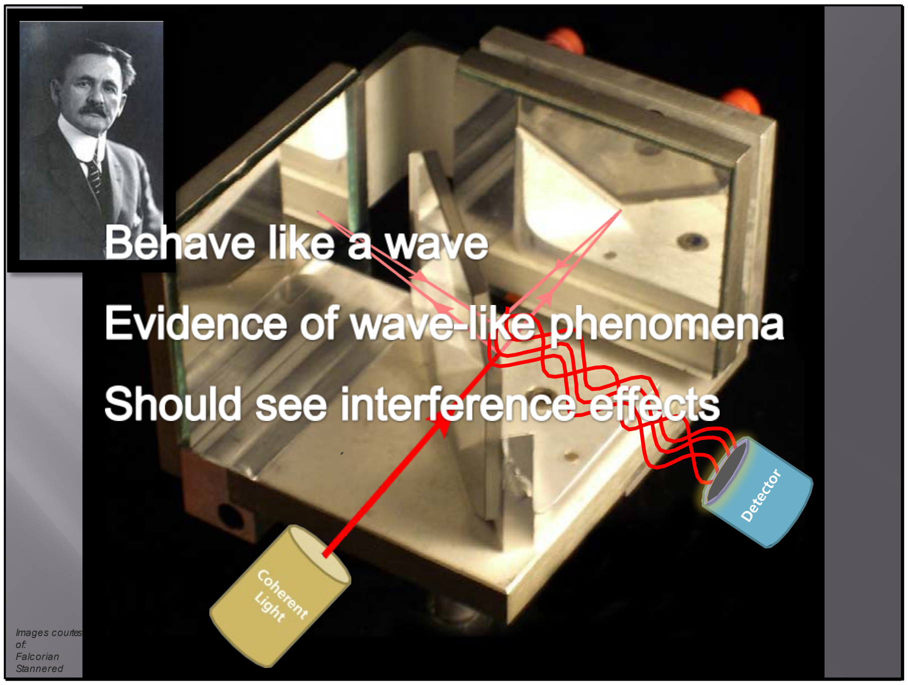
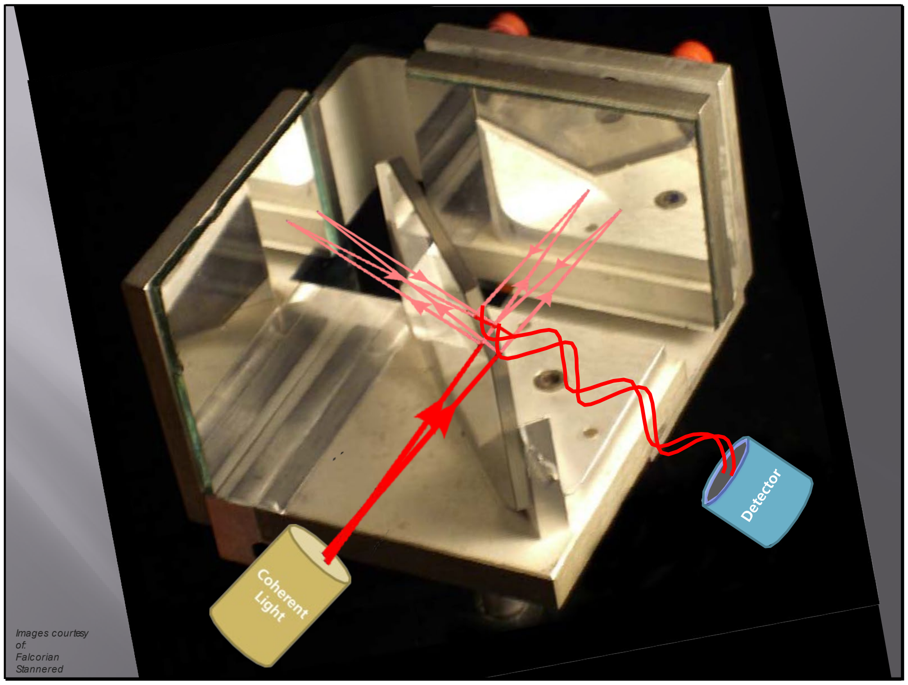
Light Waves

