PHYSICS

Ocean Motion

Introduction

Energy is a topic central to every introductory physics course. Unfortunately, it is also a concept that many students find difficult to grasp because of a lack of concrete examples.

The oceans of the world cover approximately 75 percent of the earth's surface and possess vast amounts of energy. The different forms that ocean energy takes illustrates this important concept for students.

The following information and activities are designed as part of an introductory physics course. They may be integrated into units on energy, waves or forces and are suited for use as demonstrations or small group activities. The background information provided is intended for use in teacher lectures.

Teacher Background

Energy may be found in the world's oceans in the form of waves, currents and tides, heat and fossil fuels. The activities in this section relate these energies to a student's own experience. The following terms and equations are important to the discussion of energy in the ocean.

Vocabulary

Amplitude—The magnitude of the disturbance that a wave makes in the material through which it is passing as measured from the still-water position (Figure 1).

Archimedes' Principle—An object immersed in a fluid will experience a buoyant force equal to the weight of the fluid displaced by that object.

Buoyant Force—The vertical force exerted on a body by a fluid in which it is submerged or floating. Direction is upward in opposition to the weight of the body.

Celerity—speed of a wave without respect to direction. (See Wave Celerity.)

Coriolis Effect—The deflection of an object as the result of its movement in a rotating coordinate system. On the Earth, objects will be deflected to the right or clockwise in the Northern Hemisphere and to the left or counterclockwise in the Southern Hemisphere.

Coriolis Force—A force that acts on an object in motion in a rotating frame of reference.

Current—In the ocean, the movement of water from one place to another in a regular pattern.

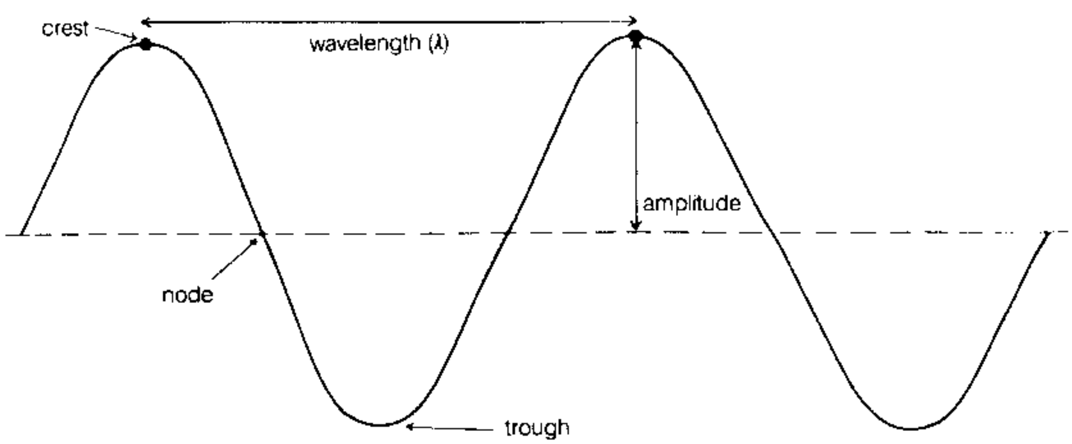
Diffraction—The bending and redistribution of the energy of a wave as it moves past an obstacle.

Energy—The ability to do work. The ability to exert a force over a finite distance.

Frequency (f)—The number of waves that pass a fixed point in a particular amount of time, usually expressed in Hertz (Hz) = 1 wv/sec.

Heat—The internal kinetic energy of a substance. The sum total kinetic energy of all the individual molecules of a substance.

Figure 1 Transverse wave



Interference—The interaction of two or more waves such that their net effect is to cancel (destructively interfere with) or reinforce (constructively interfere with) each another.

Kinetic Energy (KE)—The energy which an object or substance has due to its motion. $KE = (mv^2)/2$, where v is the velocity of the substance and m is the mass. It is measured in joules or kilowatt-hrs.

Potential Energy (PE)—The energy that an object has due to its relative position. The potential energy of an object is its mass times gravitation acceleration times its relative height. $PE = mgh$. It is commonly measured in joules or kilowatt-hrs.

Power—The rate at which energy is produced or the time rate of doing work. It is measured in watts or joules/sec.

Reflection—The abrupt change of direction of waves or particles from surfaces on which they are incident, where the angle of reflection equals the angle of incedence.

