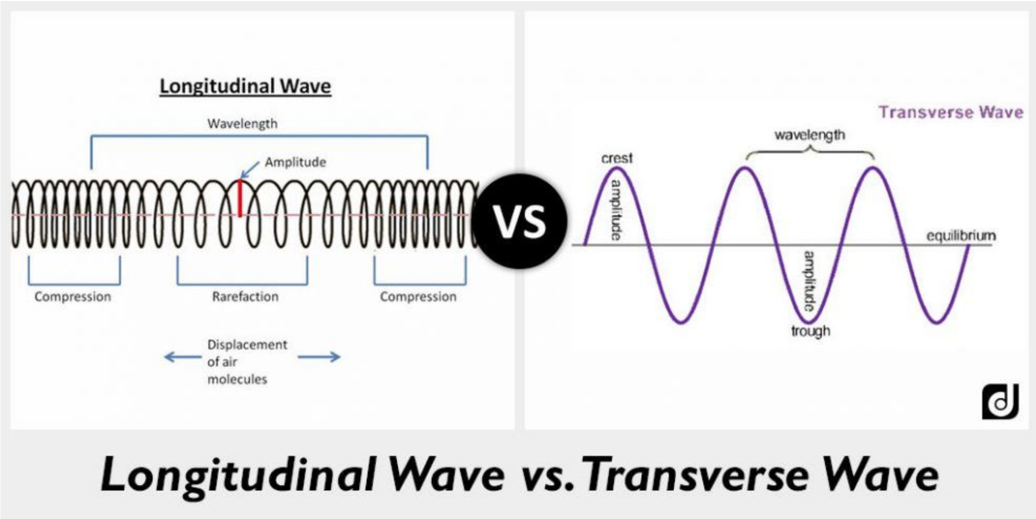

Figure 1.4 Longitudinal Wave vs. Transverse Wave

Waves are vibrations that transfer energy from place to place without matter (solid, liquid or gas) being transferred. Visible light, infrared rays, microwave and other types of electromagnetic radiation do not need to travel through a substance. They may be able to travel through a medium. They can travel through empty space. Electrical and magnetic fields vibrate as the waves travel and such waves are known as electromagnetic waves.

Certain waves, like sound and seismic waves must travel through a substance/medium which can be solid, liquid or gas. It is the medium that vibrates as the waves travel through. These are considered mechanical waves. Consider also the Mexican wave in a football crowd where each spectator stays in their seat only and moving up and down when it is his turn.

Various types of other light waves, make up the electromagnetic spectrum (see Figures 1.1 and 1.5), which comprises of radio waves, microwaves, infrared waves, visible light waves, ultraviolet waves, x-ray and gamma rays, in that order. The electromagnetic spectrum ranks the various light waves in terms of their wavelength, with radio waves being as long as buildings, to gamma rays being as small as atomic nuclei. The light we see with our eyes falls under the category of visible light waves (a form of electromagnetic radiation) and is the only wave to have the wavelength which the human eye can naturally see on this entire spectrum.