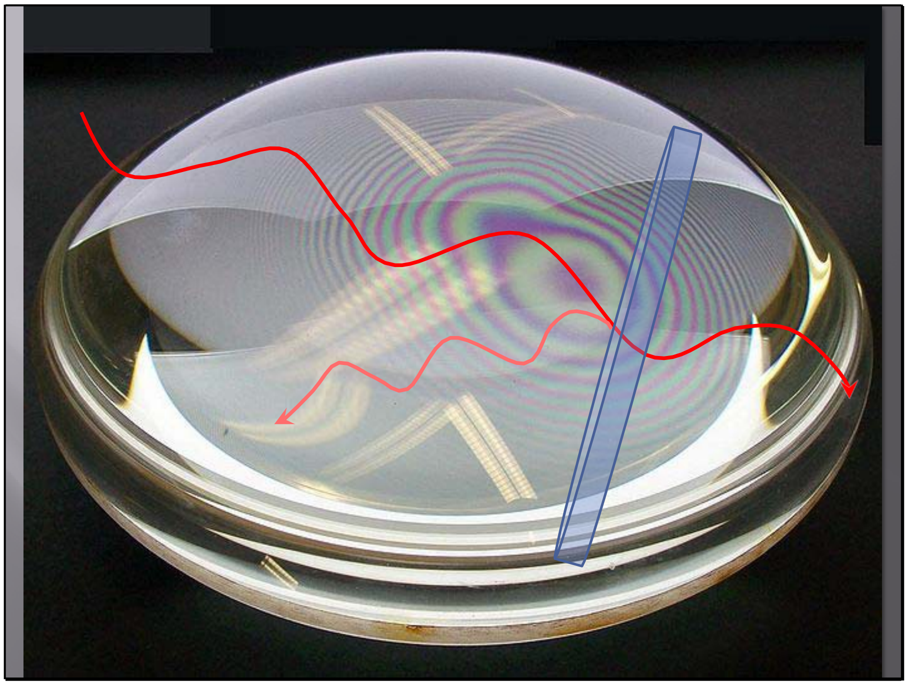


If light is a wave, we should expect to see it behave like a wave and see evidence of wave-like phenomena. Interference is one example of wave phenomena. If light is a wave, we should see interference effects. Light wave interference was used to design a famous physics device called the Michelson interferometer. An interferometer is a device that measures interference of light. Coherent light, meaning light of a single wavelength, with all waves in phase, is sent to a half-silvered mirror which reflects part of the light and transmits part of the light. Each of these beams is reflected back towards the first mirror which directs both beams to a detector or screen. When the beams reach the screen, if they arrive in phase, the waves constructively interfere, producing a bright spot or strong signal from the detector. If the beams meet out of phase, then a dark spot or weak signal is registered by the detector.



As you adjust the position of one of the mirrors through a small amount, you adjust the distance that one of the beams travels. If there had been a strong signal at the detector, you may now have a weak signal because instead of meeting in phase, the waves now meet out of phase. Adjusting the position of one mirror, therefore, causes the detector to register bright, then dark, then bright again.

Using his interferometer, Michelson was able to precisely measure the wavelength of a particular color of cadmium light to remarkable accuracy. The interference of light shows us that light has wave properties.

