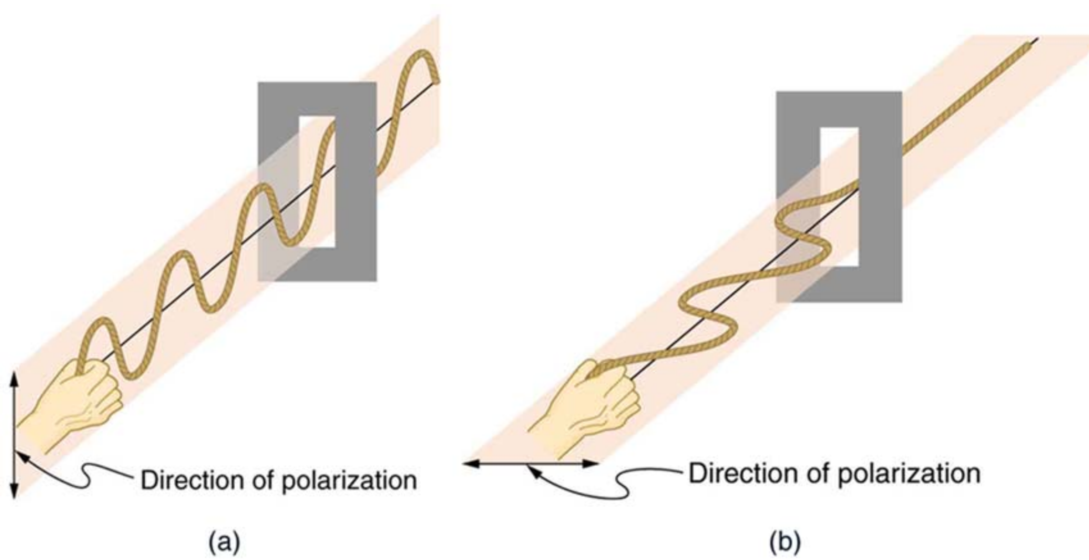
**PHYS:1200 LECTURE 32 — LIGHT AND OPTICS (4)**

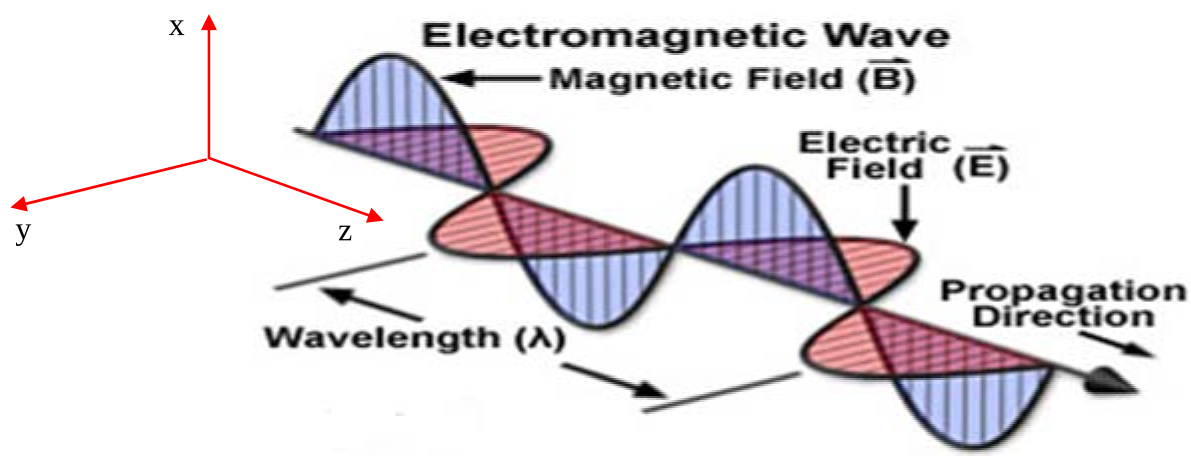
The first three lectures in this unit dealt with what is for called **geometric optics**. Geometric optics, treats light as a collection of rays that travel in straight lines and bend when they pass through or reflect from surfaces. Progress in electromagnetic theory in the 19th century led to the discovery that light waves were in fact electromagnetic radiation. The final lecture on optics deals with **physical optics**, which is a more comprehensive model of light, which includes wave effects such as **polarization, diffraction and interference** that cannot be accounted for in geometric optics. Historically, the ray-based model of light was developed first, followed by the wave model of light. Diffraction and interference are phenomena that occur not only with light waves, but with all types of waves including sound waves and water waves.