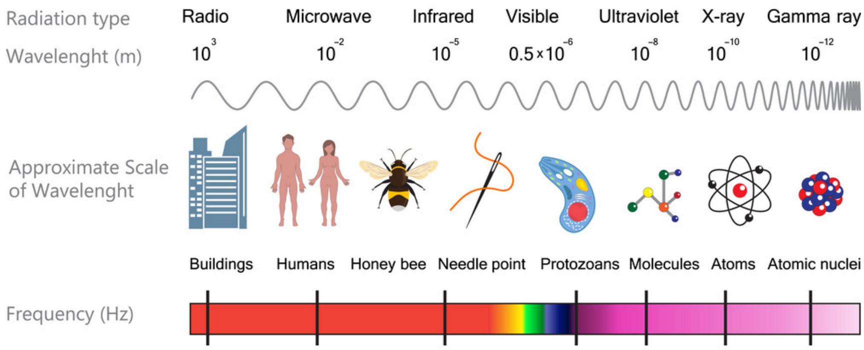

Figure 1.5 Electromagnetic Spectrum

Properties of Light

All waves, including the simplest waves like the waves caused by movement in the water to the most complex waves of radio waves used to power a telecommunications network posses properties of absorption, reflection and are all transmittable. They can be refracted, polarised, scattered and diffracted. The only difference is that other types of waves on the electromagnetic spectrum do not possess colours or shades visible by the human eyes. When light strikes an interface between two substances with different refractive indices, two things occur. These are known as reflection and refraction. An incident ray of light striking the interface at an angle, i, measured between a line perpendicular to the interface and the propagation direction of the incident ray, will be reflected off the interface at the same angle, i. In other words the angle of reflection is equal to the angle of incidence. If the second substance is transparent to light, then a ray of light will enter the substance with different refractive index, and will be refracted, or bent, at an angle r, the angle of refraction. The angle of refraction is dependent on the angle of incidence and the refractive index of the materials on either side of the interface according to Snell's Law: $n_i \sin(i) = n_r \sin(r)$. The fact that refractive indices differ for each wavelength of light produces an effect called dispersion. This can be seen by shining a beam of white light into a triangular prism made of glass. White light entering such a prism will be refracted in the prism by different angles depending on the wavelength of the light. A good example of reflection is a simple household mirror, white an example of refraction can be seen in Figure 1.6 and Figure 1.7.

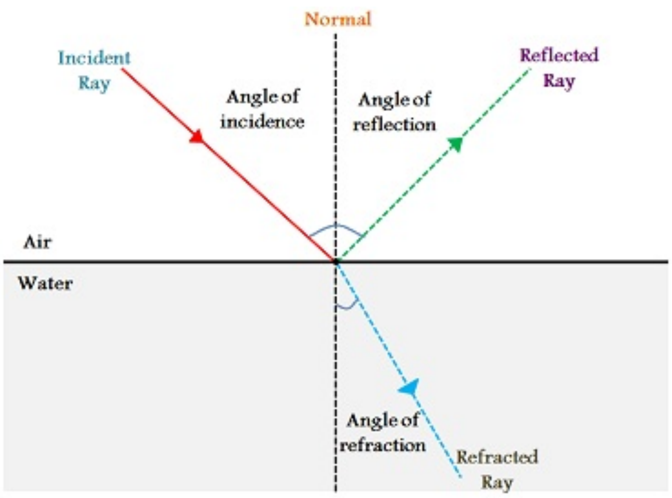

Figure 1.6 Reflection and refraction of light

Figure 1.7 Refraction

When light enters a transparent material some of its energy is dissipated as heat energy, and it thus loses some of its intensity. When this absorption of energy occurs selectively for different wavelengths of light, they light that gets transmitted through the material will show only those wavelengths of light that are not absorbed. The transmitted wavelengths will then be seen as color, called the *absorption color* of the material. Generally, materials can be categorised based on how it responds to light.

1) Opaque materials- absorb light and do not let light to pass through
2) Transparent materials - allow light to easily pass through them
3) Translucent materials - allow light to pass through but distorts the light during the passage

On polarization, normal light vibrates equally in all direction perpendicular to its path of propagation. If the light is constrained to vibrate in only on plane, however, we say that it is plane polarized light. The direction that the light vibrates is called the vibration direction, which for now will be perpendicular to the direction. An example of polarization in daily life is when a polarizing filter is used in photography (See Figure 1.8). Often, without one, photographs appear with dull colours and wrong tones. In such cases, the use of a "polarizing filter" based on a polarizing film enables only the most beautiful, blue light out of such scattered light to be transmitted, thus capturing a photo just how it was viewed by you. Light emitted by the sun, by a lamp in a classroom, or by a candle flame is referred to as unpolarised light.

Figure 1.8 Photograph taken with a polarizing filter (left) vs. without (right).

Diffraction is when light passes through an opening or edge of a body that is absorbing it and the light will spread out across the body's opening edge. The opening must be very narrow for this to happen. This is considered a wave property of light. A good example of this happening would be the "silver lining" of clouds. (See Figure 1.9)

Figure 1.9 "Silver lining" of a cloud

Properties of Light: Waves

In the 17th and 18th centuries, most physicists thought that light was a particle, because it often behaved like one. Huygen's principle that was formulated by Dutch Physicist Christiaan Huygens in the 19th century, based on the formula of d = vt (distance travelled is velocity multiplied by time). He suggested this would be the same for each individual point on a wave. By formulating a way of visualising wave propagation, he suggested that light was made up of waves vibrating up and down perpendicular to the direction of the light travels.

Huygen's Principle states that every point on a wave front can be considered a source of wavele that mover outward at the speed of the wave itself. One common phenomena that exemplifies the wave property of light is diffraction. Diffraction is the bending of light around obstacles. In addition, the Principle can also be used to define reflection and explain refraction and interference.