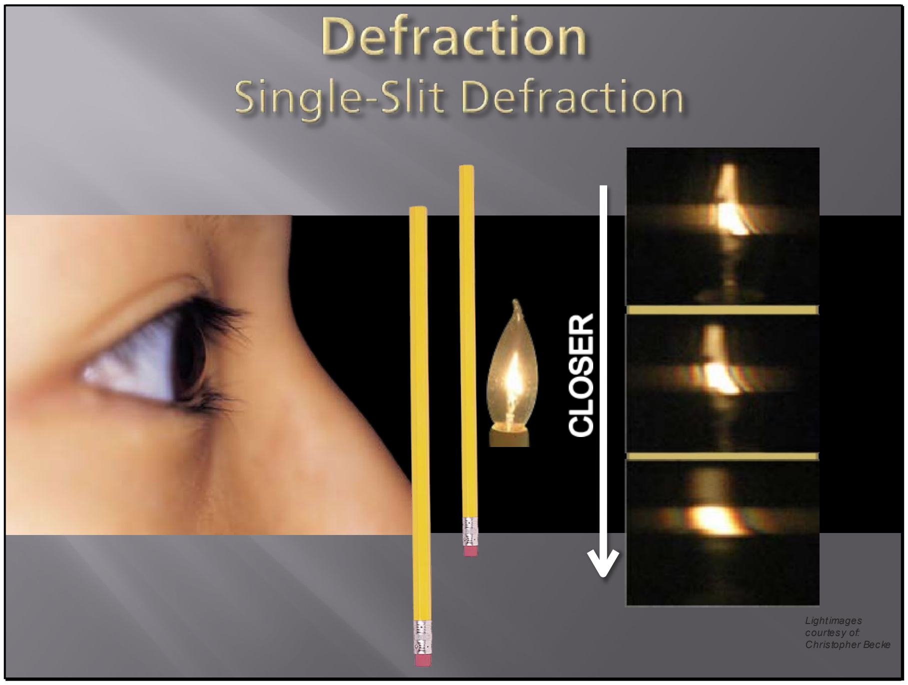


Another demonstration of light wave interference occurs with thin films, such as when oil spreads out on the surface of water. Each time light encounters a new medium, part of the light will reflect and part of the light will transmit. The light that hits the front of the film and the light that reflects off of the back of the film will interfere either constructively or destructively depending on the thickness of the film and how much light slows down in the film.

For example, with an oil film on water, you will see a repeating pattern of colors on the surface of the film. The oil film spreads out on the water and is thinner at the edges. The changes in thickness cause different wavelengths, or colors, of light to interfere constructively or destructively at different places on the film. The colors that you see are those that experience constructive interference upon reflection from the front and the back of the film. Similarly, this film interference will be observed in a soap bubble in the air, as the light reflects off the outer and inner edges of the soap film.

Isaac Newton observed similar interference effects when he placed lenses on a reflecting surface. The thin layer of air between the glass of the lens and the glass of the mirror acted like a thin film of varying thickness.

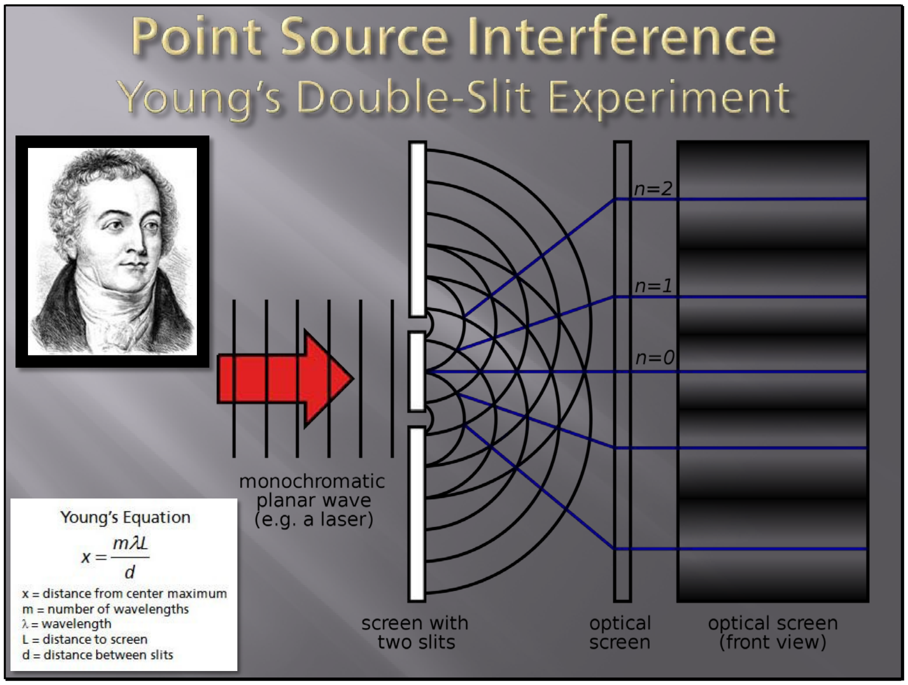
Manufacturers of high precision optics make use of thin film interference when creating antireflective coatings for lenses in optical devices, eliminating glare by ensuring light is transmitted instead of reflected. Such coatings are popular on many eyeglasses as well. All of these examples of interference are evidence of the wave nature of light.



