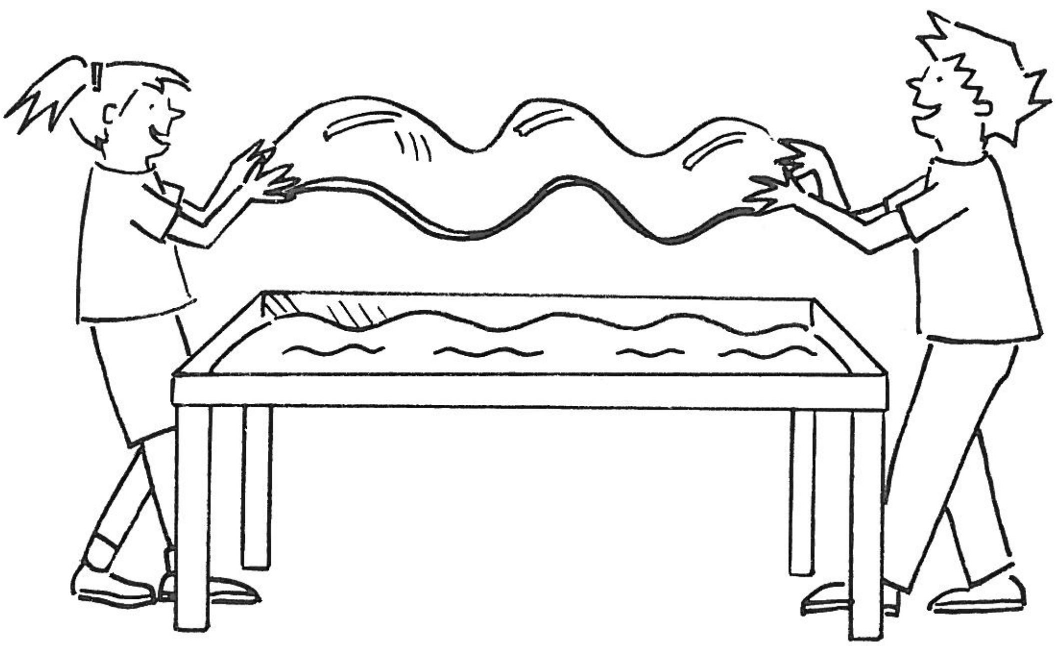
WAVES & VIBRATIONS

Science Activities for Home or Classroom



By Bernie Zubrowski

The Children's Museum, Boston

Introduction

When most people think of waves, they picture themselves at the beach playing in the water. They are either dodging the waves as they crash into the beach, or riding them on a surfboard. Calm days aren't very much fun because the water is flat, but on windy days or during heavy storms the waves can become quite big. Imagine what it would be like to attempt surfing during a hurricane or a typhoon. The winds, moving at more than a hundred miles an hour, whip up the surface of the ocean, producing gigantic waves that are sometimes taller than a battleship. Then there are the waves from volcanic eruptions. Once, in Indonensia, a tremendous volcanic eruption produced a gigantic wave that traveled hundreds of miles, overrunning small islands and flooding shorelines as far away as India.

Ocean waves can come in very many sizes, from small ripples on a calm day to waves several stories high during a heavy storm. Waves on a lake or pond don't attain the size of those of the ocean, but they can still grow large during very violent storms. Most of the time, however, they are only small ripples that quickly disappear as they move away from a disturbance.

A body of water that is even smaller and still has waves is the swimming pool. After the lifeguard blows the whistle for everyone to get out of the pool, it takes a while for the water to calm down - even though all the waves and ripples are small. Here, on a small scale, you can see what happens when there is a big disturbance. When a large person jumps into a pool of quiet water, one can see the wave travel all the way to the other side of the pool, even causing water to spill over the side. If you were to compare a picture taken from an airplane of waves on the ocean, and a picture taken of waves in a swimming pool, you may not be able to see any differences. The movement of the water in the pool looks similar to that of the ocean.

We can go a step further and make waves in an even smaller pool of water. The bathtub you have in your house and a wading pool used by small children are other places to see waves in water. The waves you can make in these very small environments have similar characteristics to those you might see on the ocean. Most people can't investigate waves on the ocean, but everyone can study their behavior in a small tank of water. Scientists and engineers sometimes build small-scale models of large-scale environments. To study the currents and try to determine where best to place a new bridge across San Francisco Bay, engineers built a model of the bay. It was the size of two basketball courts. The model was very helpful for them in determining how water moves in the Bay. You can carry out similar investigations, although your model will have to be much smaller and your experiments will have to be simple.

Investigating Waves In A Small Tank
Activity 1 - Part 1

Have you ever noticed the ripple pattern at the bottom of a swimming pool or near the edge of a pond on a sunny day? The light from the sun is focused into bright lines that move across the bottom as the waves move across the surface. These lines are formed by the curved surfaces of the waves and behave just like the waves. The lines help us to better see how waves move and interact. The patterns that are produced can be very pleasing to watch, and are fun to make. This same kind of effect can be produced indoors with a simple lighting arrangement hanging over a small pool of water in a plastic tray or even over the bath tub.

