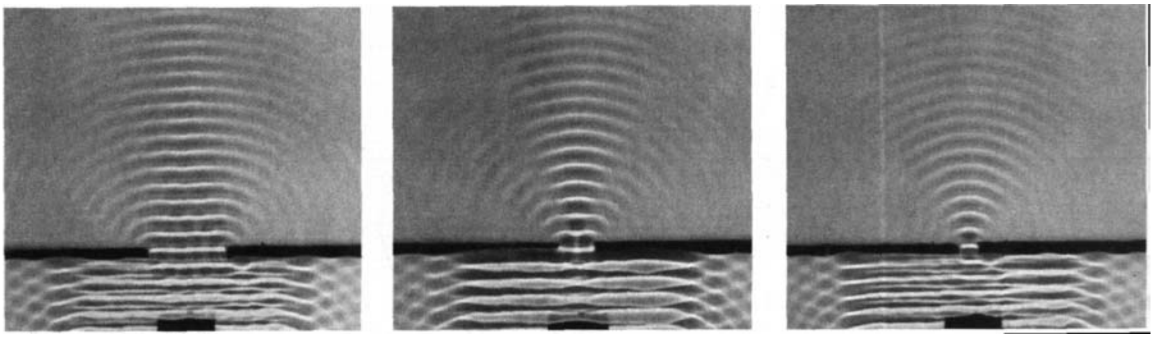
Introduction
To
Diffraction
Teachers Supplement



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Introduction to Waves

Waves are all around us in everyday life- we listen to the radio which is transmitted by electromagnetic waves, we hear each other speak by sound waves, we see waves on water. Even though these waves occur through different mechanisms- air, water, electromagnetic fields- they all have similar properties. We can exploit the properties of waves for different purposes. We use sound waves to communicate with each other all the time! We can extract energy from waves and convert it to electricity in solar cells. We use the varying wavelengths of light coming from different objects to see colors around us. The following exercises we'll investigate a property of waves called diffraction, and see how we can put it to work for us. Diffraction is a powerful tool- we can use diffraction of waves to study the structure of matter at the atomic scale. To demonstrate how diffraction works, we'll begin by working with more familiar examples of diffraction with light waves. But before beginning to talk about diffraction, and how we can put it to work, we need to understand some basic terms about waves.

Throw a rock into a pond, and a pattern of ripples will spread out in all directions, as shown below. The distance between the waves is the **wavelength** and the speed at which they travel is the **velocity** or speed of the wave. The number of waves that pass a single point in a given amount of is the **frequency** of the wave. The height from the crest to the trough of the water is the **amplitude** of the wave. If you hear a note played on the piano at middle C, the note played an octave about middle C has double the frequency and half the wavelength, and both notes travel to your ear at the speed of sound- 650mph.

Water waves are easy to understand because we can see them with our eyes. But there are other types of waves. Sound waves are variations in the pressure and density of the air and have wavelengths of centimeters. Radio waves are variations in electric and magnetic fields, and generally have wavelengths of centimeters to meters. Believe it or not, light is also a wave- and is very similar to radio waves. Light waves are also variations of electric and magnetic fields, but have wavelengths much smaller than radio waves- we'll discover just how small in the following exercises.

Photo courtesy of the NAIC - Arecibo Observatory, a facility of the NSF, and David Parker / Science Photo Library

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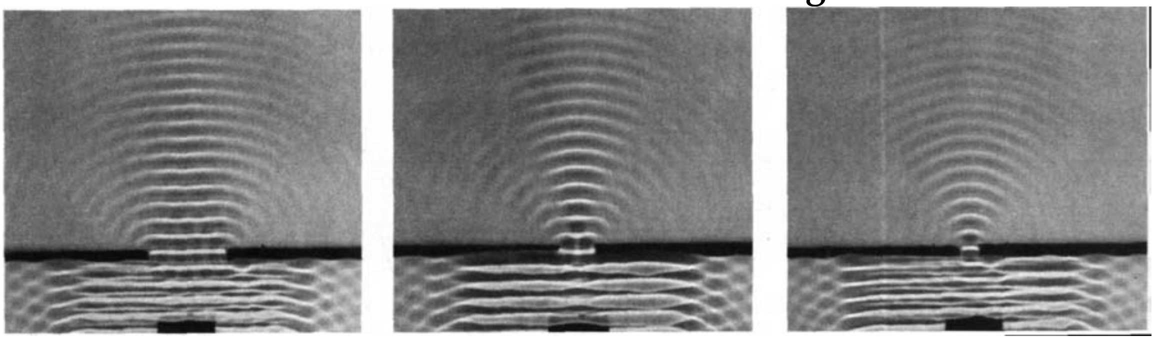
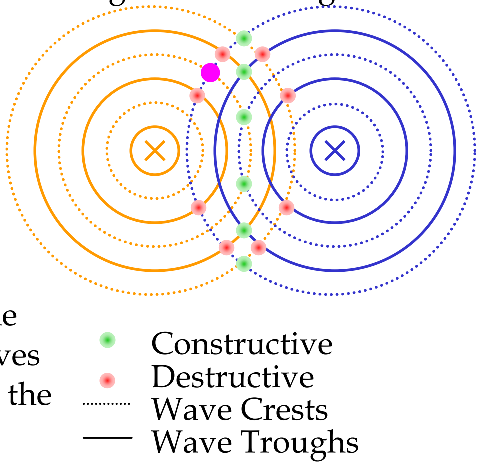
Diffraction of Waves