Diffraction is a second example of wave phenomena. Diffraction is the spreading of a wave, either around an obstacle or after it passes through a narrow opening. If light is a wave, it should exhibit diffraction.

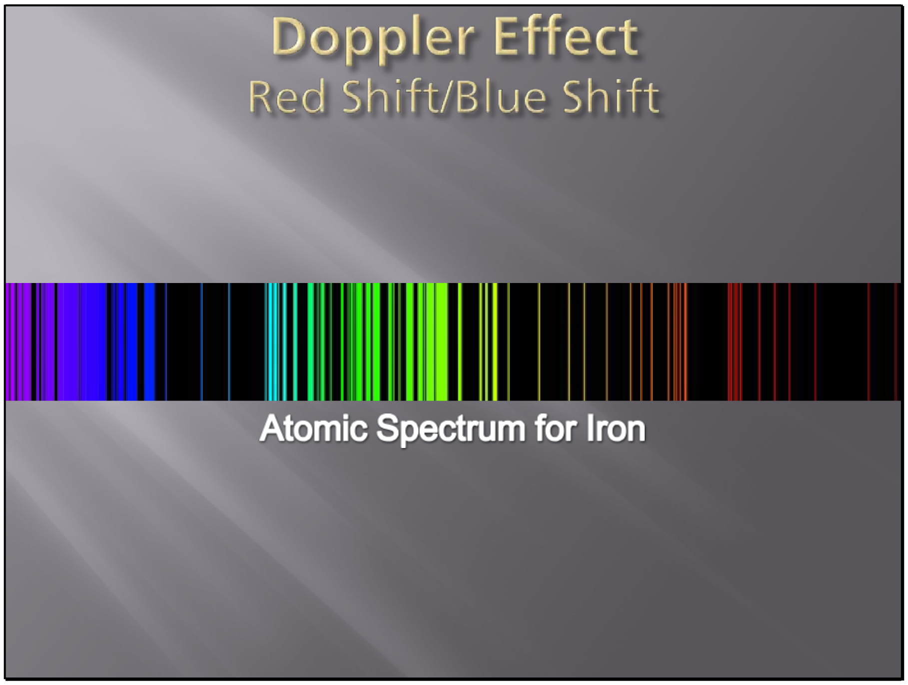
It is quite easy to demonstrate to yourself that this is the case. Take two pencils or pens and hold them vertically next to each other close to your eye as you look at a clear light bulb, one in which you can see the glowing filament. By adjusting the width of the slit between the pencils, you should be able to see the light spread out and perhaps notice a repeating rainbow spectrum on either side of the bulb.