To do this indoors you don't necessarily need a very bright light. The bulb from a flashlight will do. There are several kinds of small tanks you can use for observations. A very convenient one is a plastic picture frame. The bigger the frame, the better you can see what is happening. Another possibility is your bathtub. A third alternative is to buy a rigid sheet of plexiglass and make a wall around the edges with clay to keep in the water. The following section will explain how to set up the tank and the lights so that you can explore wave-making.

Materials

1 7.2 volt flashlight bulb

1 piece of tubing, thin wall, 1 inch long by 1/2 inch in diameter
(This is usually sold by the foot at hardware stores)

1 nail, 2 inches long

2 pieces of electrical wire, each about 3 feet long

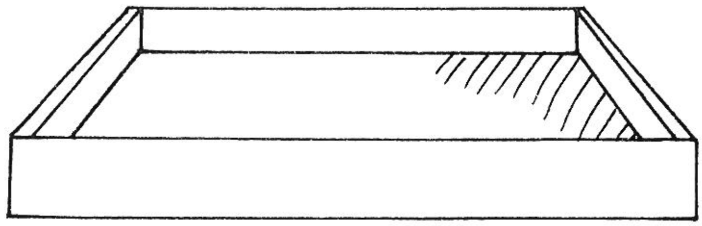
1 battery holder that holds 4 D cell batteries

4 D cell batteries

3 wood dowels, 1/4 inch in diameter, 3 feet long

If you are not making waves in your bathtub, here are two alternatives:

1 Plastic frame for photographs, 18 inches by 24 inches, the frame should have walls on the edges that are at least a half inch high. (Brand name - Dax)



1 piece of Plexiglass, at least 18 wide x 24 long inches and 1/4 inch in thickness

1 package of oil-base clay, such as Plasticene

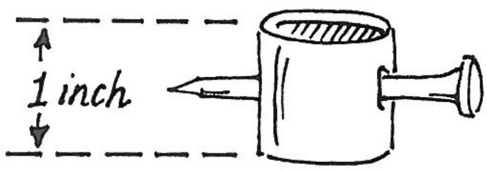
1 milk carton

rubber bands

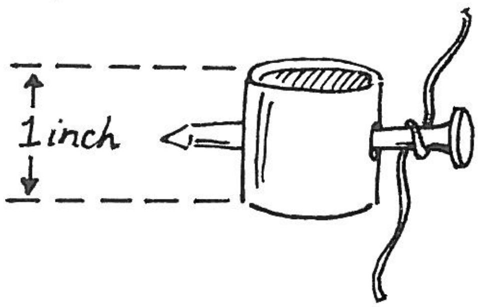
3 Pieces metal strapping, 16 inches long, about 1/2 inches wide (Can be found in lumber yards)

Setting up the lighting arrangements:

1. Using a knife or scissors, cut a 1 inch piece of plastic tubing. Force a 2-inch nail through the middle of this piece.



2. Wrap one end of a bare electrical wire around the head of the nail.



3. Place a bare end of the other electrical wire inside the tubing so that the wire is flush against the plastic, but not touching the nail. Slide the metal base of the flashlight bulb into the tubing until it touches the nail. (The base of the bulb should hold the second wire in place against the tubing.) To test your completed bulb holder, touch the free ends of the two electrical wires to the two electrical wires coming from the battery holder (having 4 D cell batteries).

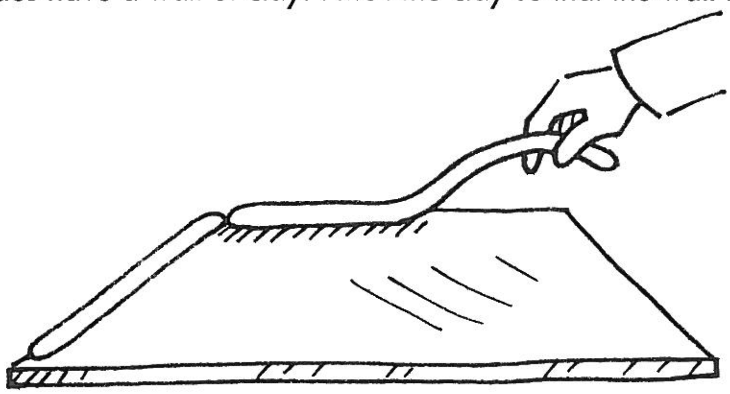
4. Make a stand with the dowels by wrapping two rubber bands near one end of the four dowels. Spread the other end and stand up as shown in the drawing.

Hang the light bulb from the top of the four dowels, securing it with a rubber band. Twist the electrical wire coming from the battery holder around one of the dowels.

Making A Tray - An Alternative To The Photo Frame

If you are going to use a sheet of plexiglass, you need to make sides to contain the water.

