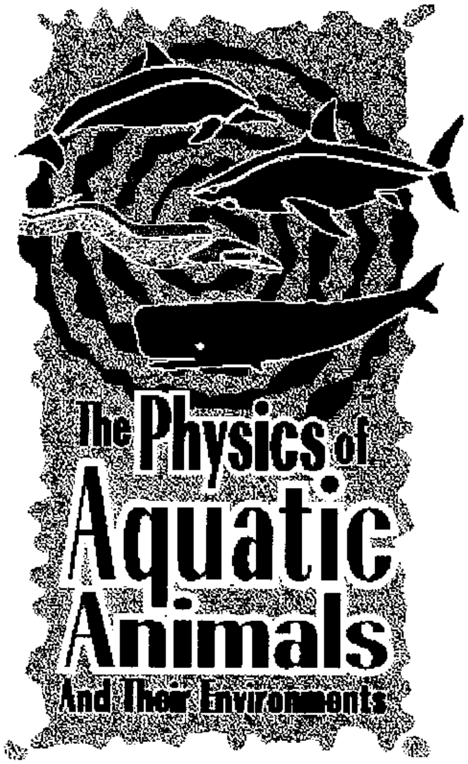

Teacher Manual

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Compiled by Ernest Malamud

Funded by the Illinois State Board of Education
Center on Science Literacy

SCITECH
SCIENCE AND TECHNOLOGY INTERACTIVE CENTER

Table of Contents

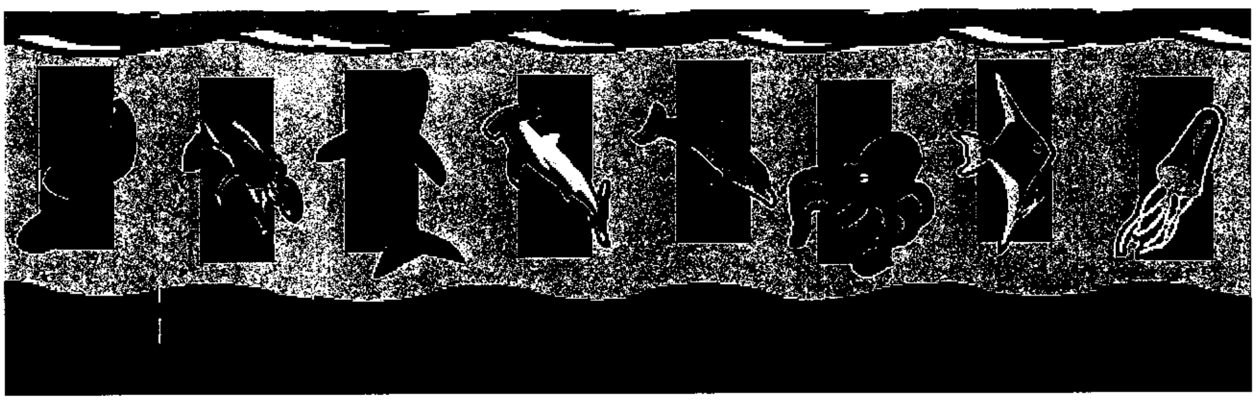
<u>Light Exhibits</u>
Light Bending in Air
Light Bending in Water
Seeing in Air/Water
Brine Shrimp Ballet and Hatchery

<u>Buoyancy Exhibits</u>
Bladders and Ballast
Whale Buoyancy

<u>Motion Exhibits</u>
Streamlines
River Olympians
RoboTuna
Microscopic Movement

<u>Sound Exhibit</u>
Dolphin Sonar

<u>Electricity Exhibits</u>
Swinging Generator
Shark Navigation
Electric Eel



Introduction

About the Project

With expert help from scientists at Fermilab, the University of Chicago, and the John G. Shedd Aquarium, SciTech in Aurora has created a new set of exhibits on The Physics of Aquatic Animals and Their Environments. The exhibition combines teaching of biology and physics in an exciting, hands-on manner that encourages active participation in the learning process.

This interdisciplinary exhibition opened at SciTech April 20, 1997. The exhibition and accompanying program is now available to Illinois schools in the greater Chicagoland area. The exhibition will also be displayed at the Discovery Center Museum in Rockford in Fall 1998 and the Lakeview Museum of Arts and Sciences in Peoria in 1999.

The exhibits appeal to all ages, but the program is geared toward students in the 4th through 6th grades. Students explore basic physics principles—density and pressure, velocity of sound, the bending of light and electrical conductivity—that make living in water different from living in air. The medium in which an animal lives profoundly affects how it is "built" and how it lives. The size and shape of an animal, how it moves, how it captures food, and the nature of its sensory capabilities differ depending on whether the animal lives in air or in water.

Each exhibit relates to a physics principle and to the life of an aquatic animal and the amazing adaptations it has made to its environment. An example is how a shark uses the electrical conductivity of water to navigate over long distances using the earth's magnetic field and the Faraday effect. Colorful signage and artwork connects the relationship between the exhibits and the physics and mathematics presented by these 3-dimensional, interactive experiences.

Using models of familiar and high-interest animals like sharks, electric eels, whales and dolphins, students compare the senses of aquatic animals with those of land animals, including humans. Students see through the "eyes" of the great barracuda, sink in the water and then rise again to the surface using a swim bladder, and echolocate their next meal like the dolphin! The exhibits encourage an appreciation of those things that aquatic animals do better than us in their environment. Students explore new technologies and discover that by studying an exceptional aquatic animal like the bluefin tuna humans can learn how to move faster through water.

The Physics of Aquatic Animals and Their Environments was developed under a grant from the Illinois State Board of Education Center on Science Literacy. Some exhibits were built under the National Science Foundation funded "SciTech Clubs for Girls" program. The Department of Natural Resources provided additional funding for this Teacher Manual, Natural Heritage Division, State of Illinois.

Program Information

The Physics of Aquatic Animals and Their Environments is offered through SciTech's Discover and Explore program. The program allows organized groups to visit SciTech and investigate a specific science topic. Discover and Explore lasts approximately 3 hours. Each program begins with an interactive Discovery session utilizing hands-on exhibits. The group is then guided through an inquiry-based interactive Explainer session and demonstration. Students also have an opportunity to explore the rest of SciTech's exhibits on their own.

The exhibits, along with the Explainer session and the activities in this Teacher Manual, were created to excite students and help schools achieve their science and mathematics goals. There are many opportunities in the program to enhance student math skills especially in using ratios and making simple graphs. Emphasis has been placed on hands-on, inquiry-based learning, integrated curriculum and new assessment techniques. We want your students to realize that science and mathematics are alive and a vital part of our world, and most importantly, accessible to them. Using the glossary spelling and writing skills can be integrated with the science.

The topics covered by the exhibits explore phenomena in our everyday lives—how our eyes work, how we swim, how sound travels, how we find our way in the world—and contrasts them with the lives of aquatic animals. The exhibits enable students to learn principles of physics and biology through an integrated approach that is both accessible and memorable.

About this Manual

The Physics of Aquatic Animals and teacher manual is divided into five chapters:

Light
Buoyancy
Movement
Sound
Electricity

Each chapter contains background information, exhibit descriptions and objectives, and hands-on activities including guided student discovery sheets. Activities include teacher demonstrations, individual student activities, and cooperative learning group activities.

Skills addressed by the Exhibits, Activities and Exercises are **Observing Phenomena, Making Comparisons, Inferring Cause-Effect Relationships, Identifying Patterns, Making Predictions, and Recording Data**, **Creativity**

Appendices will enhance the usefulness of this manual to the classroom teacher.

A. **Assessment Strategies**
B. **Language skills Glossary**
C. **References**

This manual is intended to assist the classroom teacher through different types of hands-on experiments highlighting the physical differences between air and water. We hope that this manual will serve as a stimulus for incorporating *The Physics of Aquatic Animals and Their Environments* into your curriculum.

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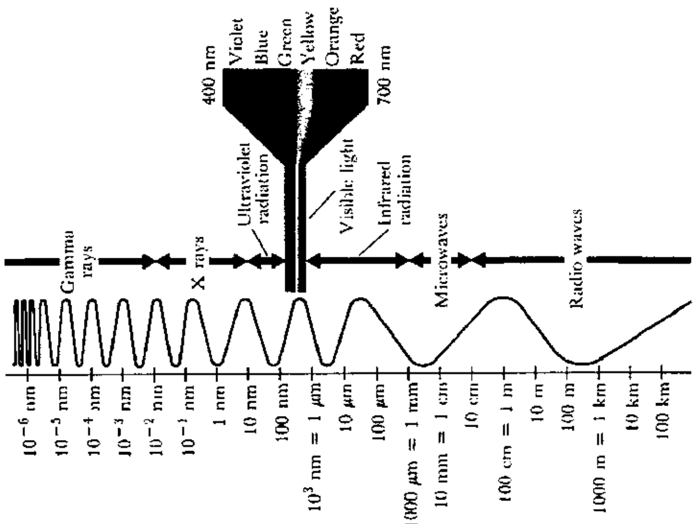
Chapter 1- Light

Background

Light is a form of energy we call **radiant energy**. There are many kinds of radiant energy. These make up the **spectrum** of electromagnetic energy. We can see only a tiny fraction of the spectrum with our eyes.



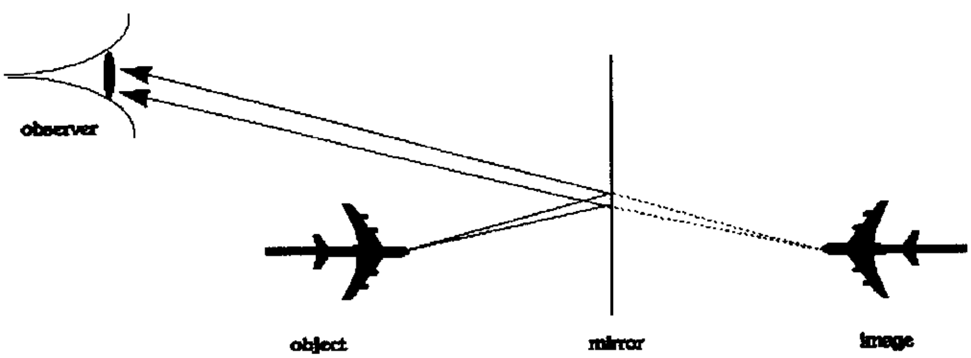
Light rays travel through space in waves. The shortest wavelengths are gamma rays, and the longest are radio waves. The visible light we see is in the middle range of wavelengths:

400 (violet) - 700 (red) nanometers (billionths of a meter)

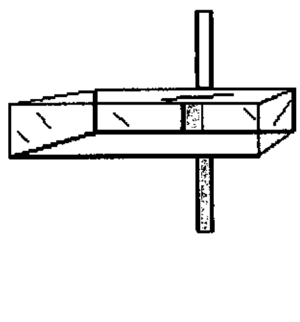
Light travels fast, 186,000 miles (300,000 kilometers) per second. Even at this speed, the light from the sun takes about eight minutes to reach us. Light from the next nearest star takes four years to reach our eyes on Earth.

Reflection, Refraction, Absorption. When a ray of light falls on the surface of an object, one or a combination of the following three things happen:

Reflection: The light may be reflected (thrown back). When a ray of light strikes a smooth reflecting object, like a mirror, it returns the ray at an angle from the surface that is equal to the angle at which it strikes the surface. It is like a ball that is thrown against a wall. The ball bounces back at the same angle at which it was thrown.