What is happening is that the amount of diffraction depends on the wavelength of the light. Different colors of light have different wavelengths, and when we see all the colors of the spectrum simultaneously, we perceive this as white light. As the light diffracts from each edge of the opening, the different amounts of diffraction separate the white light into its component colors, resulting in a unique pattern of constructive and destructive interference for each color to the right and the left of the center. The fact that light diffracts and interferes is evidence of the wave nature of light.



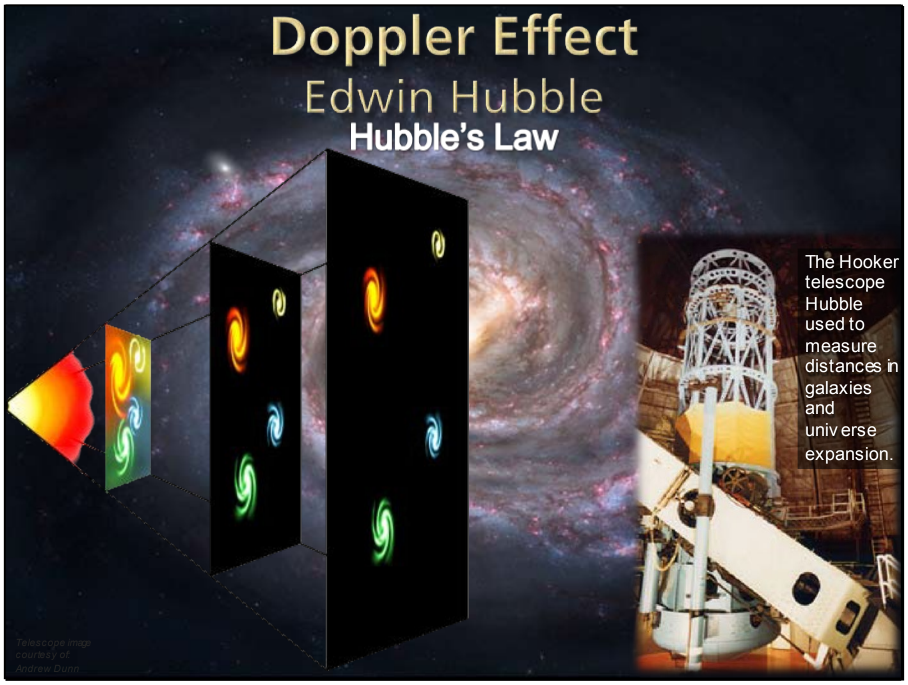
In the early 1800's Thomas Young conducted a series of experiments demonstrating interference of light. One of these experiments used two closely spaced slits. When light passed through these slits, it diffracted, just as water waves diffract.

When the light reached the screen, a pattern of bright and dark bands was observed. The center point of the screen is an equal distance from each slit, so this is a location of constructive interference, as the waves would arrive in phase with crests meeting crests and troughs meeting troughs. At a point slightly higher on the screen, the distance to one slit and the distance to the other slit differed by a half wavelength, causing destructive interference as crest met trough and resulting in a dark area. Further up the screen, the difference would be one complete wavelength, resulting again in a bright area. Young's equation describes the relationship between the wavelength, the slit separation, the distance to the screen and the distance between the bright and dark fringes. Young's double-slit experiment shows that light has wave properties that allow it to diffract and interfere.