**32-1. Polarization of Light.—Polarization** is a property of transverse waves, and thus it is a property of light waves which are transverse electromagnetic waves. The polarization of a wave is the property that specifies the direction of the plane that contains the oscillation relative to the direction of propagation. This is most clearly illustrated by considering a transverse wave on a string, as illustrated in the diagram below. The wave can be launched by jiggling the string back



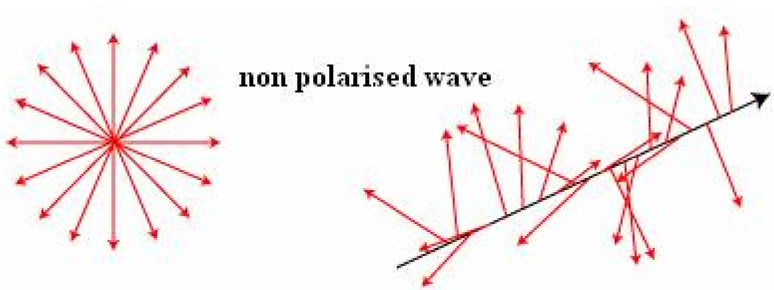

and forth either in the vertical plane as in (a), or in the horizontal plane, as in (b). These two possibilities illustrate two possible directions of polarization of the wave. Of course, there are many other planes of polarization that are possible. The polarization states would be categorized as vertical (a) or horizontal (b). The polarization state of the wave is analyzed by placing a plate with a slit (gray features in the figure) that either allows the wave to pass through [case (a)] or not [case (b)].

The polarization of a light wave (an electromagnetic wave in the visible part of the spectrum) is defined by the direction in which the electric component of the wave oscillates relative to the direction of polarization. Let us recall the structure of an electromagnetic wave as illustrated in the diagram below. An electromagnetic wave consists of mutually perpendicular electric and

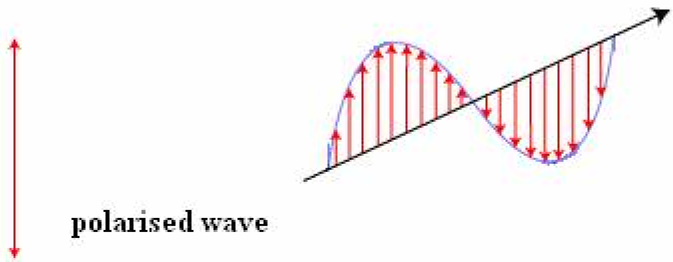



magnetic fields which are both perpendicular to the direction of propagation. For the particular electromagnetic wave shown in the diagram, the wave is polarized in the y –direction which is the direction of the electric field.

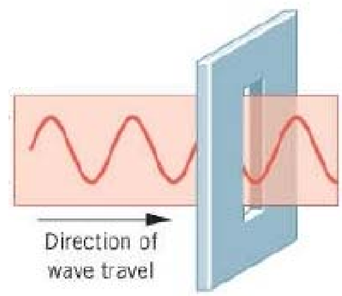
Most common light sources (incandescent lights, fluorescent lights, the Sun) emit ***unpolarized*** light. The production of polarized light requires special conditions. In unpolarized light, the electric fields of the wave are randomly oriented about the direction of propagation as illustrated in the diagram below in which the red arrows represent the electric field. For polarized light, the



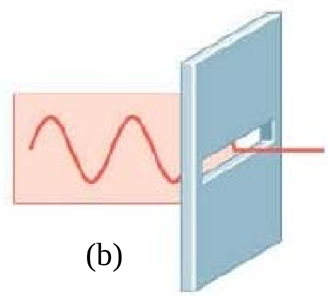

electric field vibrates in one direction only as illustrated below.