Refraction—The change in direction of a wave as it passes from one medium to another. In the ocean, it is the bending of waves toward shallow water because of a reduction in wave speed.

Sound—A type of pressure wave.

Sonar—the sound navigation ranging systems used to detect the presence and relative direction of underwater objects by means of sound waves.

Tides—The periodic variation of the surface level of the oceans caused by the gravitational pull of the moon and the sun. It also includes the equilibrium of forces of the rotation of the Earth-moon and sun-Earth system around their centers of mass.

Wave Motion—A disturbance in a medium that transfers energy from one place to another. The transfer occurs for ocean surface waves through circular motion of the water particles. The wave form moves long distances, even across oceans, but the particles of water move in a relatively small orbit.

Wavelength (λ)—The distance between successive waves, usually measured from crest to crest (Figure 1).

Wave Celerity (c)—The speed of the wave crest. $c = f$ times λ, where f is the frequency of the waves and λ is the wavelength.

ACTIVITY 1

Student Waves

Purpose

To simulate the flow of energy in a wave.

Background

When is a wave not a wave? Let's consider some waves that can take place with a classroom full of students.

The popular "stadium waves" seen at athletic events are not waves at all. There is no transfer of energy from one person to the next. Each person supplies his or her own energy to make the appearance of a wave. To make a genuine wave, people must physically interact.

There are three types of progressive waves: longitudinal as in sound waves, transverse as in seismic or earthquake-generated waves and orbital, or ocean (water) waves.

Procedure

Longitudinal progressive wave

Have six or seven students who are all about the same height stand side by side with their shoulders touching. They should stand with their feet together.

Have them close their eyes. Firmly shove one of the end students. The student on the far end will stagger off the end of the line. The energy of your shove was tranferred through the students even though they essentially stayed in the same place.

Transverse progressive wave

This is the same idea as above, except the direction of your push/pull will be perpendicular to the line. It helps to have about 10 students for this exercise. Have the students link elbows with their hands locked in front of them.

Push the first student forward about 30 cm (1 foot) and then pull him back. The energy from this push/pull will be transferred down the line of students.

Transverse waves only occur in solid materials such as earth.

Questions

1. Where in nature would you find longitudinal waves, orbital or transverse waves?

2. When an underwater earthquake takes place, seismic sea waves called "tsunamis," or tidal waves, radiate from the source. Why are they considered dangerous?

ACTIVITY 2

Water Waves

Purpose

In this activity, students will learn how to determine the frequency, wavelength and speed of water waves. And they will learn a wave is a transfer of energy, not a transfer of material. They will also observe the concepts of reflection, refraction, diffraction and interference.

Materials

ripple tank (if demonstrating only)
large, flat cake pans or cookie sheets
watch or clock with a second hand
rulers or any blunt, straight object
large chunks of paraffin or clay

Procedure

Fill your ripple tank with water. A depth of ½ inch works well. Allow the water to settle, then determine a method for producing waves.

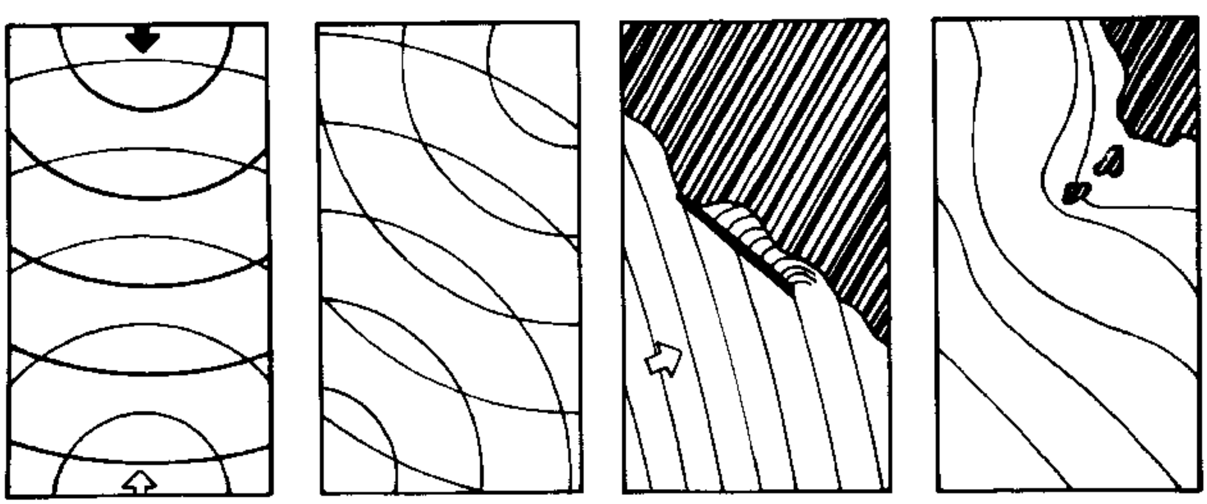
Notice how the waves reflect off of the sides of the tank (Figure 2a). Can you see how the incident or incoming waves interfere with the reflected waves (Figure 2b)? It occurs quickly so you will need to look carefully. The waves appear to move right through each other.

