6.2 Wave Phenomena

Warm Up

You and a friend both throw rocks into a lake. The rocks enter the water 1.0 m apart. If you were looking down from above, draw what you think the wave pattern for each of the rocks will look like. Place the letter X at the point or points where the waves would be the highest.

Properties of Waves

You already know several properties of waves. Waves can be reflected and refracted. All waves conform to the wave equation. There are other important properties of waves, such as constructive and destructive interference, that lead to interesting natural phenomena.

Constructive and Destructive Interference

Figure 6.2.1 shows waves coming from two different sources — A and B. What happens if the two sets of waves arrive simultaneously at the same place? The result is shown in the third diagram. The amplitudes of the two sets of waves are additive. Since the waves from source A are in phase with the waves from source B, the resultant waves have twice the amplitude of the individual waves from A or B. This is an example of what is called **constructive interference.** Notice that crests are twice as high and troughs are twice as deep in the combined waves.

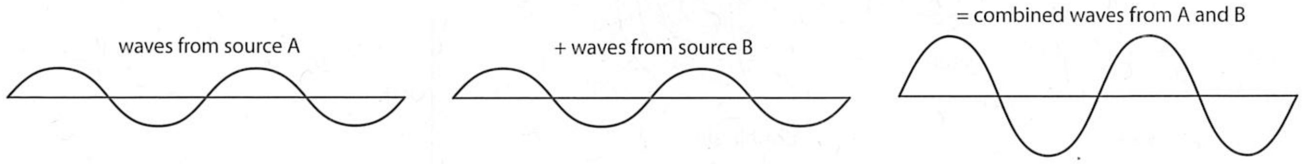

Figure 6.2.1 *Constructive interference*

In Figure 6.2.2, the waves from source A are exactly out of phase with the waves from source B. A crest from source A arrives simultaneously with a trough from source B. The two sets of waves exactly cancel each other. This is an example of **destructive interference.**

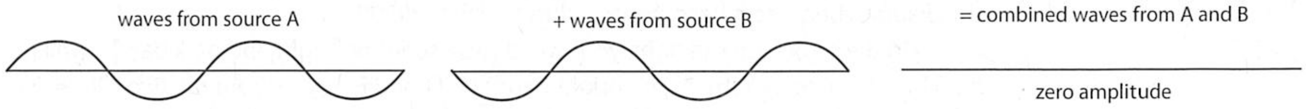

Figure 6.2.2 *Destructive interference*

ISBN 978-0-9864778-3-6

Interference of waves occurs with all sorts of waves. You may have seen interference of water waves in the wave tank. You can hear interference of sound waves if you simply listen to a tuning fork as you rotate it slowly near your ear. Each tine of the fork produces a set of sound waves. Listen for constructive interference. It's the extra loud sound. Destructive interference is the minimum sound you hear as you slowly rotate the tuning fork.

Young's Experiment

The interference property of waves was first used to measure the wavelength of light by the English scientist Thomas Young (1773–1829). Young's interference experiment, done in 1801, has great historical importance because it seemed to suggest very strongly that light is a wave phenomenon.

Figure 6.2.3 illustrates how Young's experiment was done. A single slit was illuminated by a source of light of one colour (wavelength). Circular waves spread out from the single slit. When the wave front hit the double slit, each of these two slits acted as a new source of circular waves that travelled toward a vertical screen. On the screen a series of bright and dark bands of light appeared. A sheet of photographic film could be substituted for the screen.

Young's interference experiment can be illustrated very easily now using a classroom laser. The laser automatically produces one single wavelength, and the interference pattern is bright enough to see even in a well-lit room.