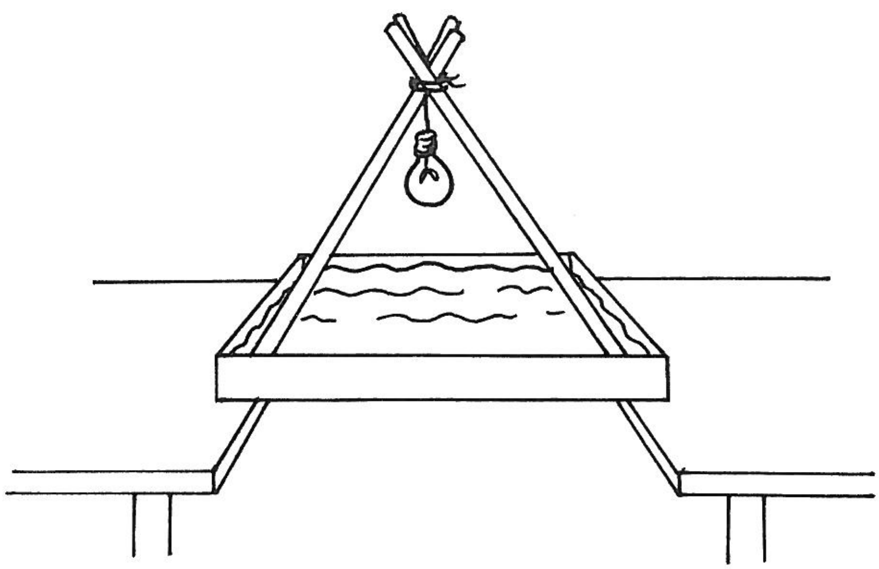
Shape a long strip of oil-based clay so that it is about a half inch thick. Press the strips of clay along the edge of the plexiglass sheet, making sure that the clay is sticking tightly to the plastic. Continue to do this until all sides have a wall of clay. Pinch the clay so that the wall is at least a half inch high.



Test the seal between the clay and plastic by adding water to the enclosure until a pool 1/4 inch deep is obtained. Look for any leaks. Work the clay at those spots which are leaking, until all are fixed.

Setting Up the Tray and Light Stand

Place the end of the tray or photo frame between two supports (such as two chairs or two tables). Position the stand so that the light is above the middle of the tray. Pour water into the tray so that you have at least a 1/4 inch pool of water.



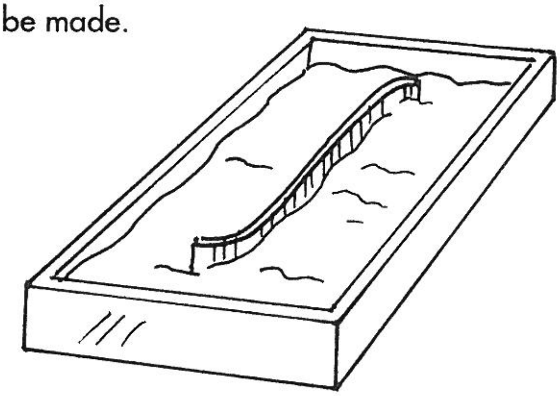
Connect the two wires from the light bulb to the two wires from the battery holder. Darken the room. Wiggle your finger on the surface of the water. If all is working well, you should see a pattern of shadows on the floor. A large white sheet of paper placed under the tank will make these shadows more visible.

Investigating Wave Patterns
Part 2

When you jiggle your finger on the surface of the water, a circular wave pattern immediately appears on the white paper underneath the tank.

Place a thin stick (about an inch wide and 10 inches long) in the water and jiggle this gently with your fingers. Waves, in the form of lines rather than circles, appear on the paper. Using these two techniques you can now observe what happens as waves combine with each other or encounter different kinds of barriers.

Remember to make rough drawings of each new pattern you observe and indicate how it was produced. This will be helpful later when you make waves with other materials. You will be able to make comparisons among all the different ways waves can be made.



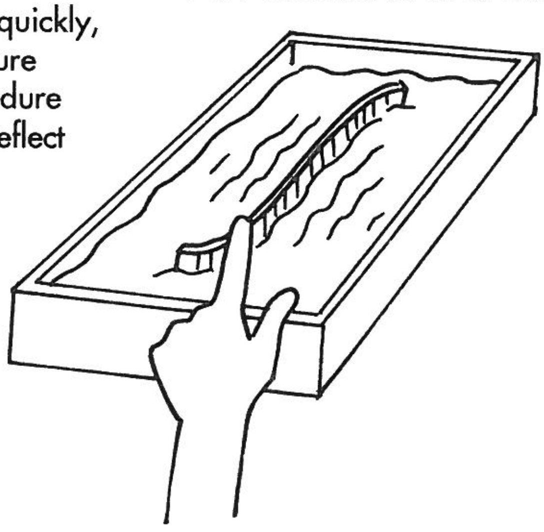
Here are some explorations you can try:

1. Jiggle one finger in the water at varying the speeds. Does the pattern change in any way as you go from fast to slow?

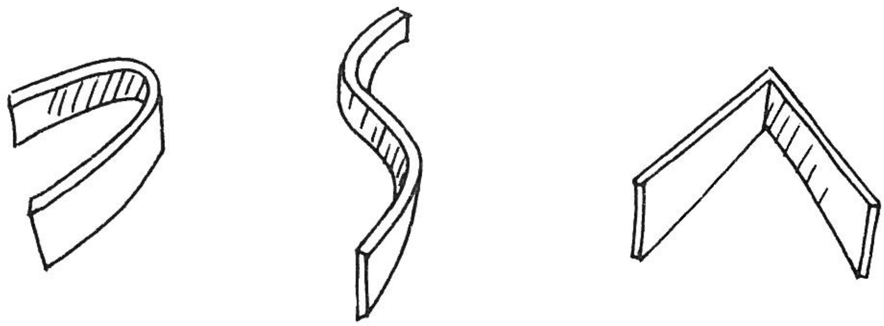
2. Jiggle one finger from each hand in the water at the same time, also varying the speed at which you move both fingers. Start with the fingers close together, then move them apart several inches and try again. Place the fingers at opposite ends of the tank and see what happens when they disturb the water.