Now place a tiny piece of paper in the water. Let the water settle. Then send a wave from one end of the tank toward the paper. The paper should just vibrate back and forth as the wave passes, but otherwise stay put.

This demonstrates that it is energy that is moving across the tank and not individual water molecules. A wave is just a pulse of energy traveling from one place to another.

Finally, place paraffin chunks or clay in the water to act as a model island. By making waves that strike the "island," you can simulate the way ocean waves diffract as they pass islands (Figure 2c). If you fill (or empty) the tank so that the paraffin or clay islands become slightly submerged, you can simulate the way ocean waves refract as they pass over reefs and sand bars (Figure 2d).

Figure 2 Wave activity



a Reflection **b** Interference **c** Diffraction **d** Refraction

Student Questions

Look at Figure 3 which is a time plot showing the number of waves passing a fixed point B in 2.5 secs. The distance between the wave crests (wavelength) is 2 cm. Using this information, answer the following questions.

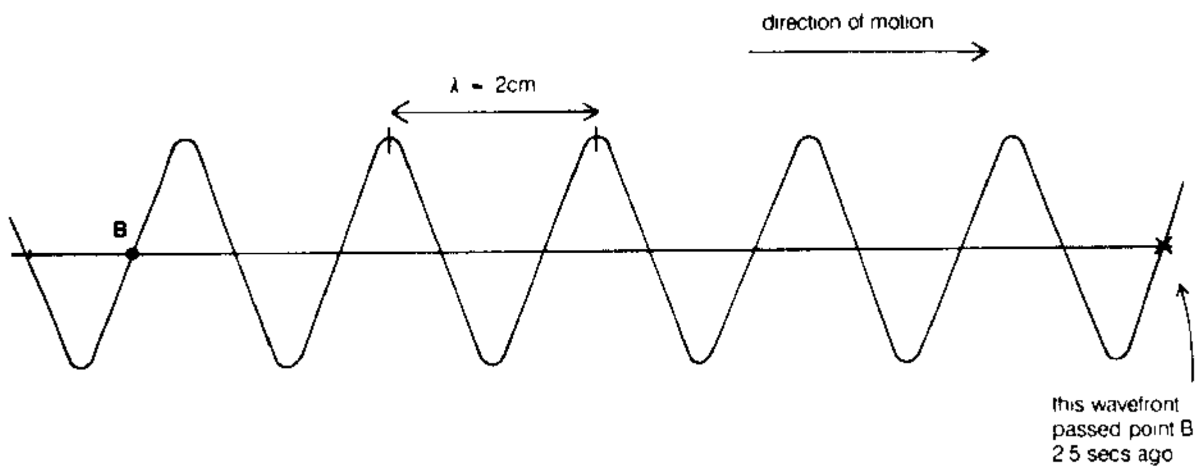
1. How many waves will pass point B (or any point) each second? This is the frequency of the waves in units of waves per second or Hertz.

2. How far will the first wave to pass point B have traveled after one second has gone by? (Hint: What does the wavelength represent?)

3. Using the fact that celerity = distance x time, calculate the speed of the water wave.

4. Notice that the same result can be obtained using the equation: celerity = frequency x wavelength. Why does this work?

Figure 3 Waves passing fixed point B in 2.5 seconds.



ACTIVITY 3

Record-Setting Water Waves

Introduction

According to the 1986 *Guinness Book of World Records*, the highest simple wave ever recorded was 34 meters (112 feet) high.