Refraction: Light may be refracted (bent). When a ray of light strikes a transparent object at an angle, the speed of the light is different inside the object, causing the ray to bend. A stick seen through a block of plastic looks broken because light travels slower in plastic than in air and the rays are bent.



Absorption: Light may be absorbed. When a ray of light strikes an object that does not reflect light, such as dark wood, the object absorbs most of the light. Light is more rapidly absorbed by water than by air. As one descends deep in the ocean (or a deep lake) the amount of light present is much less than on the surface of the earth. Animals that live deep in the water rely less on their eyes than on other senses (sound and electricity) to find things to eat, to find their way, and to avoid obstacles.

Index of Refraction. Light travels slower in a liquid or gas than it does in vacuum. The **index of refraction** is the **ratio** of the speed in vacuum to the speed in the material. The chart below gives some values:

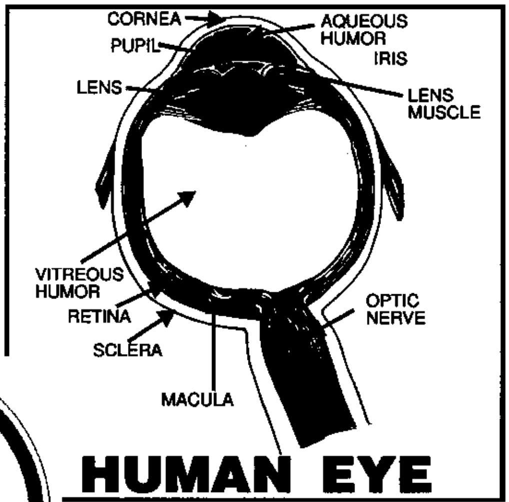
Material	Index of Refraction	Speed of Light in the material
Vacuum (no material)	1.0000	186,282 miles/sec
air	1.0003	186,226 miles/sec
plastic (lenses in exhibits)	1.5000	124,200 miles/sec
glass (as in eye glasses)	1.5299	121,753 miles/sec
fluid in human eyeball	1.3400	139,016 miles/sec
water	1.3300	140,061 miles/sec

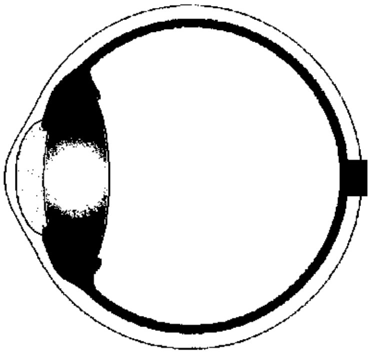
The **index of refraction** is the ratio of the speed of light in a vacuum to the speed of light in a material.. The higher the index of refraction, the more light bends. The **index of refraction** of air is about 1.00 and water about 1.33. This means that light travels 33% more slowly in water than in air. This difference in the speed of light profoundly affects the different way that animals that live in water see their environment from those that live in air.

Lenses. A lens is a piece of transparent material with at least one curved side. Lenses refract (bend) light rays and form images. The images can be larger, smaller, or the same size. A lens works (i.e. can focus an image) because of the difference in the speed of light between the lens and what it is immersed in. A slightly curved lens, like that in your eye, works well in the air, where the speed of light in air is much different from the speed of light in the lens in your eye.

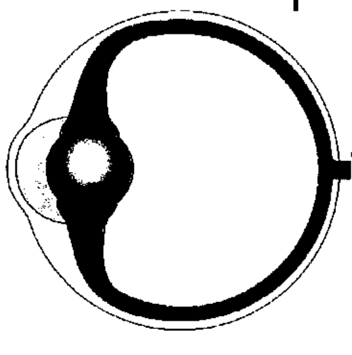
The eye. The **lens** focuses an image on the retina. The brain interprets the signal on the **retina**. That is how other animals, and we can see. Humans have eye muscles to adjust the shape of lens to focus at a wide range of distances.

Fish eyes. A spherical lens, like that in a fish's eye, works well in the water. The lens has to be much more curved than the human lens to form an image underwater. That's because the speed of light in water is almost identical to the speed of light in the lens.





LAND ANIMAL EYE



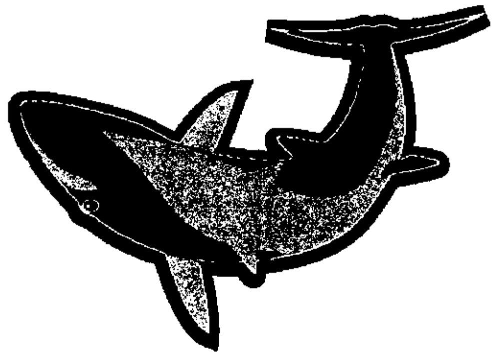
AQUATIC ANIMAL EYE

Aquatic Vision. In shallow, clear, well-lit waters such as Lake Michigan or the Florida reefs, vision is still an important sense for aquatic animals. Here we see predators with large eyes that are good for hunting, and prey with camouflage patterns (like fake eyes on a tail) to fool those predators. We also see strikingly colored fishes, which communicate species, sex, age, and special behaviors.

The eye muscles of fish and reptiles move the entire lens back or forward, and have a smaller range of focus distance. Fish eyes protrude slightly to allow fish all-around vision. However, there is little visual overlap, reducing their 3-D vision considerably. Fish lack eyelids since there is no chance of the eye drying up, and they also lack the ability to open and close their pupils to control the amount of light entering the eye.

Animals

We have chosen the **barracuda, parrotfish** and the **brine shrimp** for our exhibits on light.



Barracuda (*Sphyraena barracuda.*) Pointed jaws lined with formidable teeth could belong to no other than the "tiger of the sea", the great barracuda. These fierce marine predators are feared. Records of over 30 attacks on humans bear witness to their ferocity. The fact that the attacks on humans occur mostly in cloudy water implies cases of mistaken identity. Barracudas locate their food largely by sight, attacking brightly colored or erratically moving objects. Splashing swimmers wearing jewelry or white sneakers catch their attention, as do freshly speared fish. They are very inquisitive, and will follow divers for hours. Silver, torpedo-slim great barracudas reach a length of six feet. Their flesh, considered excellent eating, may concentrate some rare poisons from the grunts, jacks, sea basses and other reef fish they eat. Lone individuals patrol the coral heads and reefs of all tropical seas, as they do in the Coral Reef Exhibit at the John G. Shedd Aquarium.

Parrotfish. Brightly colored Parrotfish make a meal for the Giant Barracuda. Parrotfish are among a coral reef's major herbivores. With teeth fused into a beak, they graze algae down to bare limestone. Besides converting plant matter into animal tissue, their feeding clears space for the settlement of coral larvae and keeps algae from overgrowing the reef. Parrotfish are found in all tropical seas.

Brine Shrimp *(Artemia).* First written about in 1755, Brine Shrimp are not only an important food link in aquaculture projects worldwide but the subject of crustacean research which embraces all the biological science disciplines. Brine Shrimp have evolved to thrive in some of the toughest of circumstances. With virtually no defense mechanisms Brine Shrimp are forced to adapt to harsh environmental conditions in order to outlast predators. Able to survive in salinities in excess of eight times ocean strength, Brine Shrimp, along with a few species of bacteria and algae, colonized a unique niche, unsuitable for Brine Shrimp predators. These harsh habitats are inland salt lakes (such as the Great Salt Lake, Utah), and the concentration ponds of solar salt operations as occur around San Francisco Bay. As long as satisfactory environmental conditions prevail, adult Brine Shrimp reproduce by expelling live Brine Shrimp nauplii (babies) from their brood sac. However, should an environmental stress occur, a shell gland is activated and embryonic development is stopped. The embryo is wrapped with a hard substance and deposited to await more favorable conditions before resuming development. These embryos remain in this arrested state during winter months. When the spring rains come, they rehydrate and break dormancy. This occurs at the same time when algae starts to bloom, insuring adequate food supplies.

Exhibits

There are three exhibits that deal with the difference between vision in air and vision in water and the role that light plays in vision: *Light Bending in Air, Light Bending in Water*, and *Seeing in Air, Seeing in Water.* These exhibits explore the concept of refraction and apply to animals that live in the ocean as well as to our own eyes when we swim.

The fourth exhibit, *Brine Shrimp Ballet,* demonstrates how light affects *Brine Shrimp*; and how light or the absence of light sometimes stimulates movement.

Light Bending in Air and Light Bending in Water allow the student to manipulate light with two lenses. As students manipulate the lenses they learn under what conditions the lenses can form an image.

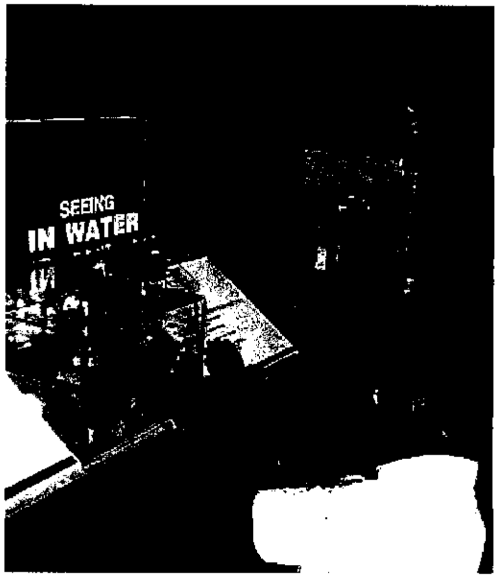
Concepts: Refraction, Index of Refraction

Objective: Students identify the relationship between the shape of the lens and its ability to focus in air or water.

How to use:
Air exhibit: Lay one lens flat in the lines of light. Try each lens one at a time. Make a single point of light with each lens.

Water exhibit: Lay one lens flat in the water pan. Take the lens out and try the other lens. Make a single point of light with each lens.

Explanation: A lens is transparent and has one or more curved surfaces. Lenses bend rays of light that pass through them. In this exhibit, the lens is a curved piece of plastic. In animals and humans, the lens of the eye is made of living, transparent tissue.



Light changes speed when it passes from one substance to another, like air to water or air to the lens of an eye. When light changes speed, it bends. This light bending is called **refraction.**

The lens of the eye must focus light to see clearly. A lens focuses light by bending it. The amount of light bending is determined by the **index of refraction.**

Physics-Biology Connection: Fish eyes are adapted to accommodate the higher index of refraction in water. Aquatic animals have eyes and lenses that are more spherical in shape than land animals.

Seeing in Air, Seeing in Water demonstrates the focusing capabilities of two different "eyes" (and lens shapes) in two different fluids, air and water.

Concepts: Refraction, Index of Refraction

Objective: Students identify which eye belongs to the land animal and which eye belongs to the aquatic animal, and why.

Skills: Observing phenomena, Making Comparisons

How to use: Use the levers to put each eye into the water. Look for the image of the parrotfish on the back of each eye. Use the levers to take the eyes out of the water. Look for the image of the cardinal on the back of each eye.

Explanation: The land animal's lens is slightly curved. This lens bends the light just right in air to produce a clear image. The land animal's lens can't bend the light enough in water to produce a clear image. The aquatic animal's lens is very curved. This lens bends light a lot more. This is great in the water, but cannot make a clear image in the air. The distance between the lens and the image also affects the ability to form a clear image.

Physics-Biology Connection: Students can relate these observations to human experience. When you go swimming it is hard to see clearly under water. If you wear a diver's face mask, your eyes will be in air and can see much better than if they are directly in contact with the water.

Brine Shrimp Ballet demonstrates that light has an effect not only on vision, but also on movement.