3. Tap on the edge of the tank or the table supporting it. Try to do this with enough force so that you make the entire tank shake. What kind of patterns do you get?

4. Place a piece of metal strapping in the middle of the tank. Touch a finger to the surface once and watch carefully as the waves travel to the metal and are reflected off of it. The reflection from the metal may be faint and happen quickly, so do this several times to get a clear picture of what is happening. Try the same procedure with the stick, observing how line waves reflect off of the metal.



5. Since the metal strapping is flexible, it can be bent into a wide variety of shapes. The following drawings suggest some shapes and arrangements that you can explore. Try inventing some of your own shapes and arrangements.



What's Happening

Varying the tapping rhythm of your finger or the stick doesn't change the wave pattern. The lines may change in thickness but the overall pattern will be the same. Banging on the table to make the entire table shake produces some very interesting patterns. Depending on how slow or fast you bang on the table, you either see checkerboard patterns of small squares or you see hexagons. You might also see bigger versions of the same shapes. The manner in which waves reflect off of different kinds of barriers varies from one shape to another. Among the many possible shapes, the semi-circle is an important one to consider. It can allow us to compare the way sound and light behave. As you saw, both the circular waves and straight-line waves concentrate to a point when they are reflected off the inside of the semi-circle. On the other hand, their reflection off the outside may have been a surprise to you. The circle waves reflect off the metal and form circular waves again. The straight waves reflect off the metal and also form circular waves.

The behavior you have seen of these small waves is similar to what you would see if you were hovering over a beach in a helicopter, watching waves encounter different obstacles as they move toward the shore.

The waves that occur on the sea are not as regular as the ones you generate in your tank, so there is not an exact similarity between the two sizes. However, their actions produce similar results, as seen in the above photos. Scientists and engineers use wave tanks like the one you have made to gain a better understanding of how sound and light behave. Both of these phenomena act as if they have wave-like properties. They don't behave exactly like the water waves that appear in your tank, but the water waves are useful because they can give us an approximate picture of something that is invisible to the naked eye. The wave tank is a very useful device because it can model phenomena that are too large to control or are too small too see.

Very Thin Waves
Activity 2

Introduction

Previously we discussed how one could go from a very large environment to smaller and smaller ones. Eventually, one can reach a level where experiments can be done in a small tank that imitates, in some ways, the action on a larger scale. We can go further in this shrinking process. Suppose one could make the pool of water thinner and thinner until it becomes just a very thin sheet stretched within a long loop of string. Would this very thin sheet behave in the same way as the thicker water in a tank? What would be the similarities and the differences?

We can make very thin sheets of water adding ordinary dishwashing soap to water. Using some very simple materials and this soap solution, one can make large sheets of soap film. The results are very exciting and fun to watch.

Materials

1 roll of Kite String

1 large tray, such as a cat litter tray or a roasting pan.

Joy Dishwashing Soap, or Dawn
(Note: Only the most expensive dishwashing soaps work well for making very large soap film sheets.)

Newspaper

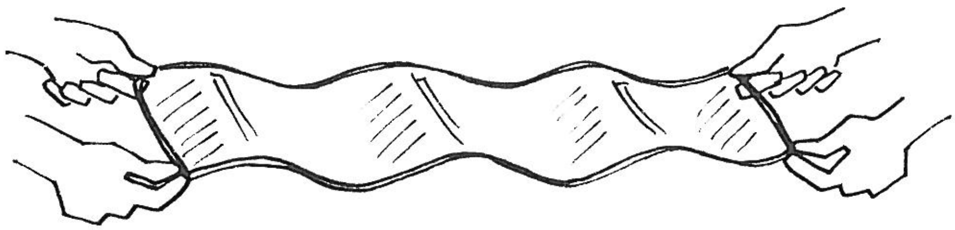
Preparing the Soap Solution:

Before adding soap and water to the tray, make sure that the tray has been thoroughly cleaned. Sometimes traces of substances in the tray can interfere with the soap in making a good solution. Measure about a cup of soap into the tray and add about a gallon of hot water. Stir thoroughly and let sit a few minutes so that the solution can cool.

Making and Using a Frame for making Soap Film Waves

A piece of string tied into a loop is all you need to make film waves. The size of the soap film can vary, but it is best to practice first with a small loop. Measure eight feet of string and tie the two ends together.