In 1933, the U.S. Navy tanker, *U.S.S. Ramapo*, was traveling from the Philippines to San Diego. During transit, the tanker encountered a storm system that produced strong winds (up to 70 mph) for more than a week across the Pacific Ocean. At the height of the storm, observers on the ship saw a mountainous wave that crested even with a platform on the crow's nest mast. From the height of the tanker's bridge, mast and stern, it was calculated that the wave was 34 meters high—as high as a nine-story building.

The largest tides in the world occur in the Bay of Fundy, between Maine and Nova Scotia. They average about 16 m (47.5 feet) when the sun and moon are lined up with the Earth (spring tides).

The greatest ocean current is the Antarctic Circumpolar Current or West Wind Drift Current between Antarctica and South America. It flows at a rate of 2.7 × 108 cubic meters/second. And its speed is .206 m/sec. The Gulf Stream flow rate is approximately one third as fast.

The highest tsunami measured 93 meters (278 feet) high and was sighted off Ishigaki Island, Ryukyu Chain on April 24, 1971. It moved a block of coral weighing 850 tons 1.3 miles. This type of wave is often mistakenly called a "tidal wave," but its cause is seismic activity such as an underwater earthquake.

Procedure

1. Using Figure 4, demonstrate how the tanker crew used the physical dimensions of their ship to calculate the height of the largest wave ever sighted. The *U.S.S. Ramapo* had a length of 164 meters. The crow's nest is located midship with a height of 17.5 meters. The wave had a period (P) of 14.8 seconds.

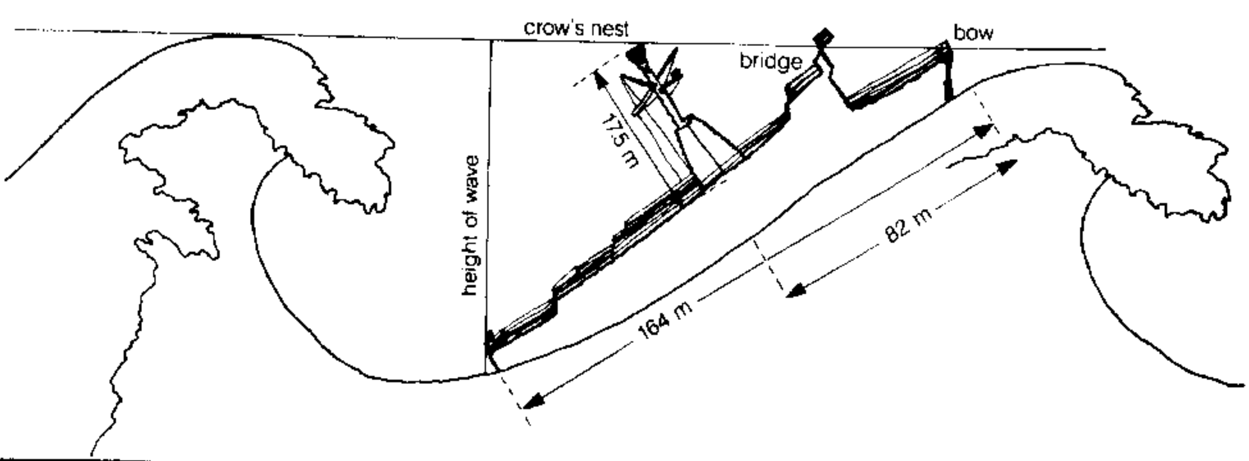
a. What is the length (λ) of the wave? [Use this formula: λ(m) = 1.56 P^2(sec).]

b. Using this λ and length of the ship, how could you determine the height of the wave? The observer is on the bridge.

2. Calculate the potential energy created by the sun and moon in lifting a block of water 30.5 m × 1,609 m × 6.1 m (100 ft × 5,280 ft × 20 ft) a distance of 7.6 m (25 feet). One cubic meter of water weighs about 9,800 newtons (2,200 lbs).

3. Calculate the kinetic energy of the West Wind Drift Current. First calculate the amount of water mass moving, knowing that there are 1,000 kg/cubic meter.

Figure 4 The *U.S.S. Ramapo* and the largest wave ever sighted



ACTIVITY 4
Snap the Whip

Purpose

To examine the relationship between linear and angular velocity. This relates to the movement of oceanic currents in relation to a reference frame rotating with the Earth.