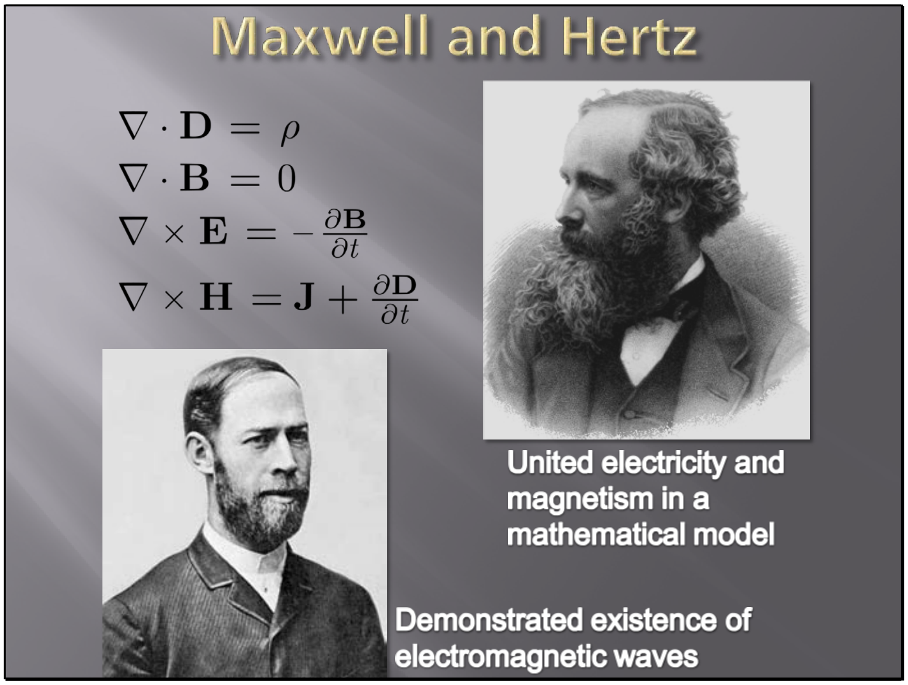


One of the wave phenomena for sound is the Doppler effect. If light is a wave, then it should experience a similar phenomenon. Remember that each element has a distinct atomic spectrum due to its specific electron energy levels.

When scientists look at distant stars, they recognize the spectra of elements such as hydrogen and helium, commonly found in stars. However, if the star is moving relative to Earth, the wavelengths of each of these spectral lines is shifted compared to their known values. If a star is moving towards us, then similarly the perceived frequencies of the light waves are higher than expected and the wavelengths would be shorter, or "blue shifted." If a star is moving away from us, then all the perceived frequencies of the light waves are lower than expected and would be seen to be stretched out to longer wavelengths or "red shifted." This shift explained the differences in the spectra that scientists observed and is another example of the wave nature of light.