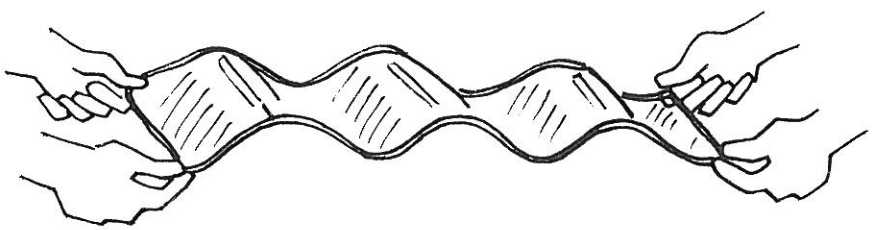
Two persons are required to make waves with this size loop. Each person takes hold of one end of the loop with both hands. The loop is placed into the tray of soap solution (make sure the entire string goes into the solution). Keep the two sets of hands next to each other as shown in the drawing and slowly raise the string until it is out of the solution. Then, slowly open up the loop by physically moving away from each other and spreading out your hands. Keep moving until the sheet of soap film is horizontal. Gently shake the sheet to make waves.



Investigating the Properties of the Soap Film Sheet

Once you have developed enough skill to make a complete soap film, here are some questions to consider:

Can you make waves of two, three, or four hills and valleys, as in the drawing?



What is the largest number of waves you can make with this size loop?

Cut a longer piece of string - one that is twice as big as the previous piece. Try making the same kind of waves as you did before.

Have one person hold one end of the loop with a finger while the other person continues holding the string with two hands and make waves.

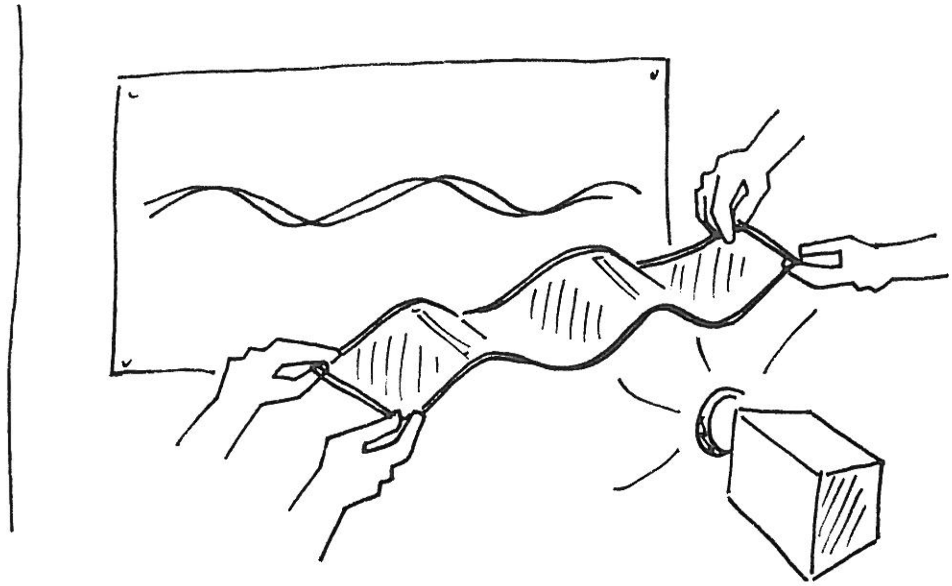
What happens to the waves as they travel to the narrow end?

Make a wide rectangle instead of a narrow one. Try moving the four hands at different rates. What does the sheet of soap film now look like?

Have one person move an end up and down, slowly or fast, and then watch how the waves travel to the other end.

Try making an even larger loop using 30 feet of string, and this time have several other people join you in making the waves.

If you have a slide projector available, position this in the room so that a shadow of the soap film is made on a blank wall as you wave the soap film.



What's Happening

The results you obtain are similar to those found with the large tank (such as a bathtub or a swimming pool) and with the smaller shallow tank. However, with soap film, the waves disappear much more quickly. Since the soap film is very light, it does not take very much energy to make it move. However, this energy is used up very quickly because it has such a large surface moving against the air.

Slow movement combined with large up and down motion makes big waves. On the other hand, fast movement combined with short up and down motions makes smaller and more waves.
If you project a bright light on the film to make a shadow you see outlines of the waves. These depend on how fast you are moving the string. Such outlines can be thought of as two dimensional representation of three dimensional waves. This is the picture you would see if you were to slice a frozen ocean wave, or any other kind of wave in water.

Investigating Waves In Solid Objects

Wave motion occurs in materials other than water. A large flag on top of a building will look like a wavy surface when the wind is blowing briskly. The large cloth coverings on the scaffolding at construction sites also make nice waving patterns on windy days. During a severe earthquake, tall buildings will undergo a wavelike motion. Thin trees shaken at their base also are like this.
A clothes line hanging between poles can be made to carry wave-like motion. Does the movement that these materials undergo resemble the movement of waves in water? What are the similarities and differences between solid and liquid substances? The next sections suggest ways of making some comparisons.