Waves travel in straight lines, as long as nothing gets in their way. The picture below shows a wave tank with waves travelling from the bottom towards a barrier. Where there is a hole in the barrier the water waves pass through unimpeded, and waves striking the barrier are reflected as shown in the picture on the left. However, if the size of the hole begins to shrink, as in the right hand picture, something curious begins to happen. The waves, which had been travelling upwards, begin to bend after passing through the barrier. In fact, for a very small hole the waves look similar to the first example of a rock being tossed in the water at the point of the hole. A wave that strikes objects of a size about equal to the wavelength is said to **diffract**. In the images, diffraction of the waves started to show up only when the hole in the barrier was about the same size as the wavelength.

Diffraction of water waves through a barrier



Lets try one more thought experiment with water waves. Instead of throwing just one pebble in the water, throw two in at exactly the same time. The circles of waves spread out from where the pebbles landed, as shown the diagram below. The water waves will begin to overlap. At the overlap points where the crests of the waves cross, the result will be higher than a single wave. Similarly, where two troughs cross the result will be lower than a single wave. The addition of heights of the two waves is called **interference**. In the above example, the waves added together to produce a wave with larger amplitude. However, there are also points in the diagram where the crests of one wave cross the troughs of the other, reducing the amplitude of the wave. In the first case, the waves are **constructively** interfering and in the second the waves are **destructively** interfering.



Lets look at the same experiment from a

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slightly different perspective. Lets look at one point some distance away from where the two pebbles hit the water, and try to figure out whether the waves are constructive or destructively interfering. Looking at points along the centerline, equidistant from both sources, the waves meet after both have traveled the same number of cycles- so they must be constructively interfering at that point. Are there any other places where constructive interference takes place?

At the point of the purple dot the left wave has traveled 2 cycles and the other 3, so that when the waves reach this point the waves will constructively interfere. At any point where the two waves have traveled a distance that differs by one wavelength, the waves will constructively interfere.

By doing a bit of geometry, it's possible to show that the angles at which constructive interference occurs are given by the following formula:

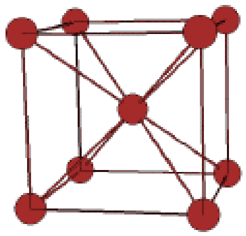
$$n \cdot \lambda = d \cdot \sin\theta$$

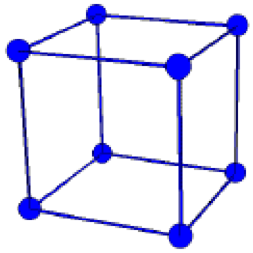
As we discovered above, there are many angles at which constructive interference occurs. In the equation above, n is an integer representing which particular interference peak we're interested in. λ is the wavelength of the wave, d is the distance between objects, and θ is the angle at which constructive interference will occur.

In the diffraction exercises that follow, we'll be working with light waves. Instead of looking at water wave height when the waves interfere, we'll be measuring light intensity. And because light waves are much smaller than water waves, the objects that cause light diffraction are much smaller than water waves. One of the most important uses of the diffraction equation above is to measure the size of objects. In the wavelength of the source is know, and the angle of the interference is measured, it's possible to calculate the spacing between the diffracting objects.

Applications of Diffraction

But much more can be learned about the objects than just the separation distance. Different patterns of objects will result in different diffraction patterns. As a result, we can use diffraction much like a microscope to view small objects. Diffraction can even be used to study the arrangement of objects as small as atoms. As shown to the right, atoms in crystals are arraigned in regularly repeated cells. Different materials will naturally form into a particular kind of cell structure- and this arraignment determines many of the properties of the material: its electrical and thermal conductivity, its color, its hardness and more. We can use diffraction patterns to discover what





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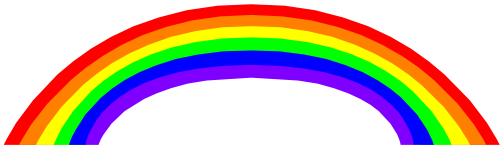
the structure and sizing of the atoms are. However, as mentioned before, in order to produce diffraction the wavelength of the light must be approximately the same size as the spacing between the objects. What kind of light is atomic sized? And how big are atoms?

In the diffraction experiments contained in the lab, students learn how big a micron (10^{-6}meters) is by measuring the width of their hair- which usually about 10 microns. Atoms are generally about .0001 microns apart in crystals- REALLY small! What sort of light has a wavelength of about .0001 microns? X-rays! By shining x-ray light through a crystal, a diffraction pattern is produced, and from the spacing and type of pattern, the atomic structure can be discovered.



One last application of diffraction that is commonly used involves diffraction of light by different colors. If multiple wavelengths of light were diffracting from the same object, the diffraction equation tells us that they will have different angles of constructive interference. In this way, diffraction can be used in a method similar to a prism- white light hitting a diffracting object gets spread out into its constituent colors.

As you can see, diffraction has many different applications in science- and you'll get the chance to see it in action!

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