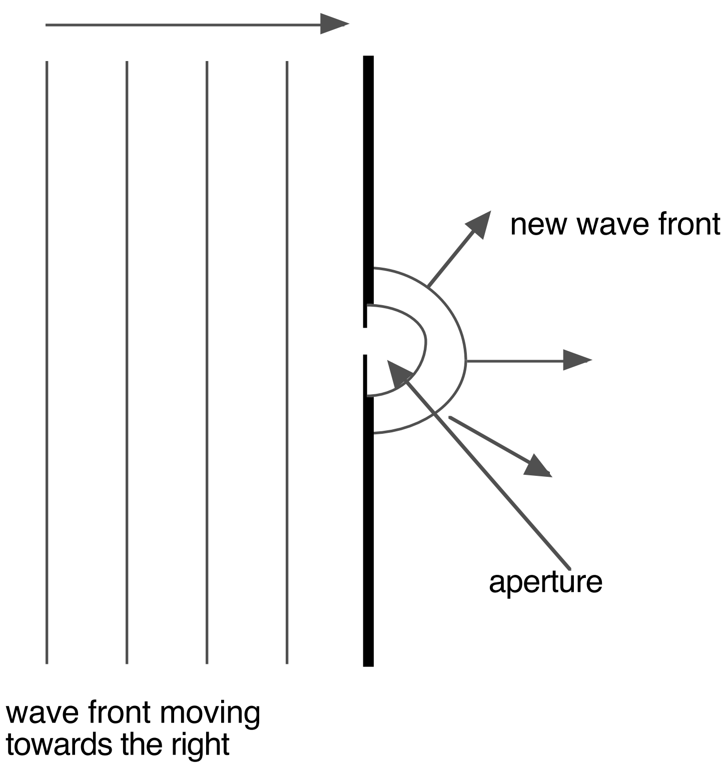
Schaums.40

Chapter 40 concerns the property of light (and all waves) know as diffraction. Diffraction occurs when a wave moves through a small *aperture* or hole in a barrier. This causes the wave to bend. THE AMOUNT THE WAVE BENDS DEPENDS ON THE SIZE OF THE APERTURE COMPARED TO THE WAVELENGTH OF THE LIGHT. THE CLOSER IN SIZE TO THE WAVELENGTH THE APERTURE IS, THE MORE THE WAVE WILL BEND.

A Dutch physicist by the name of Christian Hyugens noticed that both water waves and light waves experience this behavior and as such he hypothesized that light was a wave. He was a contemporary of Newton's and Newton was of the opinion that light consisted of a stream of particles. Since Newton was the more respected of the two physicists, most other physicists sided with Newton. We now understand that light acts both as a wave and as a stream of tiny particles called *photons*. Some physicists like to think of these photons as tiny wave *packets*.

The most compelling evidence that light behaves as a wave came form a brilliant experiment conducted by a British optometrist by the name of **Thomas Young** about 1807. It was Albert Einstein who showed that light acts as a particle in his explanation of the **photoelectric effect**, which is the ejection from metals of energized electrons when light of certain frequencies is shined on the metal. He actually received the Nobel Prize for this discovery and not for his Theory of Relativity.

Still Hyugens is not forgotten. There is a famous and important principle, know as **Hyugen's Principle** that states that if a wave front strikes a barrier in which there is a small aperture (similar in size to the wavelength of the wave) this aperture acts as a **point source** of a new wave



Of course Hyugen never had as many groupies as Newton or Einstein and is thus considered a loser among the Physics elite. He did have a moderate amount of bling however.

What do we mean by **point source**? If you were to drop a pebble in a a smooth pond, waves would emanate out from the point in which the pebble was dropped in a regular even pattern. This point would be called the point source. In a sense, the water in the pond acts very much like a spring that is momentarily being stretched and then begins to oscillate back and forth, sending the initial energy of the falling pebble outwards.

One of the fascinating and useful areas of wave research is that waves can be used to transmit both **energy** and **information**. The electromagnetic waves that send television and radio signals are just like the light waves that we use to receive information in the way of light to our eyes and energy in the way of solar energy. Their frequency and wavelength is just different. Electromagnetic waves continually oscillate between an **electric field** and a **magnetic field** that oscillate at right angles to each other.