Materials

20 feet of rope
3 students

Procedure

Go outdoors with 20 feet of rope. Stretch out the rope. Place one student at each end of the rope and one student in the middle.

Designate Student One at one end of the rope as the center of the circle; Student Two, the middle; Student Three, the outside end. Have Students Two and Three walk around Student One, keeping the rope taut. The rope becomes the radius of the circle (Figure 5).

Measure the distance that each student traveled. Remember that Student One revolved in place.

Questions

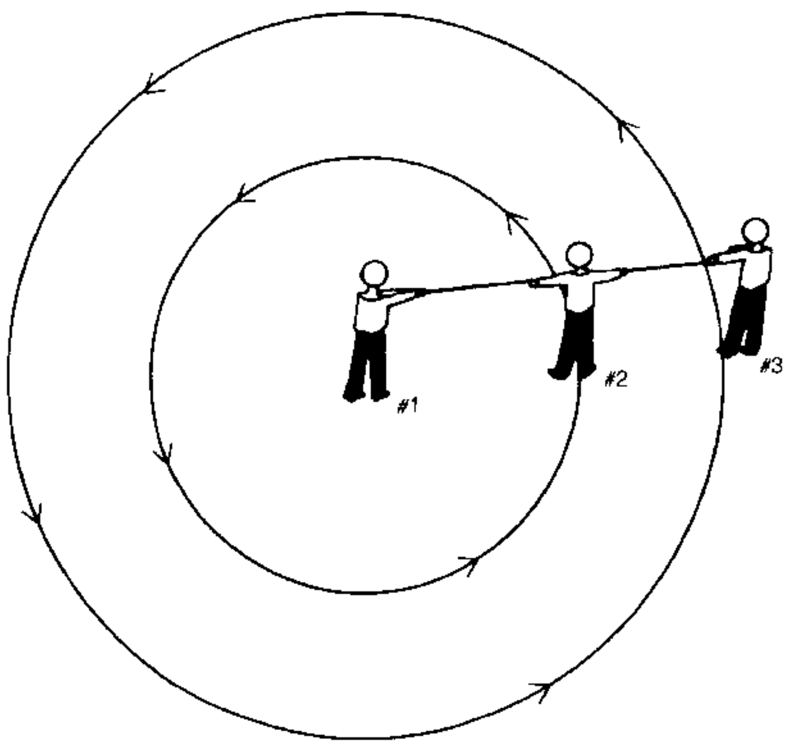
1. Who had to walk the fastest—Student One, Two or Three?

2. Who covered the greatest linear distance?

3. Who covered the greatest angular distance in degrees?

4. Plot a graph showing the distance from the center of the circle and the distance traveled. Use the formula $C_i = 2\pi r_i$, where i = positions 2 and 3.

Figure 5 Measure the distance Students Two and Three traveled while Student One revolved in place.



ACTIVITY 5
The Coriolis Effect

Purpose

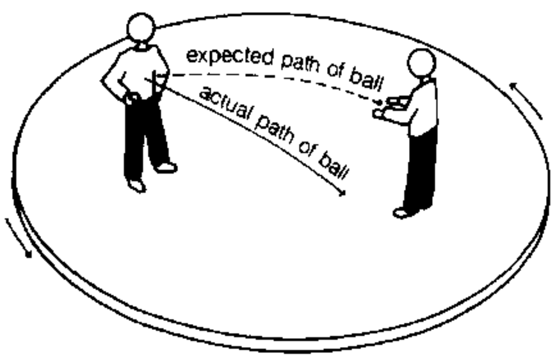
To investigate how objects are deflected in a rotating frame of reference.

Introduction

Imagine that you and a friend are standing inside a large box that is mounted on a rotating disk. But you are unaware that the disk is rotating just as you are unaware that the Earth is rotating daily on its axis.

You and your friend begin throwing a softball back and forth. As you toss the ball, it appears to be deflected to one side as if pushed off course by some unseen force (Figure 6). This makes it hard to catch.

Figure 6 The Coriolis effect



This unseen force is the Coriolis force and the deflection it causes is the Coriolis effect. Like centrifugal force, the Coriolis force is only an apparent force and the Coriolis effect is only an apparent deflection. But both are important in understanding the motion of objects in a rotating frame of reference (Figure 6).