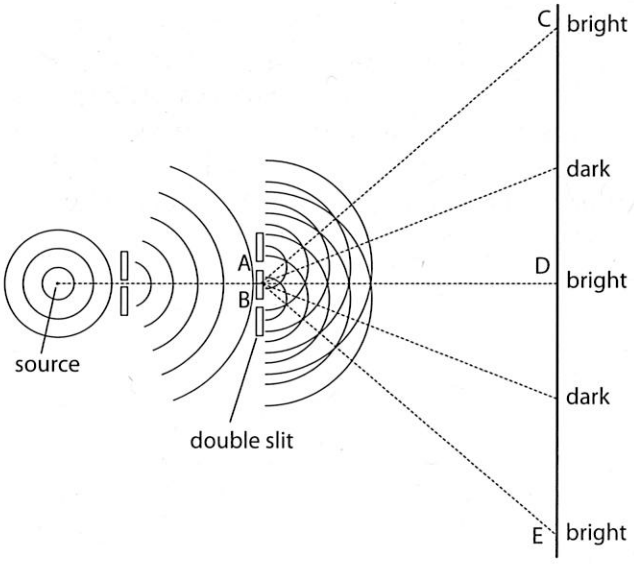

Figure 6.2.3 *Young's experiment*

Interference Pattern

In Figure 6.2.3, the concentric circles represent successive peaks of light waves coming from the slits. Troughs are midway between the peaks, of course. They are not shown in the diagram because it becomes too cluttered with detail.

On the screen on the right, you would see a series of bright and dark bands, which is an interference pattern. At the bright bands (C, D, and E), crests from the two slits arrive simultaneously, as do troughs. There is constructive interference of the two sets of waves. Notice that waves arriving at D have travelled the same distance from their slits.

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Waves arriving at C or at E have travelled distances that differ by exactly one wavelength (λ). Again, the peaks arrive simultaneously and the troughs arrive simultaneously, and there is constructive interference causing the bright bands at C and E.

Figure 6.2.3 is simplified. There will be other bright bands farther out on both sides of the central bright band. These bright bands will occur wherever the difference in distance travelled from slits A and B is an integral number of wavelengths.

At the dark bands, called **nodal lines**, waves from the two sources arrive out of phase. That is, when a crest from slit A is arriving, a trough from slit B is also arriving. The crest cancels the trough. This is destructive interference. The amplitudes of the two arriving waves cancel each other and you see no light.

Figure 6.2.4 shows the geometry of the situation, and how you can use the interference pattern to calculate the wavelength of the light. For simplicity, the first bright band adjacent to the central bright band is used.

CA is the distance from the screen to source (slit) A. CB is the distance from the screen to the second slit B. The difference in these two distances is BF, which is one wavelength.

$$BF = CB - CA = \lambda$$

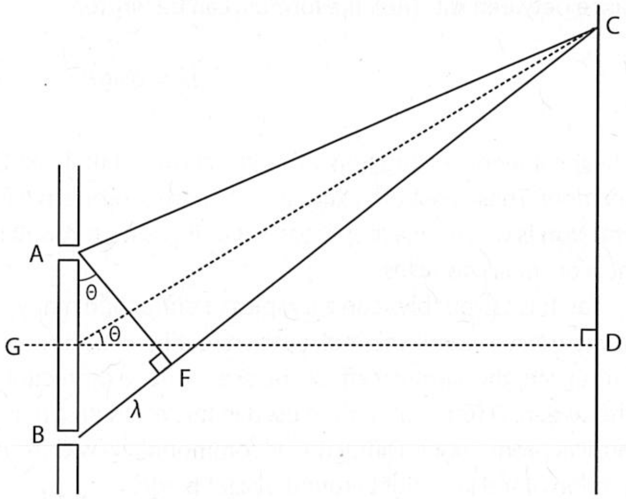

Figure 6.2.4 *Using the interference pattern to calculate the wavelength of light*

In the diagram, GD is the central maximum. A bright band appears on the screen at D. A dashed line, CG, joins the midpoint of the two slits with the bright band at C. You will note that there are similar triangles on this diagram.

Since ΔBFA ~ ΔCDG, therefore $\dfrac{BF}{CD} = \dfrac{AB}{CG}$

This means that the wavelength BF can be calculated as follows:

$$BF = (CD)\frac{AB}{CG}$$

or $$\lambda = (CD)\frac{AB}{CG}$$

where CD is the distance on the screen between the central bright band and the first bright band to either side of it; AB is the distance between the two slits or sources; and CG is the distance from the midpoint of the two slits to the first bright band on the screen.

For the second bright band, BF = 2λ; for the third bright band, BF = 3λ; and for the *n*th bright band, BF = $n\lambda$.