Waves in Thin Solid Materials

In a previous investigation, you explored what happens with large sheets of soap film. Soap film is very, very thin. The waves made with it move easily from one end of a loop of string to the other. There are sheets of plastic that you can purchase from a hardware store that also are very thin, but are still thicker than soap film. These plastic sheets, called drop cloths, come in several different thicknesses. You can experiment to see how the thickness of materials affects wave movement in plastic. The thinnest drop cloth (1 mil) is especially fun to use. You can experiment with the relationship between wave motion in different kinds of materials and the amount of energy needed to make this happen. This kind of investigation can be taken a step further by playing with bed sheets or long pieces of cloth or large blankets. Look around your house to see what you have available. Gather some friends together and have them explore making waves with different kinds of materials.

Materials

Plastic drop cloth, can be purchased at hardware or supply store.
Try to buy a drop cloth that is 1 mil in thickness and try other thicknesses as well.

Bed sheet and large blankets

Very large sheets of paper (Optional)

Making Waves

This is an activity that involves at least four people. Have each person pick up an end of a plastic drop cloth. Try making waves with this material. Experiment with as many ways you can think of to make waves with the sheets.

Here are some suggestions:

With four people on the corners of the sheet, have each person take a turn moving their corner up and down.

With four people on the corners of the sheet, have two people at a time move their side up and down.

What happens if all four people move their corners up and down together or move their corners at different rates?

Try the same with bed sheets and blankets. Remember to write down the similarities and differences among the different materials.

What's Happening

The wave movements with plastic sheets, cloth or blankets look very similar to those you can observe with soap film or water. However, the heavier cloth takes more energy to make it wave, and the waves stop almost as soon as you stop shaking the cloth. The plastic drop cloth waves don't die down as quickly as the cloth or blanket ones because the plastic is stiffer than these materials. The stiffness of the plastic allows the energy to act over a greater distance before it dies out. The thinnest drop cloth (l mil) most closely resembles the soap film when it is waving. Yet, even here there are differences. Soap film is very elastic; it can be stretched very easily. When something is stretched, it will attempt to return to its original position. Soap film waves, compared to the thin plastic sheet, are slightly slower moving because of this elasticity.

By exploring these materials, we now can say more about the generation of waves in materials. Factors such as weight, rigidity and stretchiness or flexibility determine how waves will travel through the materials. They determine how much energy you have to put into the materials to start the waves, and they affect how far the waves will travel from the initial starting point.

Waves in Two Dimensions with Rigid Materials
Activity 3

In the previous activity, you could think of the waves as happening in three dimensions. The waves move up and down in relation to your hands, and they also move away from your body toward the other people holding the materials.

Because of this it was difficult to study the waves themselves. It was hard to see how big they were and how many of them fit in between each person. One way of over-coming this problem is to makes waves with solid materials in two dimensions, i.e. by waving materials such as rope, string or metal strapping. With these materials you can see only an up an down motion relative to your hand, while the waves move in one direction towards the person holding the other end of the material. Perhaps, you have done something like this already. If you have a long clothesline outside of your house or if you have played jump rope, you may have already tried to make waves with rope. It can be fun to make very big waves or lots of very small waves. It is interesting and informative to see if you can do the same with other materials, such as string or wire.

Materials

1 Piece of long rope at least 16 feet long
(the longer the piece of rope, the more fun you can have making waves).

10 feet of very thin string, such as kite string.

10 feet of heavy twine for wrapping packages.

10 feet of thin electrical wire.

10 feet of elastic string. This can be purchased in the sewing supplies section of most department stores. This elastic comes in several widths. Buy at least two widths so you can make comparisons between the two.

10 feet of metal strapping. This is often found lying around lumber yards. It is used to hold wood planks together.

1 Slinky (Optional)

Making Waves With Rope, String and other Materials

Although you could do these investigations yourself, it is more fun and helpful to experiment with another person. Take each of the above materials and hold them between you and another person. See how many different ways you can make waves.

What is the largest number of waves you can make with each material?

Can you make just one wave between you and the other person?

Does it make a difference if you lay the material on the floor and try making waves by sliding it along the floor?

What's Happening

As you discovered with the sheets of solid material, the weight of the materials and their stiffness can make a difference. For instance, it is very difficult to make waves with the lightweight string and elastic string, but the rope and the metal strapping can be moved easily to create wave patterns. The waves tend to travel better with the metal strapping since is much stiffer than the rope. However, if the metal is too stiff or soft, such as with certain kinds of electrical wire, there is no waving at all. Therefore, there is a limited range of stiffness within which waves can be made.

You should also have observed with these materials that you have to move much faster and make smaller movements to make lots of small waves. Making one big wave with the rope is just a matter of moving up and down at just the right distance and speed, but this speed is slower than that needed to make small waves.

There is another interesting action that is similar to the water waves. If you give one quick jerk to the rope or metal strapping, the wave travels to the other person and returns back to you.
This is especially easy to see if you play with a Slinky. Because it is so springy, a Slinky allows waves to travel from one person to another and bounce back in a much more noticeable manner compared to all the other materials.