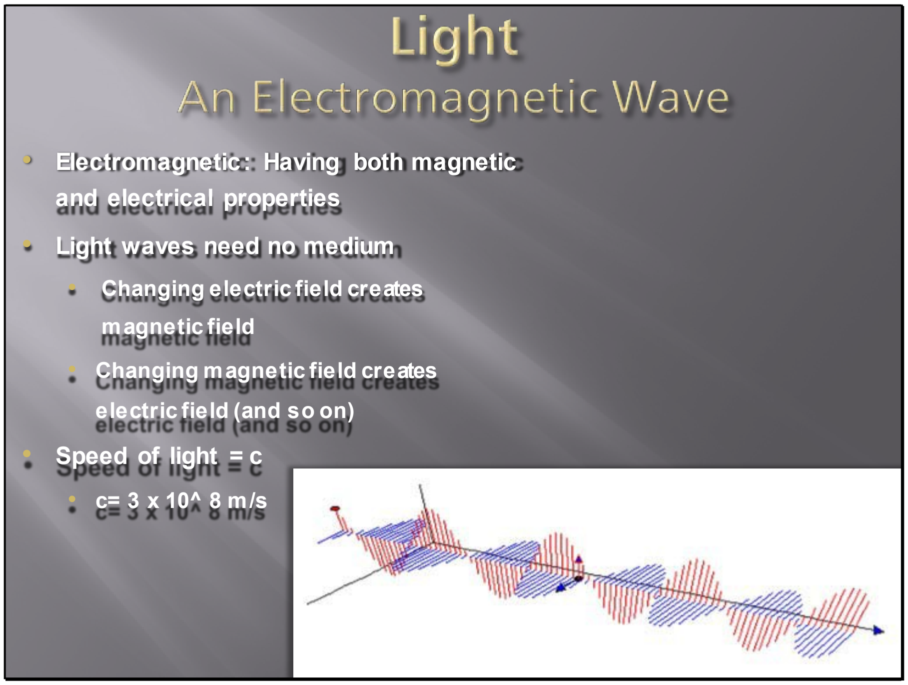


American astronomer, Edwin Hubble was the first to confirm galaxies beyond the Milky Way. He combined information about the distance of galaxies and the shifts in their spectrum to determine a direct relationship between how far a galaxy is from us and how quickly it is moving away from us. This relationship, known as Hubble's Law, helped determine that the universe was expanding. Hubble's Law has been used to calculate that at some point between 13 and 15 billion years ago, all the distant galaxies would have been at the same position in space, one of the first pieces of evidence supporting the Big Bang theory.



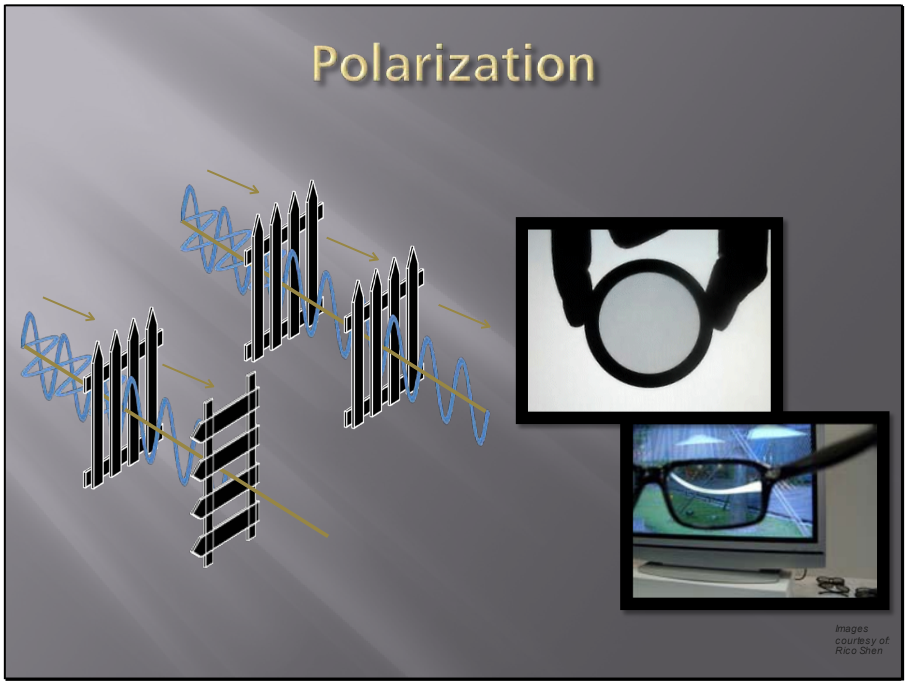
It was through the work of James Clerk Maxwell that electricity and magnetism were unified in a wave theory by only four equations. Using these equations and fundamental constants, Maxwell showed that electromagnetic fields must travel at three times ten to the eighth meters per second and concluded that light was electromagnetic radiation.

Heinrich Hertz performed experiments in which he actually produced electromagnetic waves and was able to detect them at a distance using what we would now consider a rudimentary transmitter and receiver. Among his many discoveries, his experiments showed that electromagnetic waves interfered with themselves upon reflection, creating standing waves, just as you would find on a string, providing yet more evidence for the wave nature of light. His discoveries built the foundation upon which all of our electromagnetic communications are based, from radio to satellite transmissions to cell phones. The units for frequency are named in honor of Heinrich Hertz.



We now know that light is an electromagnetic wave, having both electrical and magnetic properties. A changing electric field will create a magnetic field and a changing magnetic field creates an electrical field. This disturbance propagates through space as an electromagnetic wave which requires no medium. It can be said that the electrical wave uses the magnetic field as a medium and the magnetic wave uses the electrical wave as a medium.