Concepts: Photo-negative, photo-positive

Objective: Students observe the connection between the presence or absence of light and brine shrimp movement.

How to use: Watch the brine shrimp as the lights cycle on and off. Use the Fresnel lens (magnifier) to focus on one shrimp. (Fresnel is pronounced fre - nel, the "s" is silent. Named for Augustin Jean Fresnel, French mathematician, 1788-1827.)

Explanation: Adult brine shrimp are **photo-negative**. This means they swim away from light. Baby brine shrimp (nauplii) are **photo-positive**. They swim toward light. This phenomena is not completely understood. One theory suggests that light separates the adults from the babies, since the adults tend to eat their children!

Physics-Biology Connection: Light is a very important part of life. Light is a source of energy (to plants, which in turn feed animals), a source of information (sight), and a stimulus (provokes a movement response in aquatic organisms like *Brine Shrimp*). Students can also observe that when *Brine Shrimp* changes its swimming direction, it also flips itself over so that its underside is toward the light.

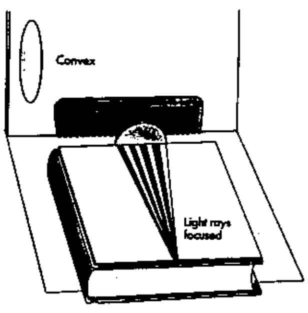
Activities and Exercises

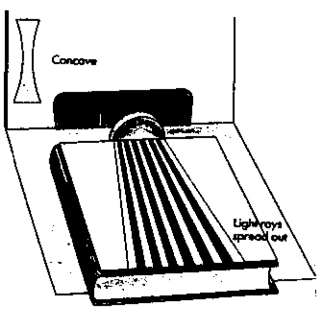
Light Activity: HOW LENSES WORK

Materials: Sheet of cardboard, Comb, Flashlight, Tape, Magnifying Glass, Sheet of white paper, Books (optional)

Procedure

1. Cut a hole in the cardboard about 1 inch (2.5 cm) in diameter and tape the comb over the hole.



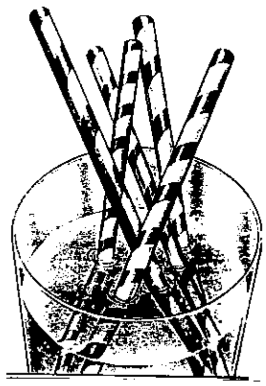


2. In a darkened room, stand the card in front of a beam of light from a flashlight.
3. Lay the white paper in front of the rays of light that come through the comb so you can see them clearly. (You may need to place the paper on top of some books.)
4. Hold the magnifying glass against the edge of the paper and notice what happens to the rays of light.

How it works
The magnifying glass is convex lens. It bends the rays so they all come together at a point. This is called **focusing** the light.

Now repeat the investigation using a concave lens, such as the glasses of a nearsighted person. In this sort of lens the middle of the lens curves inward. This time you will see that the beams of light are spread out instead of being focused.

Light Activity: BENDING LIGHT



Materials: Glass, Water, Straws, Pencil, Thick glass dish

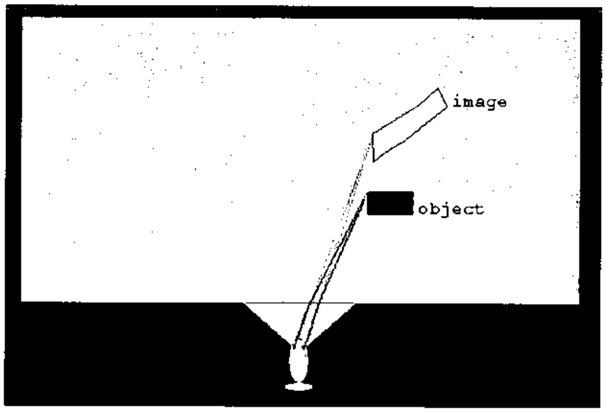
Water Can Bend Light
Fill a glass with water and place a straw in it. Look down at the straw as it stands in the water. You will see that the straw appears to bend. When you lift the straw out of the water you will see that it is still straight. The light rays change direction when they enter the water and make the straw look as if it bends in the middle. Look at your legs when they are half in and half out of the bath water and you will see the same effect!

Air Can Bend Light
On a very hot day, you can sometimes see what looks like a pool of water on the road although the road is really completely dry! Light from the sky is "bent" (refracted) by the hot air near the road and the "pool" you see is actually refracted sunlight. This is why people see mirages in the desert. The hot air bends the light so objects that are really a long way away appear to be close by.

Glass Can Bend Light
Hold a pencil behind a thick glass dish so that half the pencil is above the dish and half is below. You will find that the part of the pencil behind the glass seems to be separated from the part of the pencil in the air. This is because light travels more slowly in glass than in air. The light rays change direction at the edge of the glass and make the pencil look as if it bends in the middle.

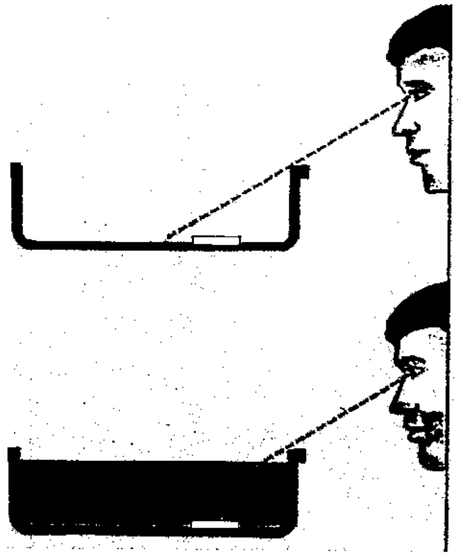
Class Discussion:

Can the fish see you? Where should you stand so the fish can't see you?



Light Activity: DISAPPEARING MONEY

Materials: Coin, Bowl or cup, Water



Procedure

1. Put the bowl or cup on the table and place the coin in the bottom.
2. Keep looking at the coin and move slowly backward until the coin disappears from view.
3. Stay standing in the same place and ask a friend to pour water into the cup or bowl. You will see the coin again!

How it works

The light from the coin is "bent" (refracted) by the water so you can see it again. Swimming pools and ponds never look as deep as they really are because light from the bottom is "bent" before is reaches our eyes.

INDEX OF REFRACTION EXERCISE

Introduction

Light travels 186,282 miles per second in a vacuum. A vacuum is a space empty of matter. The **index of refraction** equals the **ratio** of the speed of light in a vacuum to the speed of light in material. The index of refraction in a vacuum is 1.00.

Procedure

(Exercise using long division). Give the students calculators and have them calculate the speed of light when you give them the index of refraction, and have them calculate the index of refraction when you give them the speed in vacuum and the speed in a material.

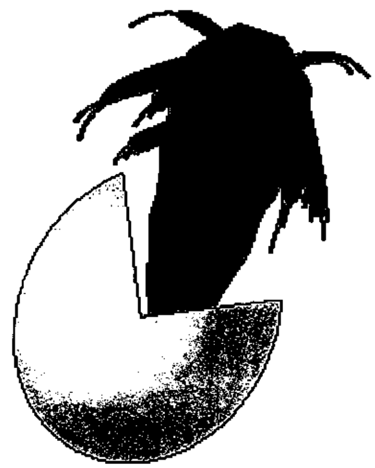
To calculate the speed of light in a material, use this formula: 186,282 miles/second ÷ Index of Refraction
To calculate the index of refraction for a certain material, use this formula: Speed of light in that material ÷ 186,282 miles/second

Class Discussion

1. Based on these data, does light travel more slowly in water or in air? (water)
2. When light travels from air to water, what's the <u>change</u> in speed? (46,165 miles/second)
3. Is the light speed in the fluid in the eye closer to water or to the speed in air? (water)

GROW YOUR OWN BRINE SHRIMP!

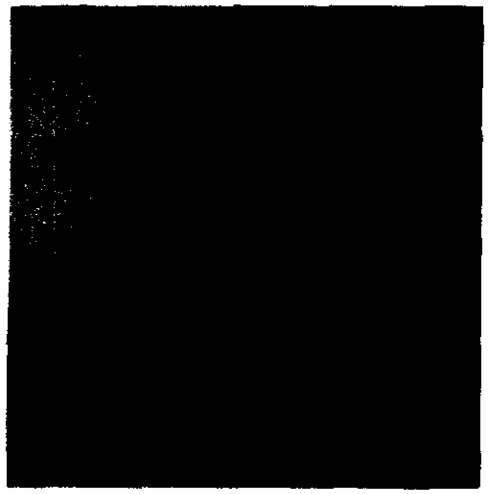
Materials: Shallow pan, Brine Shrimp eggs (100% *Brine Shrimp* cysts), Rock or aquarium salt, Thermometer, Notebook, Small packets of yeast, Brine Shrimp net (optional)



Procedure

1. Fill the shallow pan with water. Use the thermometer to make sure the temperature is between 75° and 85° F.
2. Add 8 tablespoons of salt per gallon of water. Stir well so the salt dissolves.
3. Add 1 level teaspoon of brine shrimp eggs (*Brine Shrimp* cysts).

Your eggs will hatch in about 24 hours. Baby brine shrimp are called nauplii. Your nauplii will have plenty of food from their cysts for the first two days. After that, give them a very small pinch of yeast every other day to feed them. If the water gets cloudy, change their water (you may need a brine shrimp net or handkerchief to save the nauplii!) Be careful to keep the temperature the same!



Class Project

Have your students keep a log of the brine shrimp's hatching rate and growth. Students can record which temperature works best, how much salt was added to each batch, which location in the classroom worked best (sunny window ledge, under a light bulb, etc.). Students can also make a growth chart that indicates how long it took for a batch to reach adulthood (easy to distinguish eyes, spine, tail with the naked eye).

Student Activity Sheet for LIGHT BENDING IN AIR Exhibit

There are two lenses in this exhibit. One belongs to a fish eye. One belongs to a human eye. Which is which?

TRY THIS! Put one plastic lens (flat side down) into the light. Find the point where the light comes together.

Draw what you see:
Where did the light come together? Circle answer: **Close to lens** **Away from lens**

Try the other lens (flat side down!). Draw what you see:
Where did the light come together? Circle answer: **Close to lens** **Away from lens**

Challenge:
If the light focuses (comes together to a point) too close to or too far away from the lens, things look blurry. Which lens belongs to the fish eye? How do you know?

Student Activity Sheet for LIGHT BENDING IN WATER Exhibit

There are two lenses in this exhibit. One belongs to a fish eye. One belongs to a human eye. Which is which?

TRY THIS!
Put one plastic lens (flat side down) into the light <u>inside the water tray</u>. Find the point where the light comes together.

Draw what you see:
Where did the light come together? Circle answer: **Close to lens** **Away from lens**

Try the other lens (flat side down!). Draw what you see:
Where did the light come together? Circle answer: **Close to lens** **Away from lens**

Challenge:
If the light focuses (comes together to a point) too close to or too far away from the lens, things look blurry. Which lens belongs to the human eye? How do you know?

Student Activity Sheet for SEEING IN AIR, SEEING IN WATER Exhibit

These globes are "eyes". One eye belongs to a human. The other eye belongs to a barracuda looking for its food.

TRY THIS!
1. Use the levers to put each eye into the water.
2. Take one step back.
3. Look for the image of the angelfish at the back of each eye (that's the side closest to you!).

Draw the angelfish as it appears on the back of each eye: **Left eye** **Right eye**

4. Use the levers to take the eyes out of the water.
5. Take one step back again.
6. Look for the image of the cardinal on the back of each eye.