There are materials called **polarizers** that act as filters to allow only a specific component of the electric field to pass. If the direction of polarization of the light is aligned with the axis of the polarizer, the light passes through. If the polarizer axis is oriented 90 degrees to the polarization direction of the light, the light cannot pass through. This is illustrated in the diagram on the right. In (a) the wave is polarized in the vertical direction and passes through the polarizer which has its axis also vertical. In (b) the axis of the polarizer is turned 90 degrees to the direction of polarization, so the wave cannot pass through.

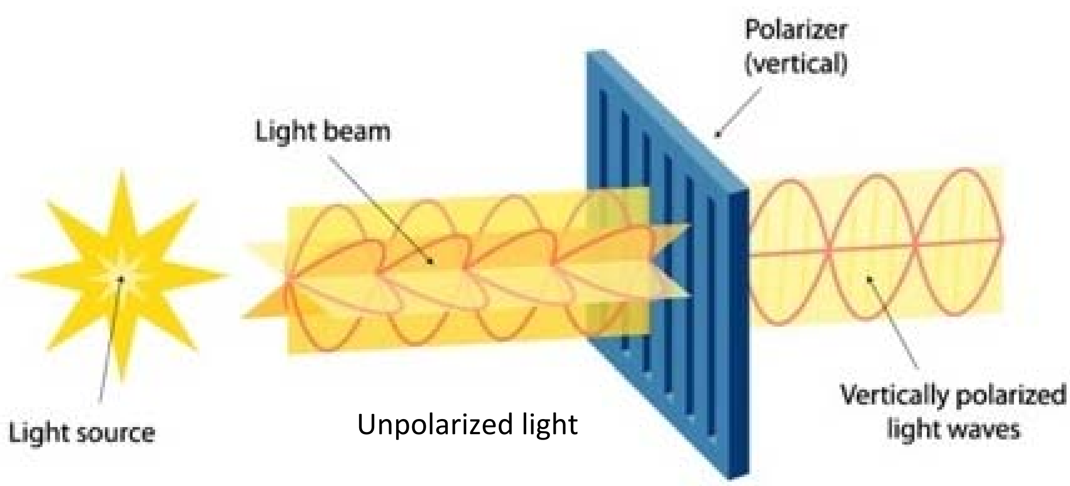



(a)



(b)

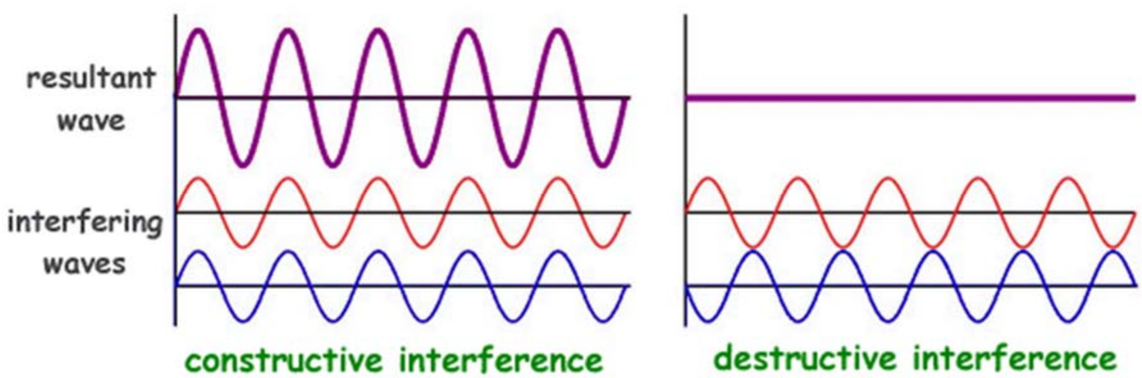
When unpolarized light is incident on a polarizer, only the component of the electric field that is parallel to the axis of the polarizer will be transmitted, as illustrated below. The polarizer has the effect of



making unpolarized light polarized. If a second polarizer is then used, it will transmit the light if its axis is parallel to the axis of the first polarizer and will not transmit the light if its axis is perpendicular to the axis of the first polarizer. (see **slide 10**). If the second polarizer is rotated with respect to the first polarizer, the light intensity will gradually decrease as their axes approach 90 degrees (see **slide 11** and photo to the right).