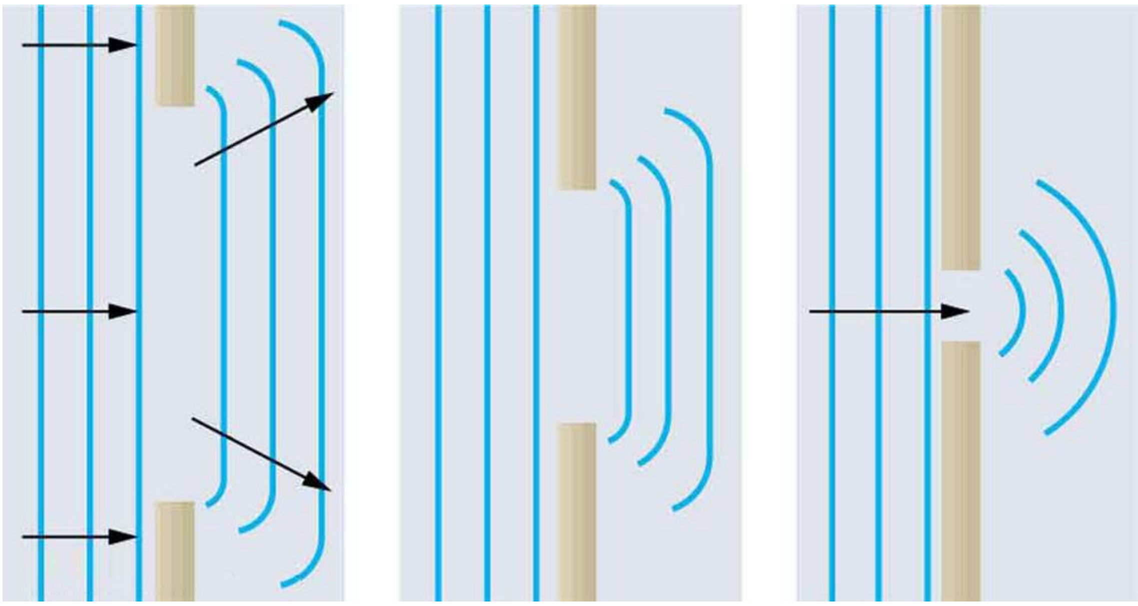

Figure 1.10 Huygens Principle: Diffraction

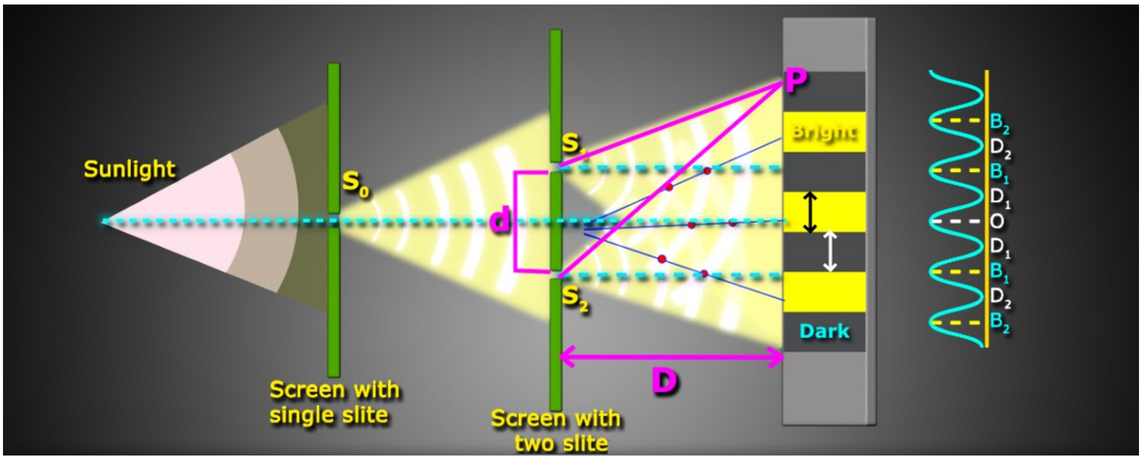

Figure 1.11 Young’s Double Slit Experiment

Thomas Young, an English physicist then decided to conduct an experiment to suggest that light was a wave, which is known today as Young’s Double Slit experiment (see Figure 1.11). He showed that light could be diffracted and it had properties of interference as well.