Draw the cardinal as it appears on the back of each eye: **Left eye** **Right eye**

7. Now look straight down into the tank at the eyes. Draw the shape of each lens (hint: the lens is on the front of the eye):
   Left eye **Right eye**
8. Which eye belongs to the barracuda? Circle answer: **left** **right**
9. Which eye belongs to the human? Circle answer: **left** **right**

Chapter II. Buoyancy

Background

The most familiar physical difference between air and water is the difference in *density*, the mass that occupies a given volume. Air at sea level and 20°C has a density of 0.0012 gm/cm^3. Pure water at 4°C has a density of 1.00 gm/cm^3, nearly 800 times greater. This greater density leads to many of the striking differences between the way animals live in water and animals live in air.

Buoyancy. One of the biological consequences of fluid density results from a force known as buoyancy. This is the force that suspends blimps in air and allows boats to float on water. If the density of any object is greater than that of the surrounding fluid, the object experiences a downward force proportional to its volume. In this case, the object is said to be **negatively buoyant** and will float. If, instead, the density of an object is less than that of the surrounding fluid, there is a net upward force and the object is **positively buoyant** and will sink.

The density of water is quite close to the body density of animals, which means that animals are sensitive to small changes in density of either their bodies or of the surrounding fluid. Even most land mammals can float as long as they keep their lungs inflated. If they exhale, however, they sink. This means that the change in body volume during exhalation is enough to change the density of the animal from something slightly less than that of water to something greater.

Present day land animals did not evolve a mechanism for substantially altering their density when they emerged from the sea. Aquatic animals, however, need only to alter their density a little to stay afloat.

- Some fish, known as the teleost, or bony fishes, have evolved a mechanism, the swim bladder, to maintain **neutral buoyancy**.

- Cuttlefish (*left*)vary the gas pressure internally, in a rigid-walled structure
- Squid replace some of the sodium ions in their tissues with ammonium, thereby reducing their density.
- Some jellyfish (*right*) reduce their density by actively excluding sulfate from their tissues.
- Some fish and crustaceans adjust their density by accumulating low-density lipids or waxes.
- The sperm whale (*next page*) adjusts the temperature in its spermaceti organ, "freezing" the oil in its head and becoming more dense in the process.

In all these cases, the animal requires considerable time to change their densities substantially, but they do have the necessary means available to them. Land animals are not so lucky. The surrounding medium, air, is the lowest-density material in our environment, and so the mechanisms of buoyancy control discussed above cannot work on land.

Sperm Whale (*Physeter catodon*). The enormous (up to 1/3 of total body length), box-like head sets it apart from all other species. The head contains a **spermaceti organ**, which is thought to focus and reflect sound and be used as a cooling organ to diminish the whale's volume and its buoyancy during prolonged dives. The giant sperm whale has the largest of mammalian brains, both in proportion to its body and in sheer mass (approximately 9 kg).

Sperm whales feed mainly on squid (especially giant squid), octopus and deepwater fishes, but they also eat sharks and skates. A sperm whale consumes approximately 3 per cent of its body weight in squid per day. There are 18-28 functional teeth on each side of the lower jaws, but the upper teeth are few, weak and nonfunctional. The gullet is the largest among cetaceans; it is in fact the only gullet large enough to swallow a human!

Giant sperm whales are very deep divers and may stay submerged from 20 minutes to over an hour. Their blubber layer is quite thick, up to 35 cm, which helps them retain body heat on a deep, cold dive.

Sperm whales use clicking noises for echolocation, but they also make a variety of other sounds including groans, whistles, chirps, pings, squeaks, yelps, and wheezes. Their voices are quite loud and can be heard many kilometers away with underwater listening devices. Each whale also emits a stereotyped, repetitive sequence of 3-40 or more clicks when it meets another whale. This sequence is known as the whale's "coda."

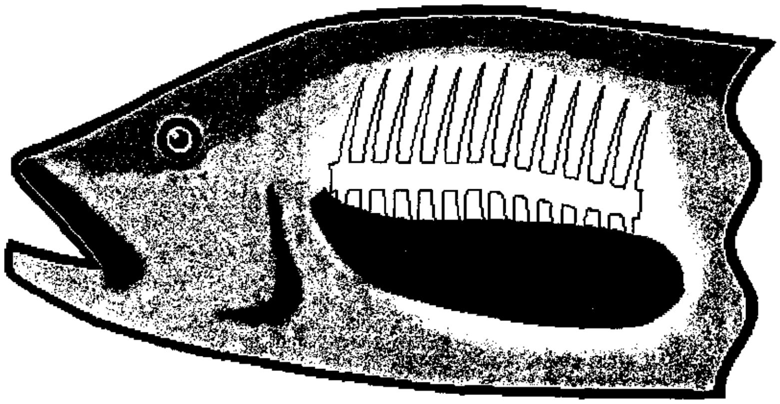
Exhibits

Bladders and Ballast Exhibit serves to introduce the force of buoyancy and shows that buoyancy is achieved differently in fish than in submarines.

Concepts: Positive Buoyancy, Negative Buoyancy, Density

Objective: Students will relate the swim bladder in most fish and the ballast tanks in submarines to buoyancy. Students will compare and contrast these two means of achieving buoyancy, and understand why one doesn't work for the other.

How to use: Watch the swim bladder inside the fish as you squeeze the bulb. Notice what happens to the fish as air fills its swim bladder. Watch the level of water in the submarine's ballast tank as you squeeze and hold the bulb leading to the submarine. Observe the reaction of the submarine as water is pumped out of its ballast tank.



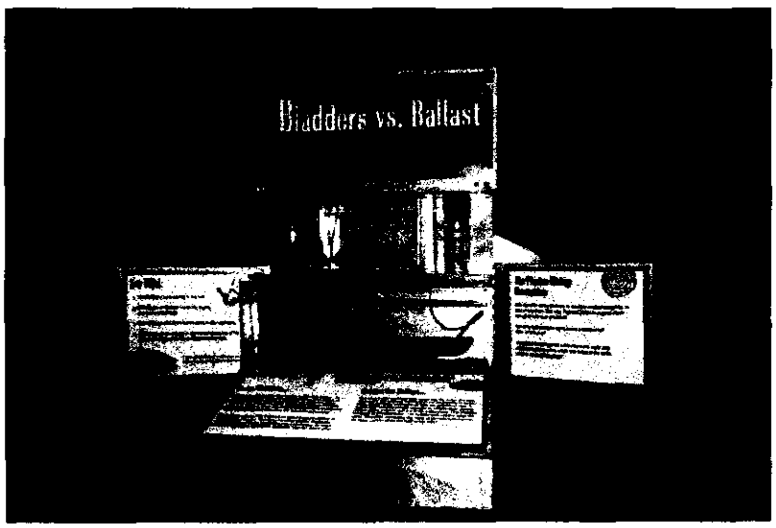
Explanation: **Density** is mass divided by volume. If an object's density is greater than the surrounding fluid (in this case water), the object will sink. If the object's density is less than the surrounding fluid, the object will float.

Fish are equipped with a bladder inside their bodies. As the fish adds air to its swim bladder, it increases its volume. The fish's mass stays the same. Since the mass of the fish didn't change but the volume of the fish increased, the fish is more buoyant (**positive buoyancy**).

The fish can also remove air from its swim bladder to become less buoyant (**negative buoyancy**). Shrinking the swim bladder decreases the fish's volume. When the fish's volume decreases, its mass occupies less space so the fish sinks.

Submarines are rigid, so they cannot change their volume. To achieve buoyancy, submarines use a ballast tank. A ballast tank holds water. Sailors must pump water in and out of the ballast tank. This changes the mass of the submarine. The submarine's volume stays the same. Increasing the mass of the submarine but keeping the same volume makes the submarine more dense than the surrounding fluid (water), so the submarine can sink.

Physics-Biology Connection: Fish use their swim bladders to maintain neutral buoyancy, or stay at one level. That way, they don't have to expend much energy to stay in one place.



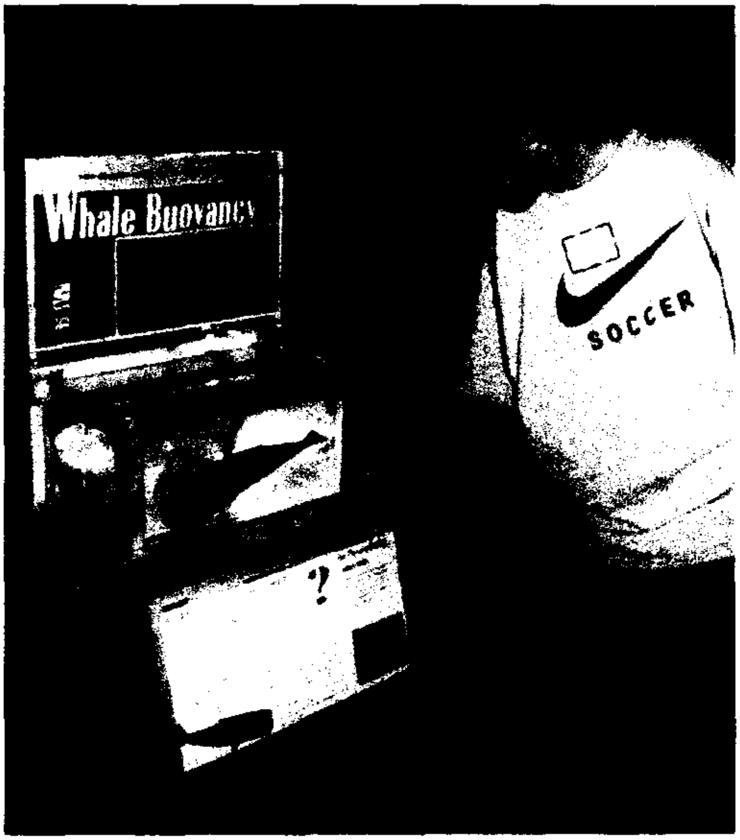
Whale Buoyancy Exhibit enables students to explore how the sperm whale dives.

Concepts: Buoyancy, Density

Objective: Students will associate density with the sperm whale's ability to dive and rise back to the surface. Students will gain an appreciation for this unique adaptation of the sperm whale.

How to use: Use the lever to move the whale up and down in the tank. You must hold the lever in place to allow the whale's "spermaceti organ" to function. Notice the liquid that fills the "spermaceti organ", located in the front part of the sperm whale's head.

Explanation: By moving the lever up and down you are controlling the whale's buoyancy, or its ability to float. In the ocean, sperm whales control their own buoyancy. To dive or float they change the density of the spermaceti wax in their heads.



Density is mass divided by volume. Objects that are more dense than water sink, while objects that are less dense than water rise. By changing the temperature of its spermaceti, a whale can make this special wax more dense or less dense.

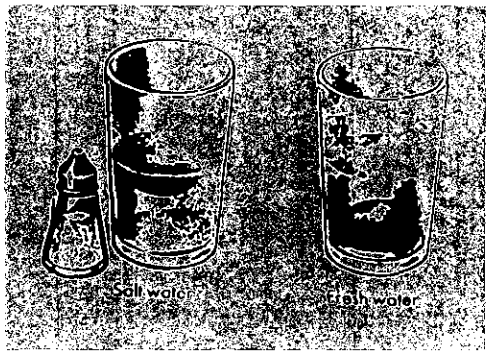
The red liquid in this exhibit represents body heat. The clear liquid represents cold ocean water. When a sperm whale wants to dive, it breathes in cold ocean water through its nose. As the spermaceti cools it begins to contract and becomes more dense. The more dense the spermaceti is, the less buoyant the whale is. Less buoyancy lets this aquatic animal dive deep.