A quick review of waves:

A wave has a **wavelength**, the distance from one crest to the next crest. In physics we must measure this in SI units of meters. Visible light has wavelengths from 400 nanometers (1 nanometer = 1 billionth of a meter) for violet to nearly 700 nm for red light.

A wave has a **frequency**, or the number of times it goes through a full oscillation each second. Frequency is measured in **hertz**, where a hertz is one divided by seconds (1/s) or s^{-1}. This is often called **inverse seconds**. Visible light has frequencies in the order of magnitude of 10^{14} hertz.

When a wave reaches a boundary between two medium, part of the wave will reflect and part of it continues on through to the new medium. **If the new medium is such that it slows the wave down, then the reflected portion of the wave will be inverted (its crests will become troughs and the troughs will become crests). This is very important in understanding why soap bubbles (thin films) show the colors of the rainbow**

A wave has amplitude, which is **one half** the distance from its crest to its trough (high point to low point)

The speed of light is 3.00×10^8 m/s. The speed of a wave is equal to its **frequency times its wavelength.**

The shorter a light wave, the higher its frequency, and the higher the frequency, the more energy it contains per photon. (ultraviolet light is more energetic than infrared light)

Electromagnetic waves are caused by the **acceleration of a charged particle**.

Interference This is the attribute of light (and all waves) that Thomas Young used to demonstrate that light was a wave. When two waves collide (you can experiment with this in a swimming pool or a bath tub) they interfere with each other.

Constructive interference. In this case the crests of the two waves collide and the amplitude of the wave is increased to the sum (or what is called the **superposition**) of the two waves. You get a very large wave or in the case of light a very intensely bright spot.

Destructive Interference In this case the crest of one wave collides with the trough of another wave, the two waves cancel and you have no amplitude at all. THis is still an example of superposition.

In water or in light, the combinations of destructive and constructive interference create what is called an **interference pattern.** This also occurs with sound waves and it is our ability to process the information from our eyes and ears of these interference patterns that greatly adds to our ability to see and hear in three dimensions. Stereo and surround sound use sound interference to give a quality of three dimensional space to audio and holograms take a picture of the the very fine interference patterns of light in order to create three-dimensional images.

YOUNG'S DOUBLE SLIT EXPERIMENT

Thomas Young knew that if he could show constructive and destructive interference from two sources of light it would greatly add creditability to the notion that light was a wave. He started with one source of light, which he **collimated** using a lens (this made the light rays from the source parallel to each other). He etched two very fine slits in a barrier that were as close together as physically possible at the time. Recall that the amount which a wave diffracts (or bends) as result of going through an aperture is a function of how close in size the slit is to the wavelength of the wave. From Hyugens principle, Young knew that the two slits would act as point sources for two new wave fronts and that these two wave fronts would then interfere with each other constructively and destructively.

About one meter from the slits, Young placed a screen. At a point exactly midway between the two slits, Young observed a very bright spot, or **central maximum**. Young correctly surmised that this spot was due to **constructive interference** since each ray of light traveled exactly the same distance from its slit to reach this point. Slightly to the left and right of this bright spot Young observed a dark band. At this point, Young surmised that the difference in the distance that each ray traveled (**the path difference)** was equal to **one half of a wave length.** Because of this, the rays were out of phase, meaning that the crest of one collided with the trough of another and **destructive interference resulted.** Just to the left and right of this dark band another bright band was observed. THis resulted from the path difference being equal to one full wavelength and once again constructive interference resulting.