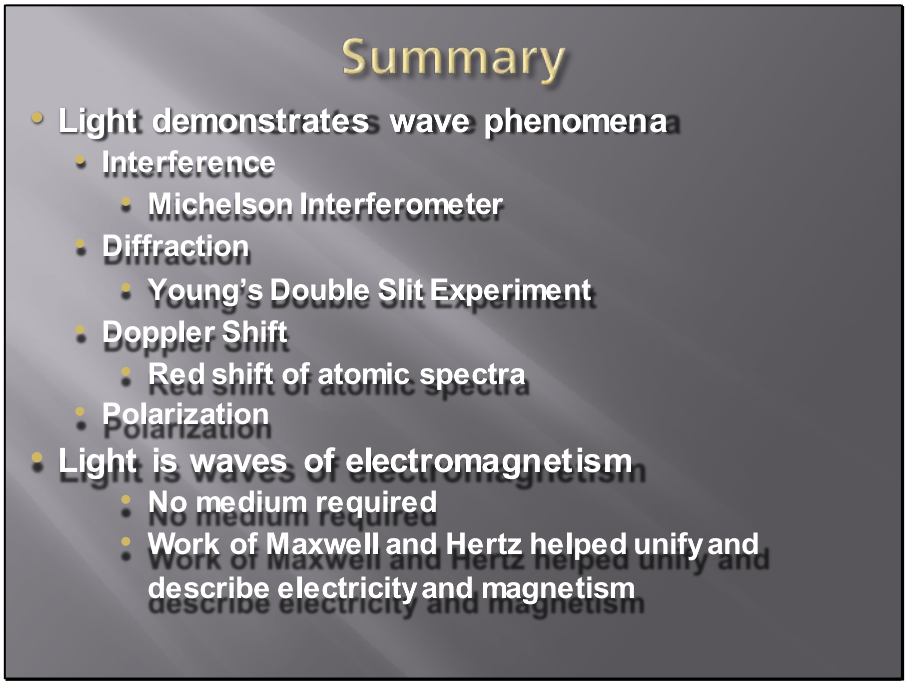
All electromagnetic waves travel at the same speed, the speed of light, represented by the letter c. The speed of light is three times ten to the eight meters per second.



Another phenomenon that results from the wave nature of light is polarization. Light is a transverse wave that is vibrating in many different directions. A polarizing filter allows the light through that is vibrating in one direction. When two polarizing filters are aligned, all the light will transmit through both. However, when one of the filters is turned by ninety degrees, none of the light can pass through the second filter.

An analogy of this is a rope strung through a picket fence. If you make a set of randomly oriented waves on the far end, the first picket fence will only allow through the vertical components of these waves. This corresponds to the initial dimming of the light through the first filter. If a second picket fence is aligned with the first, the waves that made it through the first fence will also travel through the second. However, if a second fence is turned ninety degrees, any waves that pass through the first fence will not make it through the second fence.

Polarization is the general physics principle behind 3-D movie technology. Each lens of your special 3-D glasses is polarized in a different direction. The projector transmits two overlapping images to the screen using polarized light with different orientations. Each eye will see a different image, and this allows for the three-dimensional effect to be observed. The type of polarization used in the latest movies is actually circular polarization, which is somewhat more complicated, but follows a similar principle.



In summary, light has wave properties. Evidence of these wave properties can be seen in different wave phenomena. Light interferes and diffracts, as shown by Michelson with his interferometer and Thomas Young with his double slit experiment. Light experiences the Doppler effect, just like sound waves, resulting in the red-shift of the atomic spectra of distant stars. And light also can be polarized, further demonstrating its wave nature.

Light has been shown to be electromagnetic waves that can propagate through the vacuum of space, not requiring a medium. The work of Maxwell and Hertz helped to unify electricity and magnetism and describe how electromagnetic waves behaved.