When the sperm whale is ready to rise toward the surface, it warms its spermaceti with its own body heat. This makes the spermaceti less dense and the whale more buoyant.

Physics-Biology Connection: Why do sperm whales dive so deep? For food! Deep in the oceans live the sperm whale's favorite food, squid (*above*). Most other aquatic animals can't dive so deep, so there's less competition for the sperm whale. That's important, because the sperm whale's great bulk makes it a slow hunter.

Activities and Exercises

Buoyancy activity: COOL EGG TRICKS



Salt water is more dense than fresh water, which is why it is easier to float in the sea. Your students can use this scientific fact to perform a trick with an egg.

Materials: Two glasses, Salt, Two hard-boiled eggs, Thumbtacks, Two pencils with erasers intact, Other objects of your students' choice, Tablespoon

Procedure

1. Dissolve two tablespoons of salt in a glass of water.
2. Place one hard-boiled egg, still in the shell, in the salt water and one in a glass of plain water. Ask students, "What do you observe? How can you explain these observations?"
3. Now try this. Insert single thumbtacks in the erasers of two pencils in a glass of salt water (tack ends down). The pencil should float in an upright position. Have students record their observations.

How it works

The egg floats in the salt water because it is less dense than salt water. The egg sinks in the fresh water because it is more dense than fresh water.

Challenge

Fill one glass half full of fresh water and one half full of very salty water, as before. Then, very carefully, pour the fresh water into the salt water. Try pouring over the back of the spoon to help slow the flow. Don't let the liquids mix. Gently lower the egg into the water. It should float on the salt water and look as if suspended in the middle of the glass!

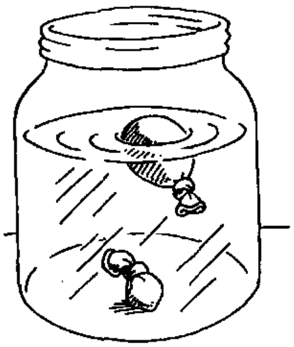
Class Discussion

Ask your class why the fresh water "floated" above the salt water during the Challenge exercise. (fresh water is less dense than salt water).

Which is denser – salt water or plain water? Try testing other objects in plain and salt water to observe flotation levels. Have your students predict the buoyancy of the objects they choose.

Buoyancy activity: FLOATERS
Students use this exercise to determine how a swim bladder allows a fish to float.

Materials: One quart (or liter) wide-mouthed jar, Two glass marbles, Two 7-inch (17.5 cm) round balloons



Procedure

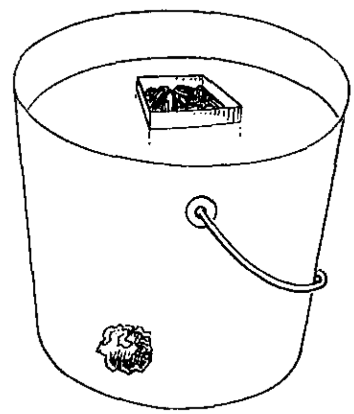
1. Fill the jar three-fourths full with water.
2. Place 1 marble inside each balloon.
3. In one of the balloons, tie a knot as close to the marble as possible. Drop the balloon in the jar of water.
4. Slightly inflate the second balloon with air, and tie a knot as close to the mouth of the balloon as possible. Drop this balloon in the jar of water.

Results: The inflated balloon floats on the surface of the water, but the deflated balloon sinks to the bottom of the jar.

How does it work?
When an object is in water, the water molecules push upward on the object. If the object doesn't weigh too much, the water molecules under the object can lift it to the surface and hold it there. Thus, the object floats. The object sinks if its weight is more than the water molecules can lift. The weight of the balloons with or without the air is about the same. However, the air in the balloon makes the balloon larger, and since it takes up more space in the water, there are more water molecules pushing up on the balloon. Thus, the balloon floats. The swim bladder in a fish behaves like the balloon. As the amount of air inside the fish's bladder increases, the fish enlarges and can then float.

Buoyancy activity: FLOATING BOAT
Students can use this exercise to determine how a heavy ship floats.

Materials: 20 paper clips. Aluminum foil, Ruler, Bucket of water

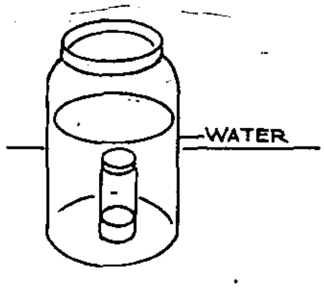


Procedure
1. Cut two 12-inch squares from the aluminum foil.
2. Wrap one of the foil squares around 10 paper clips.
3. Squeeze the foil into a tight ball.
4. Fold the four edges of the second aluminum square up to make a small square pan.
5. Place 10 paper clips in the metal pan.
6. Set the metal pan on the water's surface in the bucket.
7. Place the metal ball on the water's surface.

How does it work?
The ball and pan both have the same weight, but the ball takes up a smaller space than does the pan. The amount of water pushed aside by an object equals the force of water pushing upward on the object. The ball pushes less water out of its way they does the larger pan, and thus there is not upward force to cause it to float. Large ships are very heavy, but they have hollow compartments filled with air, which increases their **buoyancy**.

Buoyancy activity: RISING BOTTLE

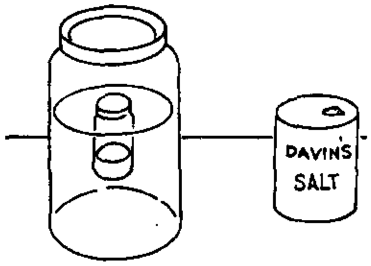
Students can use this activity to determine how salt affects buoyancy.



Materials: Large-mouthed jar (1 gallon), Small bottle with lid, 2 cups of table salt, 1 measuring cup, Large stirring spoon.

Procedure

1. Fill the jar three-quarters full of water.
2. Carefully place the closed small bottle in the water. The bottle should float on the surface. If it does not, try a smaller bottle.
3. Remove the small bottle and add a small amount of water to it.
4. Close the lid and replace the bottle in the gallon jar of water. The bottle should slowly sink to the bottom. Remove or add water to the small bottle until it sinks at a slow rate when placed in the water.
5. Remove the bottle and add 1/2 cup of salt to the large bottle of water. Stir.
6. Replace the small bottle in the jar and observe its position in the water.
7. Continue to add 1/2 cup of salt at a time until 2 cups have been added. Observe the position of the small bottle in the salty water after each measure of salt has been added.



How does it work?

Adding water to the small bottle makes it heavy enough to sink. The sinking bottle pushes water out of its way. The weight of the water pushed aside equals the amount of upward force on the bottle. This force is called **buoyancy**. A small amount of salt increases the buoyancy force, but it is not enough to overcome the downward force resulting from the weight of the bottle and water inside. The larger amount of salt increase the buoyancy force, allowing the bottle to float on the surface of the heavy salt water.

Buoyancy activity: YOU CAN'T BLOW IT

It's easy enough to blow up a balloon. But what if the balloon is submerged under water? If deep enough, your students will find that they just can't blow it.

Materials: Two plastic straws, Deep tub or bucket filled with water, Twist tie (like the ones used on plastic bags), Balloon, Masking tape

Procedure

1. Fit one end of a plastic straw into another to double the length of the straw. Seal the joint with masking tape.
2. Now insert one end of your double-straw into a deflated balloon. Push it all the way in until it is almost touching the opposite end of the balloon.
3. Wrap the twist tie around the lip of the balloon and tighten it (so that no air can escape the balloon when you blow it up.)
4. Hold the double-straw and blow up your balloon. Even though you had to blow hard to inflate it, it should be fairly easy.
5. Put the balloon under water and try to blow it up again. Was it easier or harder to blow up the balloon ?

How does it work?

You may not notice it, but there is air pressure pushing against you at all times. That pressure is from the weight of the entire earth's atmosphere, a whopping 300 miles high; it doesn't crush you because air has such small density. Water, however, is much denser than air—so much so, that only 33 feet of it exerts the same pressure as 300 miles of air. To blow up a balloon in air, the sides of the balloon must push out against the air pressure pushing in. This is easy for your lungs to do. But under water, the pressure increases dramatically. It's very difficult to push the sides of the balloon out against the water pressure pushing in.

Classroom discussion and demonstration: BUOYANCY AND BALLAST

Ships float because their overall (average) density is less than that of the water they float in. Ships are buoyed up by a force equal to the weight of water that the ship displaces. An increase in density because of overloading or taking on water, whether from above or below, can cause the ship to go down.

Objectives

- Students will determine the density of floating container by experiment.
- Students will explain in their own words why ships sink or float.

Materials: Inflated basketball (optional), Aquarium or other large container for water, Plastic zipper bag (about 2 L capacity), Food coloring

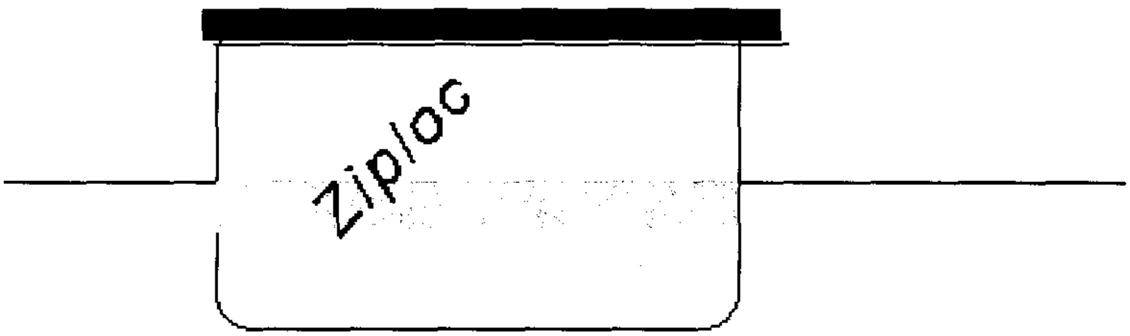
Procedure

On the chalkboard or on chart paper, make a data table with seven columns labeled:

# of nails (by twos from 0-20)	**Total mass** in grams	**Volume** in milliliters-- will be the same for all trials	**Density**	**Sinks/ Floats**	**Volume displaced** -- difference between original water level and final level with the tube in the water	**Height of tube**-- above water surface

1. Discuss examples of substances that float, such as wood, rubber inner tubes filled with air, and oil. Have students think of ways each could be made to sink, and why.

2. Recall or demonstrate what you must do in order to totally submerge a basketball full of air. What do you feel when you push it under water? What happens when you let go? What causes the ball to behave as it does?



3. Fill a plastic zipper bag about half full of colored water. Blow some air into the bag and seal it so that it is puffed up. Ask what would happen if the bag of water were lowered into a larger container of water such as an aquarium.
4. Lower the bag in the water. Observe that the bag floats. Note that the water level inside the bag is the same as the level outside the bag. If the water level in the large container is marked before the bag is lowered and then again once it is in the water, the water level will be seen to have risen.
5. Ask what would happen if additional water were to be added to the bag as it is floating in the water. At what point would the plastic bag sink? Try it when all predictions have been made. The bag will float until it is completely full of water and then sink slowly to the bottom. Discuss possible explanations for this behavior.