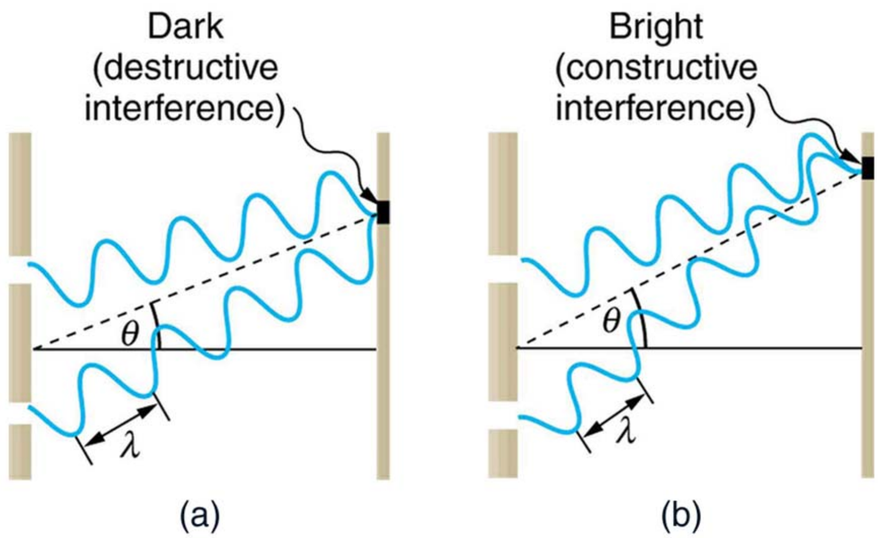
Sunglasses are often made using Polaroid lenses. Polaroid lenses are effective in reducing glare or reflected light, since reflected light is often polarized. The original material, patented in 1929 and further developed in 1932 by Edwin H. Land, consists of many microscopic crystals of herapathite embedded in a transparent nitrocellulose polymer film. The needle-like crystals are aligned during manufacture of the film by stretching or by applying electric or magnetic fields. With the crystals aligned it tends to absorb light which is polarized parallel to the direction of the crystal alignment, but transmits light which is polarized perpendicular to it.

**32-2. Interference of Light.—**Since light is a wave, it exhibits wave **interference effects**. We will briefly review wave interference by reference to the diagram below. Interference is the

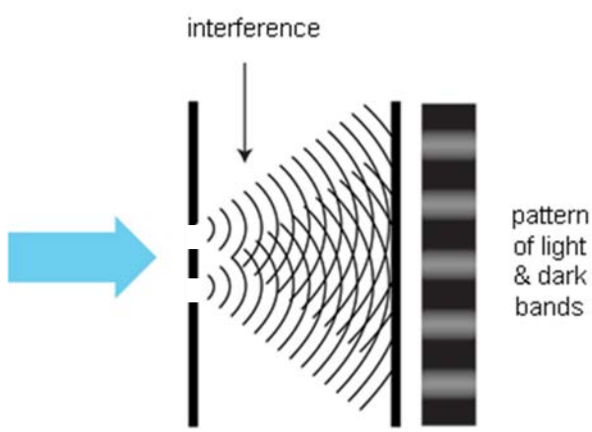



process by which two or more waves are combined to produce a resultant wave. There are two extreme possibilities that can occur when two waves are combined: **constructive and destructive interference.** Constructive interference occurs when two synchronized (the peaks occur at the same place) waves are added together as shown on the left side of the diagram above. When these waves are combined, the resultant wave has a larger amplitude; if the individual waves have the same amplitude, the resultant wave has twice this amplitude. Destructive interference occurs when the waves are totally out of phase. One wave has its maximum value when the other wave has its minimum value. When these wave are combined, cancellation occurs. If the two waves have the same amplitude, they cancel completely and the resultant is no wave, as illustrated by the flat line.