Young's double slit and diffraction grating

d = distance between the two slits in the Young's double slit experiment or the distance between two consecutive lines in a diffraction grating
(this distance is very small and in order to make light bend this distance should be on the order of the wavelength of the light) (all waves experience diffraction)

x= the distance along the screen from the central maximum to an ensuing `1111111111`1``````````````` ` ``` \order bright spot(or maximum)

λ (lambda)= the wavelength (in meters)

L = the distance from the double slit or diffraction grating to the screen

n = bright spots will occur every time the path difference is 1,2 ,3, 4......n wavelengths

$$\sin\theta = \frac{\lambda}{d}$$

$$\tan\theta = \frac{x}{L}$$

$$\sin\theta = \frac{\lambda}{d}$$

Small angle approximation

For small angles (up to about 15°)

$\sin\theta \approx \tan\theta$

$n\lambda = \frac{dx}{L}$ (the number wavelengths is equal to the **dux on the lake)**

40.16 This is just the Young's double slit experiment using sound waves. In reality this is very hard to duplicate in a room since sound bounces off the walls and the listener hears it coming from many sources (instead of just two)

40.17 The path difference for each reflected wave is equal to two times the thickness of the film. Thus, constructive interference will be observed for wavelengths of light that are equal to two times the thickness of the film. This is actually used to measure the thickness of very fine films.

40.18 Since $\frac{n\lambda}{d} = \sin\theta$ and we are given the wavelength and *d*, we can solve for the angle when n = 3 1nd n =2

40.19 Use the old ducks on a lake formula for n = 2 and n =3.

40.20 Use $n\lambda = \frac{dx}{L}$ to find x for n = 2 and n =3. The third dark spot will occur between them.

40.21 Each dark spot (fringe) represents one half wavelength. A *μ*m is called a micrometer and is equal to 1 x 10^{-6} m. 589 nm is equal to 5.89 x 10^{-7} m (but you knew that) Do the math.

40.22 For the yellow light, the path difference is equal to 580 nm, so you might think that the yellow light would experience constructive interference and it would reflect strongly. But recall that when the ray strikes the boundary between air and the air film, the reflected part is inverted. This causes the first reflected ray to be out of phase with the second reflected ray and destructive interference occurs. **THE YELLOW LIGHT WOULD EXPERIENCE CONSTRUCTIVE INTERFERENCE IF THE AIR FILM WAS 1/4 WAVELENGTH THICK.**

40.23 When light is slowed down, either its wavelength must shorten or its frequency must decrease since speed equals frequency times wavelength. Frequency cannot decrease because that would result in a buildup of wave fronts at the boundary. Therefore the wavelength must decrease by a factor equal to the index of refraction 0r 589 nm/1.4. Otherwise the problem is the same.

40.24 Same principle as 40.23

40.25 The formula for single slit diffraction is the same as for double slit diffraction but instead of *d* substitute "*w*" where *w* is the width of the double slit. THe formula then gives **dark bands** (destructive interference) instead of the bright bands given by the formula for double slit interference.

40.26 First solve for "d" using $\frac{n\lambda}{d} = \sin\theta$. Be sure to convert 600 nm to meters. Once you find "d" (it will be in meters) take the inverse of this number. This will give you lines per meter. Convert that to lines per centimeter.

40.27 2000 lines per cm is equal to 2.0x 10^5 lines per meter. To find "d" in meters, take the inverse of this number. Then use dux on a lake.

40.28 Just like 40.27. For part b, recall that sine can never be greater than 1

40.29 You probably could guess that one, but to make it formal

$$\lambda = \frac{dx}{nL}$$

$$\frac{\lambda_1}{\lambda_2} = \frac{\frac{dx}{2L}}{\frac{dx}{3L}}$$

Where d, x, and L are equal in the numerator and the denominator

40.30 Find d first and then use $\frac{n\lambda}{d} = \sin\theta$ to find the angles for each wavelength of light.

40.31 From the fourth order of the hydrogen you can derive "d." from $\frac{n\lambda}{d} = \sin\theta$. Then you can use that value to find the wavelength of the sun'[s infrared light.

40.32 A with a little circle above it is called and angstrom and is equal to 10^{-10} m. Notice that an X-ray has a short wavelength and thus a high frequency, thus is highly energetic and consequently more dangerous than regular light. By " how far apart are the diffracting planes" they are asking you to solve for "d" in the equation $\frac{n\lambda}{d} = \sin\theta$.

IF YOU HAVE DONE ALL THESE PROBLEMS AND UNDERSTAND THEM YOU ARE A NERD BUT I WON'T TELL ANYBODY.