Class Activity: How ships float

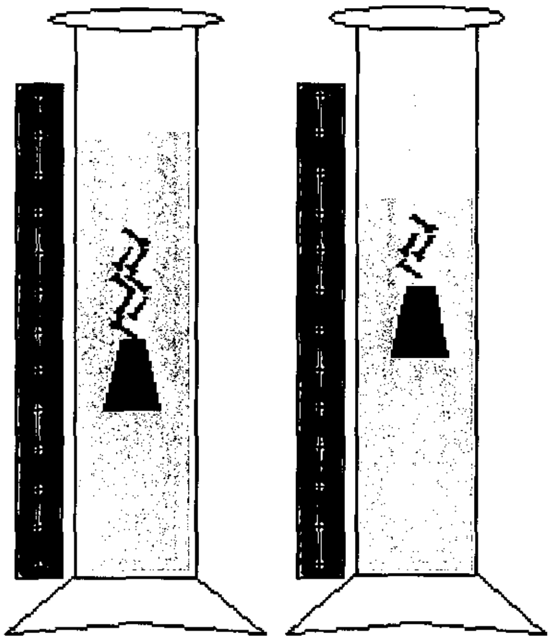
Materials: Test tube, 15 x 100 mm, Solid rubber stopper to fit tube, 100-mL graduated cylinder, 20 "4 penny" finishing nails, about 4 cm long (1.5 in.), Balance, Metric ruler, Graph paper, Micropipette (eye dropper)

Procedure:

1. Show students the 15 x 100-mm test tube and tell them that in this exercise it will represent a ship or barge. Ask for student volunteers to fill in the class data table. Add 20 4-penny nails to the tube and stopper it with a rubber stopper, noting how far the stopper is pushed into the mouth of the tube. You will need to stopper the tube in this same point each time you change the "cargo" in your "ship".

2. Use the balance to determine the total mass of the ship: tube, nails, air, and stopper.

3. Determine the volume of the ship by water displacement. Place about 75 mL of water in the 100-mL graduated cylinder and record its exact level. Carefully slide the stoppered, loaded ship into the water with the stopper down. Push the ship completely underwater and record the volume of water in this large container. The difference between these two volumes is the volume of the ship. This volume will be the same for all trials.



4. Now, make a prediction: What is the maximum number of nails it can hold and still float?

5. Carefully remove the tube from the water and dry it thoroughly. Remove two nails, replace the stopper (same position), and repeat all measurements until the ship is empty of cargo. Record all the data in the table. The volume of the tube will be the same as originally measured.

6. Determine the density of the ship for each load of nails by dividing the total mass by the volume. Express it in units of grams/milliliters.

7. Just for fun, vary the procedure by filling the tube with water instead of nails.

8. Use these questions and challenges to guide students' analysis of what they have observed:

   a. Explain the fact that the volume of the ship does not change even thought the mass changes. (Volume is determined by the shape of the ship, and is constant because the tube does not change shape as mass—or cargo—is added.)

   b. How does the height of the tube above the water surface change as the number of nails and mass of the tube change? (The tube sinks deeper into the water)

   c. Determine the mass of nail cargo by subtracting the mass of the ship without nails from the mass of the ship plus the nails for each trial. Is there a relationship between the mass of the cargo and the volume of water displaced in each case? If so, what is it? Why?

   d. Construct a graph that relates the number of nails to the density of the boat. Label the vertical (Y) axis Density and the horizontal (X) axis Number of Nails. Draw the smoothest curve possible through your data points. What does the shape of the line tell you about the relationship between the amount of cargo and the density of a ship? Make a mark on the line which represents the nail/density condition just between sinking and floating. Compare this density to that of water.

e. Describe the density conditions necessary for an object to float, sink, or suspend at one level.

f. Which will cause the level of water in a pool to rise more: placing a ten pound rock directly in the water, or placing it in a boat floating on the water's surface?

Class discussion:
Emphasize these principles in discussing class results:

1. An object (ship) will float if its overall density is less than the density of the fluid (water) in which is immersed.

2. An object immersed in water is buoyed up by a force equal to the weight of water is displaces.

3. The density of an object is calculated by dividing its mass by its volume.

4. Buoyant force upward is caused by the force of gravity downward. When an object is in a fluid, whether it is floating or immersed, the pressure on its underside is greater than on its topside. (In the same way, the pressure on a diver builds as he or she goes down deeper under the water because the weight of the water is greater).

The demonstration can be varied by using salt water or water at different temperatures.

Classroom activity: HOW LONG DOES A WHALE DIVE?

Introduction
Many articles have been written about the length of whale dives. Below is a list of the dive lengths of six different whale species, recorded by trained whale observers.

Example: Gray Whale 2, 3, 5, 3, 2

Add the five numbers: total = 15 minutes
Calculate the average = **15 ÷ 5 = 3 minutes**

Mink Whale 5, 4, 4, 3, 2

Average in minutes:____

Sperm Whale 40, 52, 57, 55, 55

The sperm whale is the champion diver. The longest dive observed by a free swimming sperm whale was 93 minutes.

Average in minutes: ___________

Blue Whale 13, 14, 11, 11, 12, 8, 11, 10, 8, 11

Average in minutes: ___________

Bottlenose Whale 42, 45, 20

This whale has been known to stay submerged for more than 70 minutes when harpooned.

Average bottlenose whale dive duration in minutes: ____

Below you will find typical diving patterns of four different whales and humans. The dives given are not record depths or record dive lengths for any of the species. The sperm whale is the champion diver of all animals. The deepest recorded dive is up to 7,300 feet. Record the average dive times you calculated for each of the whales listed below. The gray whale is completed as an example.

Species	Depth	Length of Dive	Food
Human	40 ft.	1-2 minutes	pizza
Gray Whale	100-200 ft.	3 minutes	bottom feeder
Blue Whale	300-600 ft.		krill
Bottlenose Whale	1500 ft.		squid

Sperm Whale	3000-5000 ft.		squid

Student Activity Sheet for Bladders and Ballast Exhibit

1. SQUEEZE the bulb leading to the fish. Draw what happens to the air bladder inside the fish.
2. SQUEEZE the bulb leading to the submarine. What does the submarine do when you squeeze the bulb?
3. Notice the cut out in the submarine. Inside the submarine is a ballast tank. Draw what happens to the ballast tank when you let go of the bulb.

Student Activity Sheet for Whale Buoyancy Exhibit

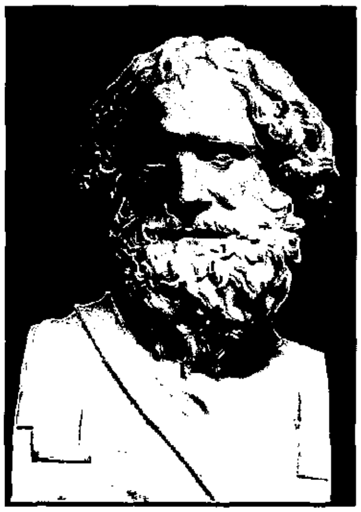
How does the sperm whale dive so deep?

1. Draw the model sperm whale in this exhibit.
2. PUSH the lever all the way down and hold it. What happens to the whale?
3. PUSH the lever all the way up and hold it. What happens to the whale?
4. Try to make the whale stay near the middle of the tank. This is called neutral buoyancy.

What do you think more buoyancy is called? **Positive** **Negative**
What do you think less buoyancy is called? **Positive** **Negative**

The Story of Archimedes' Principle

One of the earliest known successes of applied mathematics was in fluid mechanics, or at least fluid statics, namely Archimedes' principle that the buoyant force on an object is equal to the weight of the fluid displaced.



Archimedes of Syracuse is widely regarded as one of the three most brilliant men of history, with Sir Isaac Newton and Carl Friedrich Gauss as the others. All three would be considered applied mathematicians today, though all three are also claimed as physicists (by physicists) and pure mathematicians (by pure mathematicians). But I think we have the best claim, not that the modern distinction would have meant much to them.

Archimedes is perhaps most popularly known for his discovery, also involving fluids, of how to decide if his cousin the King's crown was made of pure gold or an imitation alloy. Whilst Archimedes was bathing, he realized that the volume of water displaced when an object is immersed is measurable, which allows one to measure the density of an irregularly shaped object, thus allowing its purity to be assessed. It is said that he leapt naked from the bath, shouting "Eureka!" (meaning 'I have found it!' and not, as Terry Pratchett maintains, 'Someone get me a towel!') and ran to tell of his discovery.

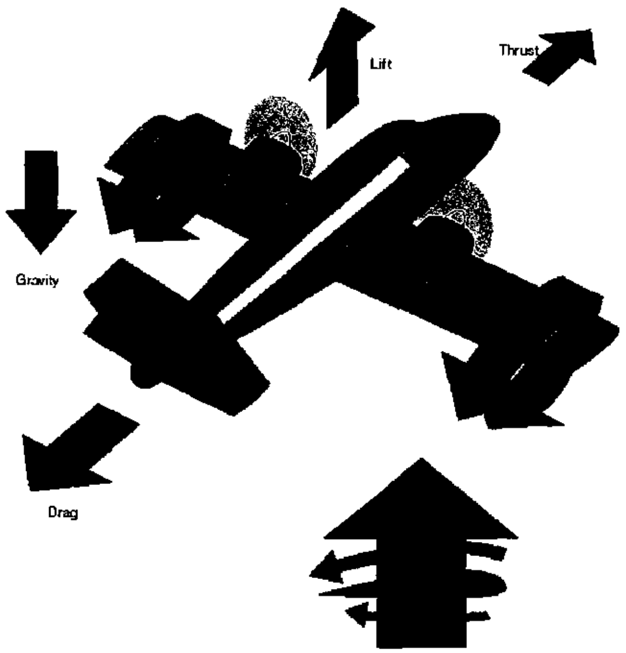
Challenge: what else did Archimedes discover? When did he live?

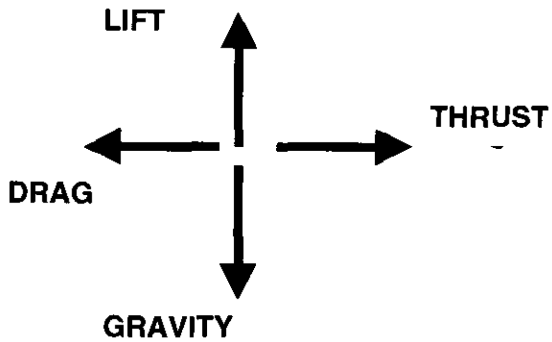
Chapter III. Movement

Physics Background

Thrust, Lift, Drag, and Gravity

For a stationary animal in a moving fluid, air or water, the fluid pushing against the animal exerts a pressure called **drag**. The amount of drag depends on the size and shape of the animal. Streamlined objects disturb the flow of the fluid less and have a lower drag. If the animal is not to be swept backward it must exert a **thrust** to balance the drag. If the animal wants to move forward, its thrust must be greater than the drag. When a fish undulates its body and tail, a thrust is created. The same applies to birds, bats, insects and airplanes as they fly through the air. Humans create thrust when they swim by dragging their arms and legs through the water. Thrust can also create **lift**. The thrust that propels a tuna, whale, or porpoise rapidly through the water is provided by the lift created as its tail oscillates back and forth.





Viscosity. Fluids such as air and water are different from solids in their ability to flow. How rapidly a fluid flows, or is deformed by a given driving force, is determined by the fluid's **viscosity.**

Water is much more viscous than air. For example, at 20°C, the viscosity of water is fifty-five times that of air; the liquid is "stickier" than the gas. Viscosity depends on temperature of both air and water, but in opposite directions. Over the range of 0° to 40°C the viscosity of air increases by about 11%, while over the same temperature range the viscosity of water decreases by 64%. Seawater is slightly more viscous than fresh water.