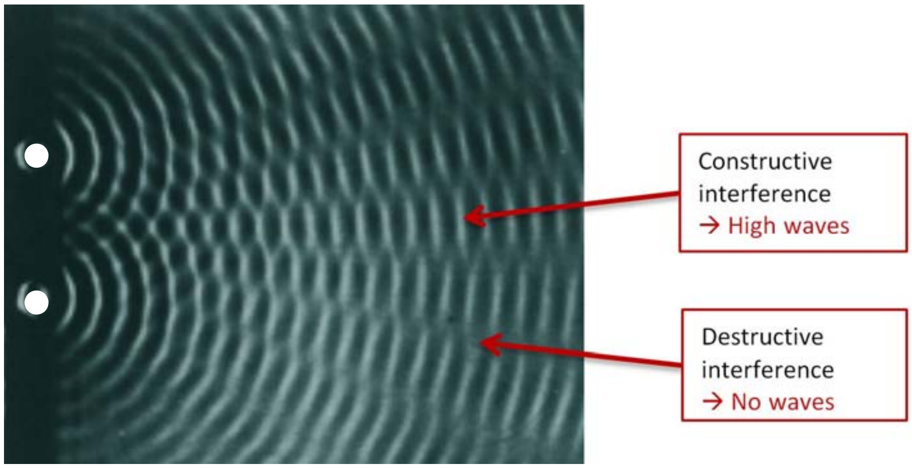
The result of light interference after passing through a double-slit is shown in the diagram on the right. The light is viewed on a screen to the right of the slits. A series of bright and dark bands are observed. The bright bands correspond to positions where constructive interference occurs,




and the dark bands corresponds to the positions where destructive interference occurs. Thomas Young performed this experiment in 1800 demonstrating that light was a wave.

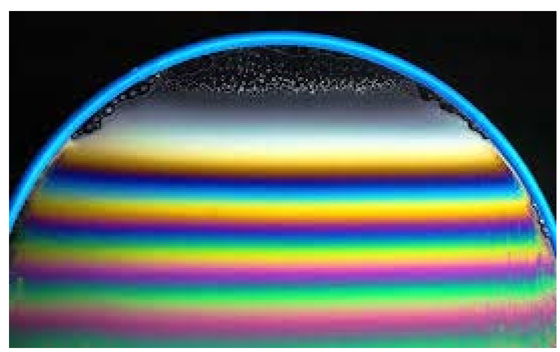


Interference occurs with all types of waves. The diagram below illustrates the interference of waves on the surface of a shallow tank of water. The waves are generated by two small spheres (white dots) that bob up and down in the water producing ripples. The ripples that propagate from the two sources interfere with each other and produce stronger waves due to constructive

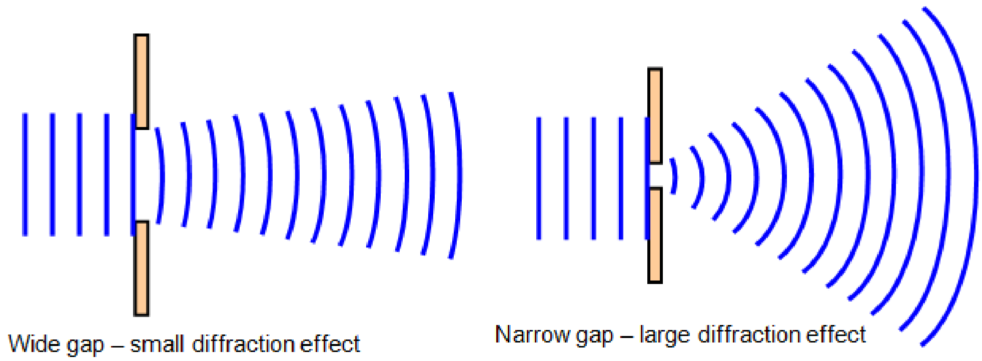


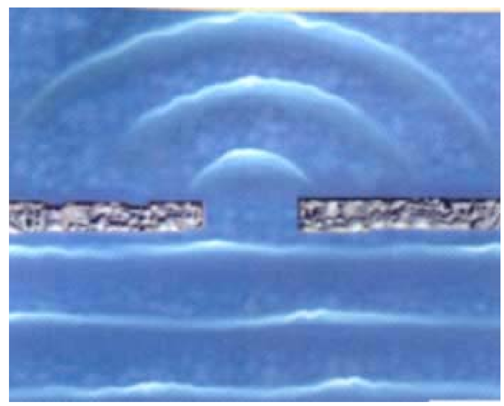

interference, or wave cancellation due to destructive interference. The water tank is illuminated from above, and the shadows are observed on a flat surface underneath the transparent tank.