Although the Earth is rotating, we do not take its rotation into account when we are examining the motion of a car traveling along a highway. That is because the car's size, speed and the distance it travels are small compared with those of the Earth.

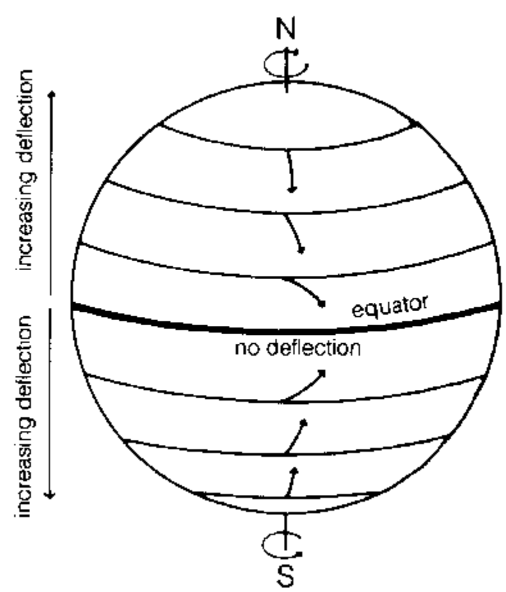
The car is kept on the highway by the friction of the tires, and the driver makes minor adjustments in directions. Therefore, we consider the car to be moving in a stationary frame of reference. Objects not in contact with the Earth, such as missiles and spacecraft, are not affected by the Coriolis force.

But for earthbound objects that are faster than cars, this is a different case. We must examine their motion in the Earth's rotating frame of reference. The situation is more complex because of the spherical shape of the Earth. Winds and ocean currents are deflected in a manner similar to that of the softball in the example given earlier.

As winds and oceans move across the Earth's surface, they experience the Coriolis effect. The further north or south they are from the equator, the greater the effect will be. That is why winds and water flow in a clockwise direction in the Northern Hemisphere and in a counterclockwise direction in the Southern Hemisphere (Figure 7).

The Coriolis force (CF) is proportional to latitude and speed. It is 0 at the equator and maximum at the poles. It is also more apparent in faster moving objects.

Figure 7 The Coriolis force



Materials

Coriolis demonstrator, a "Lazy Susan" or masonite board. Even a round, adjustable piano or swivel stool will work.
"magic slate"
a ball bearing (½-inch) or a marble

Procedure

Spin the top of the swivel stool or a Lazy Susan slowly. Draw a piece of chalk directly across the chair or rotating plate. Even though you moved the chalk in a straight line, the mark was curved (S-shaped). Experiment with spinning the stool in different directions. Or start your mark from the middle of the stool or Lazy Susan.

Roll a ball bearing or marble across the magic slate on a Lazy Susan with no rotation.

1. What path does the ball follow?

Rotate or spin the Lazy Susan with the masonite slate on top in a counterclockwise direction and roll the ball across it.

2. Describe the ball's motion.

3. Predict the direction of the ball if the board was rotated in a clockwise direction.

Rotate the demonstrator in a clockwise direction.

4. What happened?

5. The center of the board represents the poles of the Earth. Predict what would happen if you released the ball from the center of the board when it was rotating clockwise. Predict what would happen if you released the ball from the center of the board when it was rotating counterclockwise.

Release the ball from the center of the board when it is rotating clockwise.

6. What happens?

Release the ball from the center of the board when it is rotating counterclockwise.

7. What happens?

8. When you turn the demonstrator in a counterclockwise direction, which hemisphere is it representing? And if you turn it clockwise, which hemisphere is represented?

9. Did the ball follow a curved path or a straight-line path?

ACTIVITY 6

Archimedes' Principle—The Tip of the Iceberg

Purpose

To make a scientific prediction and then analytically compare the prediction with measurements made.

Introduction

Archimedes was a Sicilian scientist who was told by a king to find a way to determine whether or not a crown was made of pure gold. Some jewelers were not honest and would mix lead with gold when making crowns.

Archimedes was a hard working scientist. He often got so involved in solving problems and inventing things that he forgot to bathe. Then, the king's soldiers would forcibly drag Archimedes off to the bath.

According to the story, it was on one of these rare bath days that he learned how to distinguish between a fake crown and one of pure gold.