Moving in Air, Moving in Water.

Water's viscosity has a profound effect on locomotion for smaller organisms like protozoa. In an interesting biological twist, these organisms must overcome viscous drag, but they must also rely on viscosity to provide their thrust. The *Microscopic Movement* exhibit explores how these tiny aquatic organisms get around.

All living things live in a fluid, either air or water. Air is a gas and has no defined shape and no defined volume. Water, a liquid, has a defined volume but no defined shape. The physical characteristic that unifies gases and liquids is viscosity, their resistance to the rate of deformation. For example, a force is required to move a spoon through honey; the faster the fluid is stirred, the more force is required. However, it does not matter how far the honey is stirred; as long as a constant force is applied, the fluid deforms at a constant rate. The dynamic viscosity in water is ~ 60 times greater than in air.

How fast do animals move? The fastest aquatic animals are fishes, probably the yellow-fin tuna and the wahoo; both have been clocked at about 21 meters/sec in 10 to 20 second bursts. The fastest aquatic mammal, the killer whale (Orca), is somewhat slower at about 15 m/sec.

The fastest aerial animal is the peregrine falcon, which can reach a speed of 97 m/sec. In level flight ducks and geese can sustain speeds of about 29 m/sec, while the fastest insect, the deer-fly, can reach 16 m/sec in short bursts.

100 cm/sec = 1 meter/sec (m/sec)
To get miles/hour, multiply m/sec by 2.24.

Animals can propel themselves through fluids (either air or water) at about the same speeds that winds and currents move relative to the earth.

Where the animals live. In salt water, which covers 71% of the earth's surface, some animals live right at the shore, pounded by waves or in burrows in soft sand. Others live in the rich nearshore areas, where nutrients mix constantly and sunlight produces tremendous growth. Still others roam the almost barren open oceans, far from land. A very specialized group of animals lives in the cold, dark depths of the oceans, able to live without light and at great pressures.

In fresh waters there are ponds, lakes, streams and wetlands. Aquatic animals may be found in the steamy tropics, the harsh polar regions, or in the middle, temperate zones. Each group has adapted to the physical, chemical and biological characteristics of their environment.

Portrait of a River. There are a surprising number of different habitats in a river, many more than in the still waters of lakes or ponds. Water flow depends on the slope of the land. Younger rivers tend to have steep slopes, fast-moving water and narrow floodplains. Older, larger rivers carry more sediment, flood larger areas of nearby land, and have only periodic rapids or riffles.

Water striders, whirligig beetles and others use the water tension to ride the surface of rivers. Fish swim throughout the water column and some "walk" along the bottom, joined by insect larvae, snails and crayfish. Beaver and muskrat burrow into streambanks, while clams and worms hide among rocks and in sandy bottoms.

Animals react to the flowing water in a variety of ways. Some have shapes and methods of locomotion that allow them to swim against the current, like the rainbow trout in the *River Olympians* exhibit. Some fish that cannot swim against the current avoid it by staying close to the bottom and behind rocks, like darters and sculpins. Others, among them bluegills and other sunfish, congregate in the slow-moving waters under trees and at the inside of bends in the river.

Large rivers have large fish. When breeding time approaches, these adult fish swim upstream, into small tributaries and streams, to lay their eggs. The young grow in the rich, protected smaller waterways, gradually moving downstream into the larger rivers as they mature.

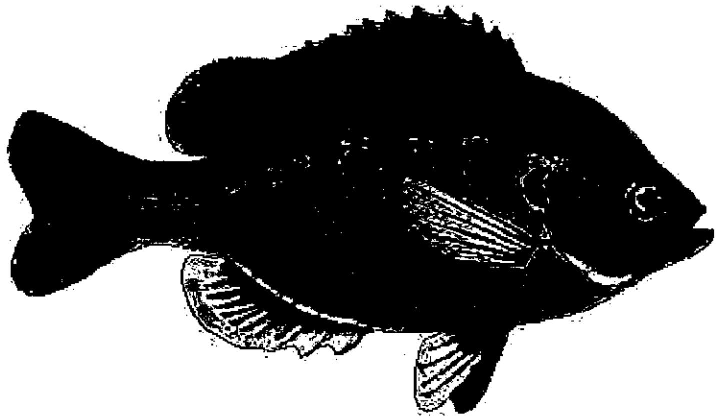
Fish Shapes. To reduce the friction of forward motion, most aquatic animals have streamlined bodies shaped roughly like a football. This body shape poses a minimum amount of resistance as water flows over it.
You can tell a lot about a fish's habitat by the shape of its body. Tuna, which are extremely fast, are shaped like torpedoes. Fish that live in strong flowing streams, like trout and many species of minnows, also have torpedo-shaped bodies that allow them to navigate strong currents.

The elongated bodies of eels and other snake-shaped fish are perfect for slithering through holes or among bottom vegetation, but are not good for fast swimming. A shape like a pancake, with fins sticking out from the body, is good for maneuvering among weed-choked shallows in lakes and ponds or among sharp-edged coral on reefs.
Some shapes have little to do with efficient movements. A number of fishes have rigid, even hard bodies and are decidedly unstreamlined. These slow-moving fishes often produce venom or are extremely well-camouflaged (no need to swim fast for protection) and eat slow-moving animals or hunt by stealth.

Animals

We have chosen the **bluegill**, the **rainbow trout**, and the **bluefin tuna** for the exhibits on movement.

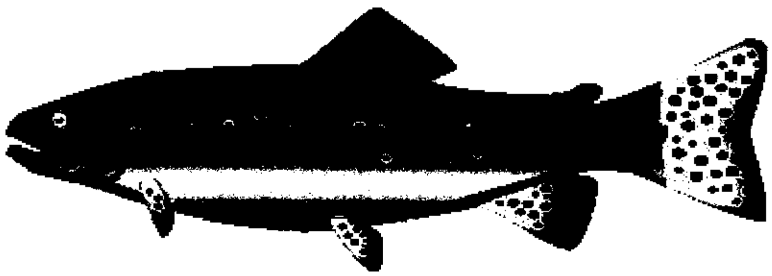
Bluegill (*Lepomis macrochirus*) are in the sunfish family, and are related to bass, crappies, pumpkinseed and others. Lurking in weed beds and under ledges, these freshwater predators peer out and lunge for smaller fish or a fisherman's bait. Also lurking in the same places are largemouth bass. Bluegills are one of their favorite foods!



Like all sunfishes, the bluegill uses its tail like a fan to dig out a nest in the bottom of a stream or lake. After the female deposits her eggs in the nest, the male single-mindedly guards the eggs and chases away all other fish, including the female.

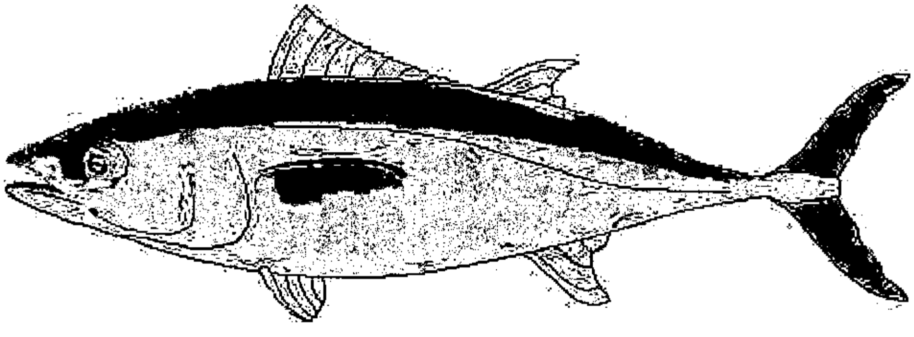
The bluegill is named for the bright blue patch on each gill cover. The colors become exaggerated during the breeding season. School children voted the bluegill Illinois' state fish.

Rainbow Trout (*Salmo gairdneri*). This beautiful fish, , is a native to the western United States, but because of it is so good to eat has been raised in hatcheries and introduced by the millions into cold streams and lakes around the world. Black dots pepper the rainbow's back, tail, fins and the wide red patch on each side.



Some rainbows live in the ocean and migrate to rivers to lay eggs. Others live and spawn in cold streams and rivers, where they challenge anglers with legendary fighting and leaping agility. Rainbows forage on the bottom for invertebrates and small fishes, or rise to the surface to eat insects or the hopeful fisherman's hand-tied artificial fly.

Bluefin Tuna (***Thunnus maccoyii***) are large, cigar-shaped fish and live near the sea's surface.



The bluefin tuna swims fast (speed bursts of up to 70 km/h have been recorded. To do this, this tuna must eat a large amount of food every day. Their diet consists mainly of fish, crustaceans (e.g. krill), and squid. At various stages in its life other fish, seabirds, sharks or killer whales may eat the bluefin tuna.

The bluefin tuna can be found throughout the southern oceans of the world. They are a highly migratory fish and travel long distances throughout their life cycle.

Exhibits

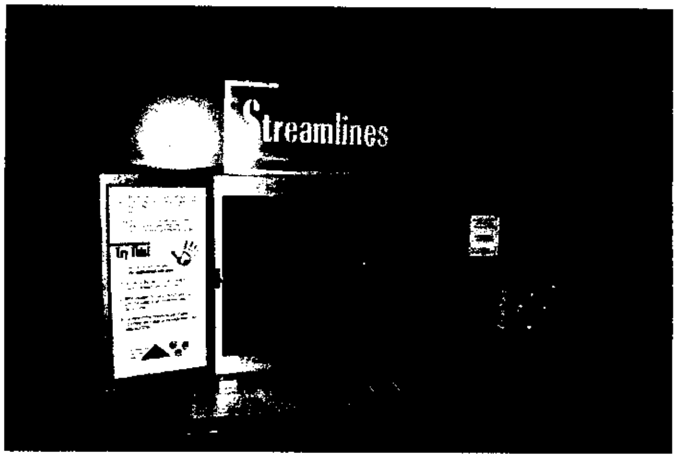
Exhibits that deal with movement in water versus movement in air:
Streamlines, River Olympians, RoboTuna, and Microscopic Movement.

Through these exhibits the observer can explore:
- how shape influences the movement of air or water over that shape;
- how subtle variations in shape relate to aquatic habitat;
- how people are translating aquatic adaptations into new technologies;
- the role that buoyancy plays in the lives of aquatic animals;
- the relationship between density and viscosity;
- how these two physical principles affect the lives of the tiniest of aquatic animals.

Streamlines enables students to see how different shapes affect the amount of turbulence generated as air flows over and under an object.

Concepts: Streamlining, Turbulence, Drag, Lift

Objective: Students will identify which shapes are streamlined. Students will infer the most appropriate shape for different levels of flow in terms of streamlining.



How to use: Insert the different wood shapes into the moving air stream. Use only one shape in the experiment test area at a time. Observe the disturbances in the air flow.

Explanation: Air flow hits the front of each piece and flows either over it or under it. As the air flows, it gets mixed up, or **turbulent**. Turbulence causes **drag**. Drag is a force that slows a moving body down. If a shape causes little turbulence, we say that shape is **streamlined**.

Look carefully at the airplane wing when it is oriented the way it would be in level flight. Notice that the lines of flow are closer together under the wing than above it. This means that the air pressure is slightly less above the wing. This difference in pressure causes **lift**. Lift works against the downward pull of gravity.

Physics-Biology Connection: Airplanes, birds and fish are streamlined to save energy. Some fish are more streamlined than others. By looking closely at a fish's body shape, you can tell whether that fish lives in slow water or in fast water.