In general, for the nth bright band:

$$n\lambda = (\text{CD})\frac{\text{AB}}{\text{CG}} \text{ and}$$

$$\lambda = \frac{(\text{CD})(\text{AB})}{n(\text{CG})}$$

This relationship can be used to calculate the wavelength of light from an interference pattern. It can also be used to calculate the wavelength of water waves in a wave tank.

If you are familiar with simple trigonometry and you study Figure 6.2.4, you will notice that the ratio of side CD to side CG of triangle CDE is equal to the sine of angle G (which is called θ on the diagram). You will see that the formula for the wavelength can, therefore, be written

$$\lambda = \frac{\text{AB}}{n}\sin\theta$$

where θ is the angle between the line GD (central bright band) and the line GC (*n*th bright band), and n is the number of the bright band. If the symbol d is used for the distance between slits (AB), the formula can be written

$$n\lambda = d\sin\theta$$

Diffraction

You hear someone talking from around a corner. Light leaks through a crack in a closed door. These are both examples of another property of waves called diffraction. **Diffraction** is when a wave spreads out as it passes through narrow openings, around corners or small obstacles.

You have probably seen examples of diffraction many times, perhaps without knowing what it was. If you look out at streetlights through a window screen or a fine mesh curtain, the *starburst* effect you see is due to diffraction of light waves as they pass by the screen. Diffraction is often used in television programs to obtain starburst effects in musical productions. Diffraction is commonplace with sound. Figure 6.2.5 shows the diffraction of red laser light around a razor blade.

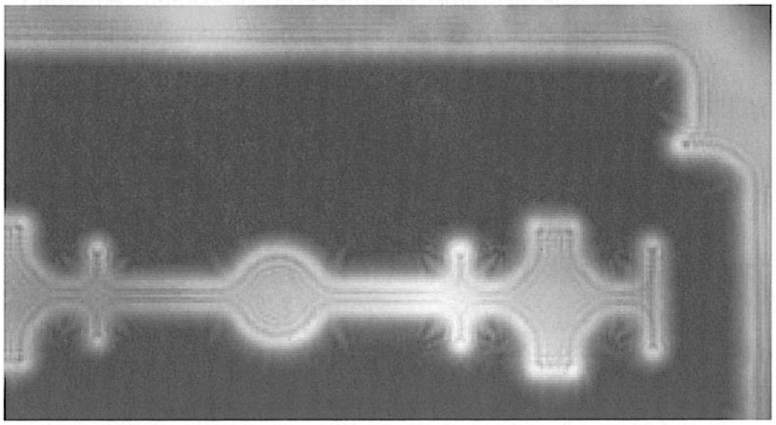

Figure 6.2.5 *Using the interference pattern to calculate the wavelength of light*

The Doppler Effect

When a fast car or motorbike approaches you, the pitch of its sound rises. As the vehicle goes by, the pitch lowers. The effect is quite noticeable if you watch a high-speed automobile race on television. What causes this change in pitch? Austrian physicist C. J. Doppler (1803–1853) was the first to explain the effect in terms of waves, and therefore the effect is called the **Doppler effect**.

Figure 6.2.6 illustrates sound waves coming from a moving source. The vehicle is moving to the left. Sound waves coming from the vehicle are bunched in front of the vehicle, which tends to catch up with its own sound. (This diagram exaggerates the effect.) The wave fronts or compressions are closer together in front of the vehicle and farther apart behind the vehicle.

The observer at A hears a higher pitch than normal, since more compressions and rarefactions pass his ear per second than pass the observer at B. Observer B hears the normal pitch of the vehicle's sound. Behind the vehicle, compressions are spaced out, since the vehicle is travelling away from the sound it sends in that direction. The observer at C hears a lower pitch than normal. Fewer compressions and rarefactions pass his ear per second than if he was at A or B. As the vehicle passes observer A, he will hear the pitch go from high to normal to low in a very short time interval. He will hear the Doppler effect.