*Thin film interference*.—The phenomenon of light interference is responsible for the **colors** one sees when looking at a thin film of oil on water, soap bubbles, and CDs. White light that reflects from these surfaces undergoes interference (slide 15) and the various wavelengths of the white light interfere at different locations and thus the white light is separated into colors. The photo on the right shows the colorful pattern created by a thin soap film.



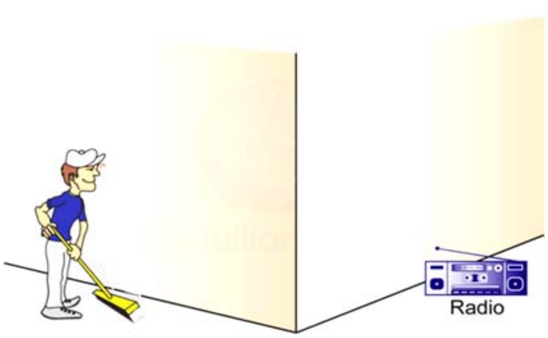
**32-3 Diffraction.—**Diffraction is **the spreading of a wave as it passes through a narrow opening. Diffraction is due to the interference of waves**. When a wave encounters an obstacle with a narrow opening, **the wave is NOT simply cut off by the opening** so that only a portion of the wave passes through as indicated in the diagram below. In other words, a simple geometric shadow of the opening is **not observed**. Rather, what actually occurs is illustrated below. As the wave passes through the opening, it spreads out in all directions. In fact the narrower the gap, the more diffraction that takes place – the wave spreads out even more, as illustrated below:

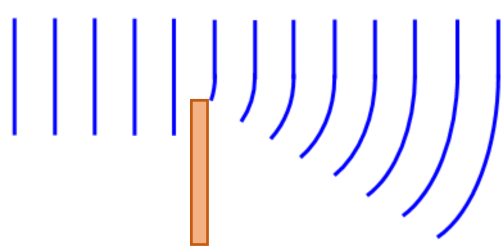


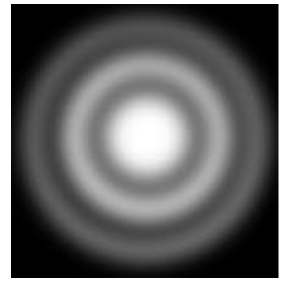
**Diffraction occurs with all types of waves**. The figure on the right illustrates the diffraction of water waves when they impinge on an opening in a wall. The relatively straight wave fronts turn into curved wave fronts when the wave passes through the opening.

The **diffraction of sound waves** around a wall makes it possible for us to hear sounds originating in another room even if we are not in the direct line with the source as shown on **slide 20** and in the diagrams below.



When light is incident on a small hole in a plate, a **characteristic pinhole diffraction pattern** of concentric bright rings, similar to that shown on the right, is seen on a distant screen (slide 22).



*Resolving power.*—Diffraction of light by obstacles or even lenses limits our ability to **distinguish closely spaced objects**. **Resolving power** is the ability of an imaging device to separate (i.e. to see as distinct) points of an object that are located at a small angular distance or it is the power of an optical instrument to separate far away objects, that are close together, into individual images. The photos on the right are diffraction patterns generated by light from two points passing through a circular aperture, such as the pupil of the eye. **Lord Rayleigh** established a criteria (known as the **Rayleigh criterion**) for deciding when two objects are barely resolved. Two point sources are regarded as just resolved when the principal diffraction maximum of one image coincides with the first minimum of the other. If the distance is greater, the two points are well resolved and if it is smaller, they are regarded as not resolved. The diffraction of light by the lenses in cameras on a satellite is the ultimate limiting factor in determining the smallest object that can be seen on earth by a satellite.