Archimedes noticed that the water level rose as he lowered himself into the bath. This meant that his body displaced a volume of water. Since an object's density is equal to its mass per unit volume, there must be a relationship between that object's density and the density of a fluid in which it is immersed.

From this, we get Archimedes' Principle: an object immersed in a fluid will experience a buoyant force equal to the weight of fluid displaced by that object.

The direction of the buoyant force is up, opposing the weight of the object. Furthermore, if the object floats (i.e, its density is less than or equal to that of the fluid), the magnitude of its weight will be equal to the magnitude of the buoyant force.

By measuring the mass of the king's crown in air and in water and comparing those measurements, the crown's density could be determined. Today, we have more efficient methods for determining the authenticity of crowns, but Archimedes' Principle is still used to study the behavior of objects in fluids.

For example, we know that fish are naturally equipped to deal with the buoyant force. Many fish have a sac called a swim bladder that is filled with gas. By releasing or taking in gas, fish can control their overall density and avoid being forced to the surface or to the ocean floor. This knowledge of how fish control density has aided development of exploratory vessels used in underwater research.

In the following activity, you will use Archimedes' Principle to predict what percentage of an iceberg is underwater. You will then make measurements to test the accuracy of your predictions.

Materials

2 half-gallon milk cartons
a tank or large bowl
fresh water (from the sink)
salt water (50 grams of table salt to 1 liter of water)
measuring tape

Procedure

The day before doing this procedure, pour enough water to fill the bottom third of two half-gallon milk cartons. Freeze.

The density of an object is its mass per unit volume. The density of ice is 0.92 g/cm³. The density of fresh water is 1.00 g/cm³. The density of salt water (35 ‰) is 1.03 g/cm³.

Since ice is less dense than fresh water or salt water, it will float.

The density equation is: $\rho = m/V$ or $m = \rho V$; since $\vec{W} = mg$, then $\vec{W} = \rho V g$.

ρ = density	m = mass	V = volume
$\vec{W}$ = weight	g = gravity	

1. Write an equation relating the buoyant force to the water's density, volume and acceleration due to gravity.

2. Write an equation relating the weight of an iceberg to its volume, density and acceleration due to gravity.

3. Using the two equations above, find the percentage of an iceberg that is below the surface of fresh water.

4. Repeat Step 3 for salt water.

5. Remove your icebergs from the milk cartons, and measure the volume.

Volume of iceberg in fresh water (Iceberg 1) = ________

Volume of iceberg in salt water (Iceberg 2) = ________

6. Very gently, place Iceberg 1 into a tank or large bowl of fresh water. As quickly and as accurately as possible, scratch out the line where Iceberg 1 breaks the surface of the water.

7. Measure the volume of Iceberg 1 that is above the surface of the water. (This part doesn't melt as much as the submerged part. What is the reason for this?) Subtract this number from the total volume of Iceberg 1 found in Step 5. Compute the percentage of Iceberg 1 that is below the surface.

Repeat the above procedure, placing Iceberg 2 in salt water.

8. Repeat the calculations in Step 7 for Iceberg 2.

Percentage Below Surface (fresh water) ____________

Percentage Below Surface (salt water) ____________

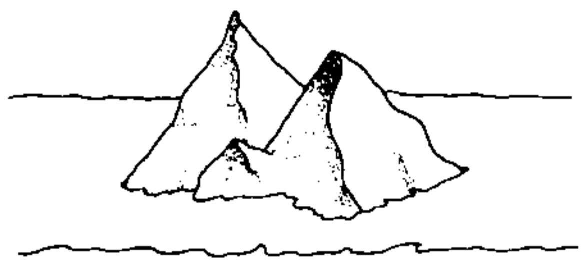
9. Compare your measured values with those you predicted earlier.

Use percent difference:

% difference = ______ measured value ______ × 100
measured value − predicted value

10. Finish the drawing of the iceberg shown below (Figure 8). Sketch in the bottom of the iceberg, giving an indication of the how much ice is above and below the surface of the water.

Figure 8 Iceberg



Competency Factors/References

Competency Indicators

Physics/Academic—

1.1 know how to solve problems using basic algebra and trigonometry;

2.1 know laws, mathematical expressions and factors that represent and affect various types of motion;

2.2 know how to analyze systems that involve vector quantities and components;

5.1 know the general properties of wave phenomena; and

7.1 know that energy is transmitted by means of wave motion.

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