Assuming the size of each slit is less than the wavelength of light, two waves diffract through two similar size slits and travel to the centre of the screen and since they both travel the same distance, they reach the centre whilst in phase and constructive interference occurs (bright fringes/lines) but if two waves diffract but they travel different distances.

If two waves diffract but now travel different distances. The waves will be out of phase and so when they reach a point on the screen, destructive interference occurs (leading to dark lines).

Another example which shows light is a wave is that the brightness of light is proportional to the amplitude squared. Given light has wavelength, speed and amplitude and that wavelength determines the type of colour, speed is determined by whether the light passes through a medium. The amplitude of a light wave depends on the number of photons per second being emitted. The greater the amplitude of a certain type of light, the greater the number of photons per second of that type of light.

For refraction of light, applying Huygen’s Principle to a straight wavefront travelling from one medium to another where its speed is less, the ray bends towards the perpendicular, since the wavelets have a lower speed in the second medium.

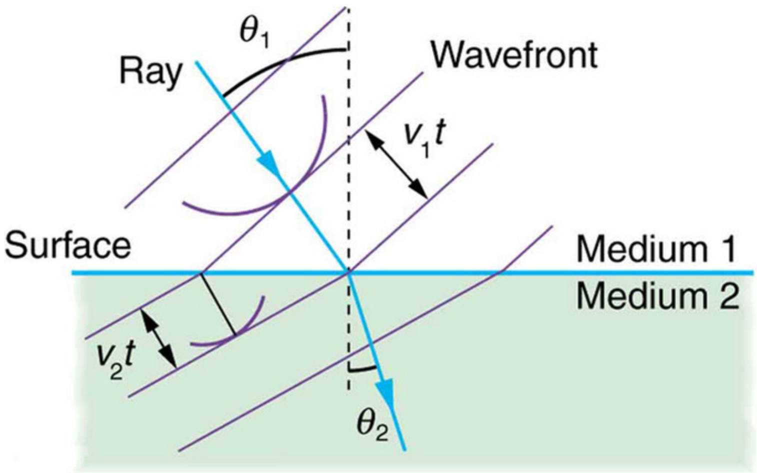

Fig 1.12 Huygens Principle: Refraction

On reflection, when a wavefront striking a mirror, the wavelets were emitted as each point on the wavelets struck the mirror. The tangent to these wavelets shows that the new wavelet has been reflected at an angle equal to the incident angle. The direction of propagation is perpendicular to the wavefront, as shown by the downward arrows.

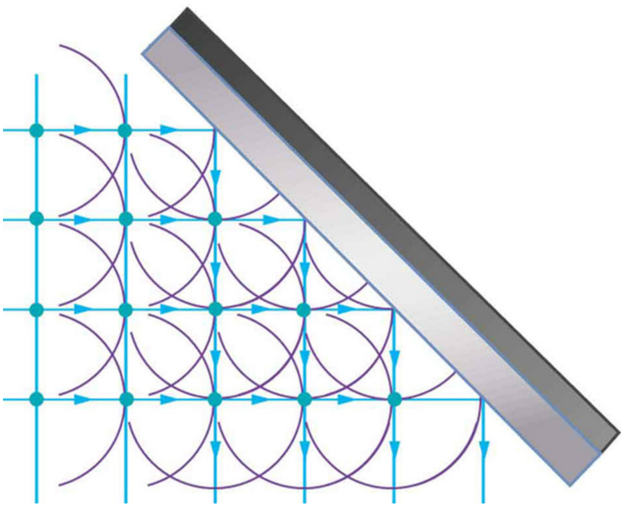

Fig 1.13 Huygens Principle: Reflection

Conclusion

Based on Huygens Principles and Thomas Young's double slit experiment, light exhibits certain behaviours that are characteristics of any wave and would be difficult to explain with a purely particle view. Light reflects and refracts in the same manner that any wave would reflect and refract. Light undergoes interference in the same manner as any wave.Since light behaves like a wave, one would have good reason to believe it might be a wave. Even Albert Einstein believed that light is a particle (photon) and the flow of the photons is a wave.

Yet there is still more reason to believe in the wavelight nature of light.

Overall, the information and evidence presented here only *suggests* that light likely is a wave phenomena. Even as of today, no *solid* evidence exists to let physicists declare light a wave or particle phenomena at the same time.

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