A Model Wave Machine
Activity 4

When you were exploring water waves, you saw that they could be investigated in a more systematic manner by making a small model such as a small water tank. This enabled you to control more carefully what was happening and to better observe the kinds of wave patterns that were generated. A similar kind of approach can be made with waves in solid materials. From the previous activities with solid materials, you saw that the weight, stiffness, and elasticity of the material made a difference in how waves traveled.

A long time ago, a scientist named Clerk Maxwell made a wave device that enabled him to investigate some properties of waves. He used metal bars and a metal strapping, but you can create a similar device with just tape, drinking straws, and nails. The device will help you to understand waves better, and it will also be fun to watch. Once you finish your experiment you can keep it as a kinetic sculpture.

Materials

250 Plastic Drinking Straws.

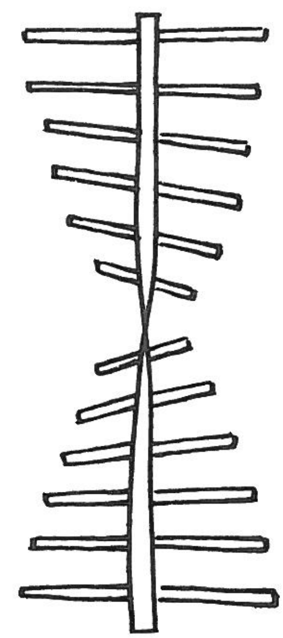
1 roll masking tape, 1/2 inch wide.

1 roll masking tape, 1 inch wide.

50 3-inch-long nails.

1 box Paper clips.

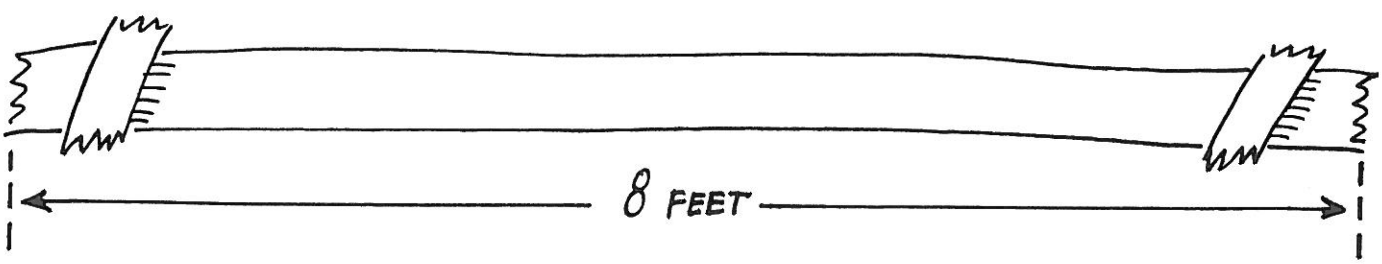
1 Ruler 12 inches long, plastic or wood.



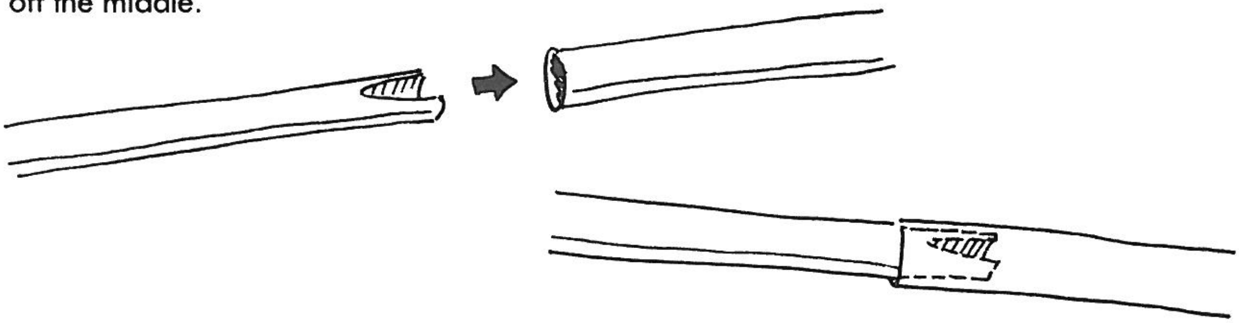
Assembled Wave Machine.

Assembling Your Wave Machine:

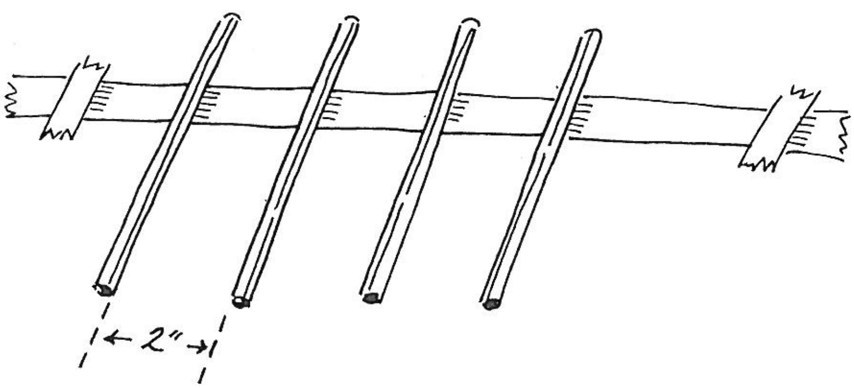
Find a table or clear an area on the floor that is at least eight feet long. On this surface, carefully lay down a strip of masking tape that is ten feet long. The sticky side should be facing up. The tape should be in a straight line. Two short pieces of tape are placed at each end to hold this strip in place as shown in the drawing.