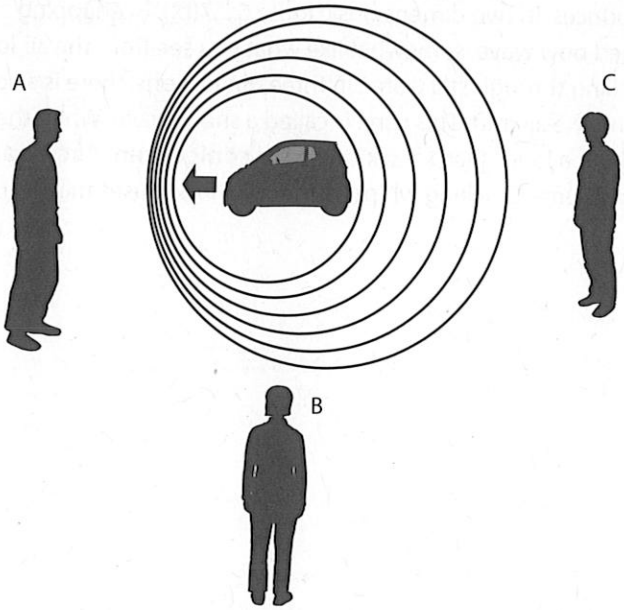

Figure 6.2.6 *The wave fronts are closer together at the front of the moving vehicle as it moves forward and more spread out behind.*

The Sound Barrier

An extreme case of the Doppler effect occurs when an aircraft or bullet travels at the same speed as the sound it is producing. At the leading edges of the aircraft, the compressions it creates tend to bunch up and superimpose on each other (Figure 6.2.7(a)). This creates a wall or barrier of compressed air called the **sound barrier**. Great thrust is needed from the plane's engines to enable the plane to penetrate the sound barrier. Once through the barrier, the plane experiences much less resistance to its movement through the air. The plane, once through the sound barrier, is then supersonic. Its speed is now greater than Mach 1!

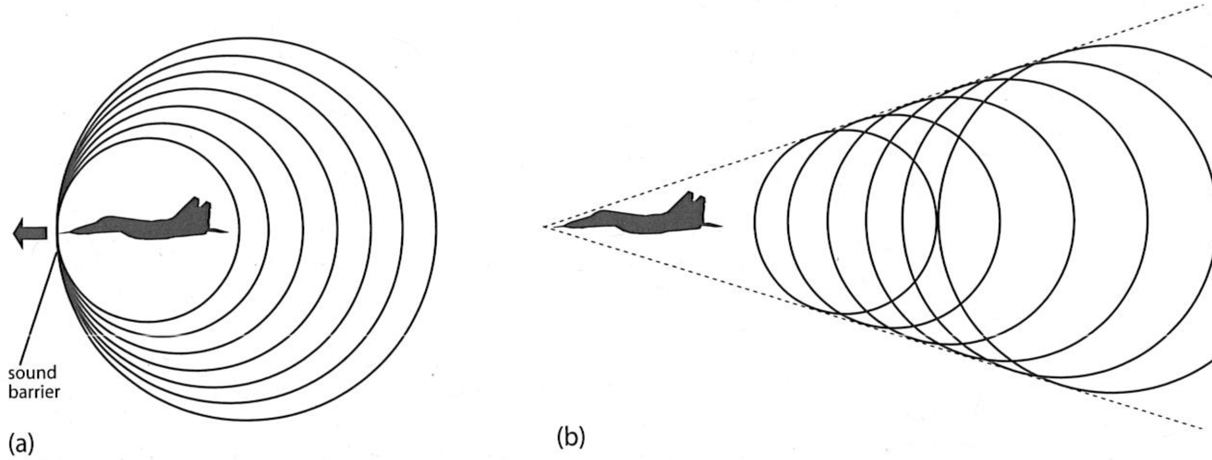

Figure 6.2.7 *(**a**) The airplane travelling at the speed of sound creates a wall of compressed called the sound barrier; (**b**) An airplane travelling faster than the speed of sound creates a shock wave that you hear as a sonic boom.*

Shock Waves and the Sonic Boom

If a plane travels *faster* than sound, it gets ahead of the compressions and rarefactions it produces. In two dimensions (Figure 6.2.7(b)), overlapping circular waves form a V-shaped bow wave, somewhat like what you see from the air looking down at a speedboat travelling through still water. In three dimensions, there is a cone of compressed air trailing the aircraft. This cone is called a shock wave. When the shock wave passes you, you hear a loud, sharp crack called the **sonic boom.** Aircraft are not the only producers of sonic booms. Cracking whips and rifle bullets causes miniature sonic booms!