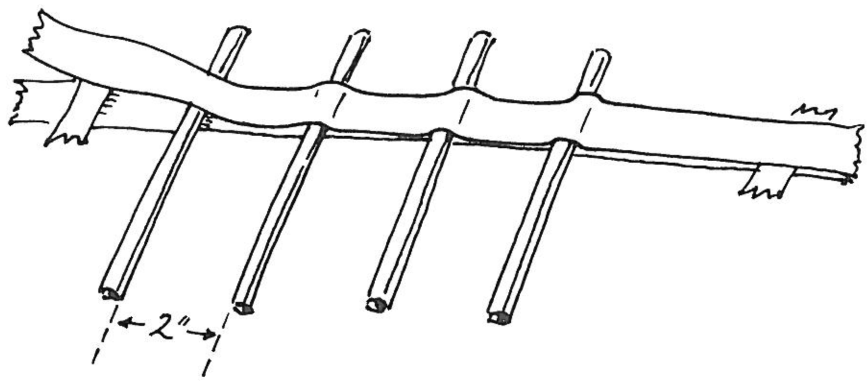


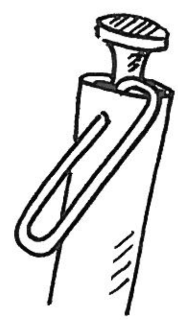
Join two straws together, making sure that the total length is exactly 14 inches. Make a mark on these joined straws at seven inches. Make 50 joined straws in this manner, remembering to mark off the middle.



Place a straw segment about twelve inches from one end of the tape on the floor. Center this segment by placing it on the middle mark. Press down firmly so that the straw sticks to the tape. Place another straw 2 inches from the first straw segment. Center it and press down firmly. Continue to add straw segments in this manner until you reach a point about 10-12 inches from the other end of the tape.







Next, insert the three-inch nails into each open end of the straws. They will have a tendency to slip out easily. You can prevent this from happening by first sliding a paper clip into both ends of the straws and then sliding the nail next to the paper clip as shown in the drawing.

Carefully take the row of straws up from the floor and hang this in a place where it is secured at the top as well as at the bottom.

Experimenting With Your Model Wave Machine

Start by moving one of the straws back and forth, watching what happens to the other straws. You can move a single straw fast or slow or continuously or in a stop-and- start manner. Before you move the straws in any manner, first wait until all of them have come to a complete stop. If you don't, you can become confused as to what kind of movements are actually happening with each different starting movement. Note carefully the time it takes for the movement to travel from the bottom straw to the top straw.

Move one straw and wait, then move the same straw again. Watch as the two movements travel to the top straw. What happens as they reach the top straw? When the two movements approach each other, do they combine or do they pass each other?

What does the whole device look like when you move one straw back and forth, repeating this motion for a minute or more?

What happens if you give the bottom straw with the nails attached to it a big push?

What happens if you move the bottom straw and then hold a straw several feet away?
Does the movement stop at the straw you are holding or does it move beyond this one?

Hold the bottom end of the tape where it is attached to the floor so that the tension increases in the tape. Try to make this as tight as possible without tearing the tape or pulling away the attachment at the other end. Move the straw as you did before. How does the movement along the straws change as you change the tension?

Take all the nails out of the straws. Move the straws as before. How does the movement along the straws compare to the arrangement when there were nails?

Make another set of straws and place these on the tape, but this time double the thickness of the tape so that it is stiffer than before. Add nails and set up as before. Repeat the previous activities. Does the fact that you have changed the stiffness of the tape make a difference in how movement travels up and down the model?

What's Happening

In the first arrangement of straws and nails, moving one straw results in the movement travelling up to the top and then being reflected back down to the bottom again. Moving one straw, waiting, and then moving it again produces two movements. Both movements travel to the top and are reflected back down to the bottom. What is surprising is that the two pass each other with out interfering each other's movement. Moving one straw back and forth for a while can create a wave like pattern along the entire model.

Taking out the nails from the straws makes each straw much lighter in weight. When you move one straw with this arrangement, the movement is slow and dies down very quickly. Just the opposite happens when you change the tension in the tape. In fact, the movement in this situation is much faster than when the model is just hanging. Likewise, making the tape stiffer also gives a faster movement.

Here you have a situation imitating the results obtained when exploring string, rope, metal strapping, and elastic. The stiffer the material, the more energy one has to put into it to make it wave. At the same time, the energy will move through it more quickly. Increasing the weight tends to slow down the motion, as we saw when comparing different kinds of blankets and sheets of plastic.

If we make this device much more carefully and measure how we change each of the factors that affect the wave movement, we could begin to put together mathematical formulas that could be used to predict wave motion in a variety of materials.

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