Students can also relate streamlining to everyday life by imagining riding a bike against the wind.

River Olympians enables students to see how slight differences in shape affect the amount of turbulence generated as *water* flows over a fish shape, demonstrating the difference that streamlining makes to an aquatic animal.

Concepts: Streamlining, Turbulence, Drag

Objectives: Students will observe the relationship between small differences in shape and resistance in water. Students will infer the relationship between streamlining in air and in water. Finally, students will interpret reasons for different fish shapes in varied aquatic environments, and understand that animals and their natural habitats are well matched to each other.

How to use: Use the levers to put each fish into the water (one at a time). Wait for the water to settle down. Look behind each fish for an area where the white lines get mixed up (use the red dots on the bottom of the tank to help you remember).

Explanation: Water is much more dense than air. This means that even slight differences in shape can cause a difference in drag. The chunkier fish, the bluegill, causes more turbulence than the sleeker (streamlined) fish, the rainbow trout. The swirled water occurs much more quickly (closer behind the fish) for the bluegill than for the trout.

Physics-Biology Connection: The more streamlined a fish, the less energy it takes to swim through water. If a fish is less streamlined, it will take more energy to swim. Air is much less dense than water, so the force needed to move through air is lower. This means that land animals can have lots of different shapes. Even so, streamlined land animals move the fastest—like the jaguar.

ROBOTUNA: WHAT CAN WE LEARN FROM FISH?.

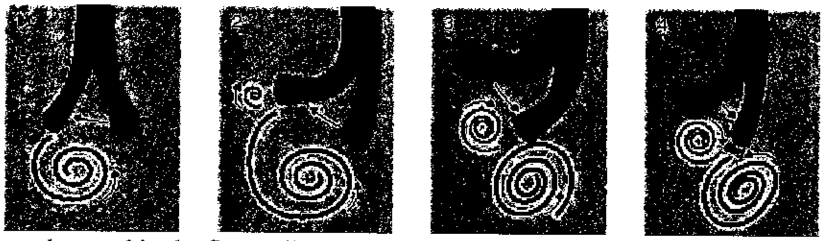
This exhibit is named after the Massachusetts Institute of Technology *RoboTuna* project.

Robotuna is an example of **biomimesis**, how humans can learn from animals. Using a robotic tuna, scientists at the Massachusetts Institute of Technology are learning to make better designs of ships, submarines, and research vessels. The idea of learning from nature to improve today's technology is an emerging science called **biomimesis**. What other kinds of aquatic animals could we base a technology on?

Concepts: Turbulence, Drag, Technology

Objective: The purpose of the RoboTuna exhibit is to encourage students to make the connection between pure scientific research and the eventual development of technologies that help people. It also has a biology message - i.e., how fast different animals move through water - the tuna is one of the fastest.

How to use: Press the black button to start the flow in the tank. Watch the fish's tail movement and the water around it closely. You should see the vortices (turbulence) created by the fish's body and its tail. If you are having trouble seeing the vortices, press the orange button to inject dye into the tank to make these vortices more visible.



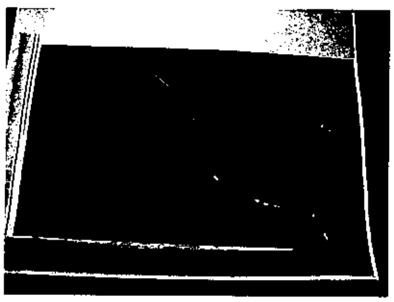
Explanation: As students observed in the Streamlines and River Olympians exhibits, turbulence normally causes drag, which acts to hamper a fish's swimming. The tuna is an exception. Tuna use turbulence in the water around them to their advantage.

The tuna senses the pressure differences of the incoming vortices as they move along its side. To capture energy from the vortices, the tuna instinctively times the flapping of its tail to create vortices spinning in the opposite direction. These vortices meet and weaken the incoming vortices. The tuna flaps its tail forcefully in one direction. It quickly follows this flap with another in the opposite direction. When the two vortices meet they combine and create a jet. This produces a strong, sudden thrust and makes the tuna one of the fastest fish around. (Speed bursts of up to 70 km/hr have been recorded.)

Physics-Biology Connections: Our exhibit was inspired by the Massachusetts Institute of Technology's RoboTuna. Engineers at MIT built a robotic tuna to mimic the movement of the tuna, one of the fastest fish in the world.

Why build a RoboTuna? Think about a modern day submarine. Even though it is streamlined, it takes a lot of energy to run one. And even though it is using a lot of energy, it is still a slow and ponderous machine. Now consider the tuna. Sleek *and* fast. By researching the way a tuna moves, scientists and engineers can then try to translate their observations into better technologies. For example, the scientists at MIT hope to apply what they learn about RoboTuna to research submarines. Their work can also be applied to many other kinds of ships and submarines.

Microscopic Movement: How microscopic animals move in the water: cilia and flagella
One-celled animals in this exhibit: Amoeba, Euglena, Paramecium

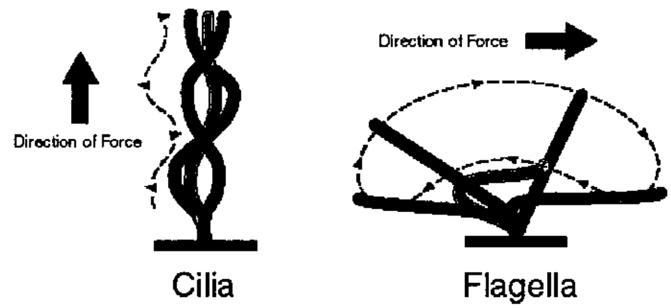


Concepts: Viscosity, Newton's Law, Momentum

flagellum (pl. flagella) Tiny whiplike appendage, capable of movement.
cilium (pl. cilia) A short, usually stiff, usually unicellular, marginal hair.
Cilia and flagella are projections from the cell. They can move and are designed either to move the cell itself or to move substances like water over or around the cell. Cilia and flagella have the same internal structure. The major difference is in their length.

Microscopic Movement enables students to explore how the tiniest of aquatic animals get around, and how a protozoan's environment both helps and hinders its movement.

Objective: Students will make the connection between viscosity and the action of cilia and flagella. Students will gain an appreciation of the special adaptations that these tiny aquatic organisms have developed to survive and thrive in their environment.



How to use: Press the button to the left of each microscope and observe the slides. The left microscope has preserved slides of protozoa, while the right microscope has a slide of live protozoa.

Left Microscope: Notice the differences between the protozoa. Notice which have cilia and which have flagella.

Right Microscope: Notice the different ways the protozoa move. Identify the different types of protozoa in this culture (amoeba, paramecium, and euglena). Look at the pictures on the exhibit to help you identify the different types.

Explanation: Protozoa is a type of organism, neither plant nor animal, made up of only one cell. Protozoa have adapted special ways of moving through water. Moving through water is much more difficult than moving through air because the viscosity of water is 70 times greater than the viscosity of air.

Viscosity is the degree to which a fluid resists flow under an applied force. Water is more viscous than air. Protozoa have evolved ways to deal with the difficulty of moving through water. Protozoa have cilia, flagella, or pseudopods that help them move.

Cilia are thousands of tiny hair-like projections that cover the surface of a cell. Cilia wave in a coordinated way to move the protozoa in one direction. A flagella is a long tail-like appendage that is waved back and forth to move the protozoa. Pseudopod means "false foot". The protozoa extends a pseudopod in the direction it wants to travel. The rest of the body flows into the pseudopod to move the animal.

Newton's Law is the principle of physics that is important in understanding how movement is produced by the action of cilia and flagella. Newton's Law says that if the protozoan pushes on the water, the water must push back on the protozoan with equal force and in the opposite direction. The water pushing on the protozoan is what makes the protozoan move.

Momentum must be conserved. The mass of the water that protozoa move through is large compared to the protozoan's mass. The water is barely moving so it has a small velocity. The protozoan's mass is very small. Due to conservation of momentum, the velocity at which protozoa move must be larger than the water's velocity:

MASS multiplied by velocity	**=**	**mass multiplied by VELOCITY**
(Water)		**(Protozoa)**

Physics-Biology Connection: Protozoa move in response to a stimulus. A stimulus can be food, light, temperature, or chemicals. Cilia, flagella, and pseudopodia are not only used to produce movement for protozoa. They also help protozoa eat. Cilia and flagella may be used to sweep food toward the protozoan's mouth. Pseudopodia may be sent out to search for food. If food is found, the pseudopod surrounds the food to trap it so the protozoan can eat.

Activities and Exercises

Classroom activity and research project:
1. Convert the animal speeds given in the Physics Introduction to Chapter III from meters/second to miles/hour.
2. Look up in the library or on the World Wide Web typical and maximum speeds of water and air on the earth.
3. Compare the fluid speeds with the animal speeds.

HOW DO WINGS WORK? Activity related to Streamlines and River Olympians Exhibits

Materials: Strip of paper

Procedure: To see how wings work, blow hard over a strip of paper, and watch the paper rise.

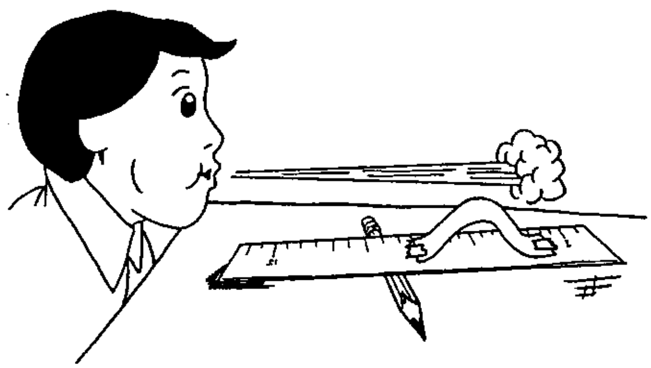
How it works
The faster air flows, the lower its pressure. So as you blow, the pressure under the paper becomes greater than above it. This pushes the paper up.

Conclusion
The shape of a wing is called an aerofoil. It is designed so air flows faster over the top of it. This lifts the plane up.

Activity related to Streamlines and River Olympians Exhibits: WINGING IT

Materials: Pencil, Ruler, Strip of paper (as wide as the ruler and 4" long), Tape

Procedure
1. Tape one edge of the strip to the ruler so that it lines up with the 1-1/2" mark. Tape the other edge down at the ruler's 5" mark. The paper "wing" should have a bulge in it.
2. Balance the ruler across the pencil. Then push the ruler a little past the balance point, so the paper-wing end seesaws down and touches the table.
3. Now, lay your chin down at the opposite end of the ruler and blow toward the wing. The paper-wing end of the ruler lifts up!



How it works
The curve makes the top of the wing longer than the bottom of the wing. Therefore, the air on top has to flow faster than the air on the bottom (under the ruler) to arrive at the back of the wing at the same time. The fast air flowing over the top pushes down less than the air below pushes up-so up it goes!

Activity related to the RoboTuna Exhibit: CREATE A NEW TECHNOLOGY!

Introduction
Scientists at the Massachusetts Institute of Technology are learning from aquatic animals to make better designs of ships, submarines, and research vessels. The idea of learning from nature to improve today's technology is an emerging science

called **biomimesis**. These scientists and engineers have already built a RoboTuna, a RoboPike, and are working on a RoboLobster.

What other kinds of aquatic animals could we base a technology on? What kind of task would your technology help with? For instance, the RoboTuna may one day help submarines travel underwater faster with less energy. The robotic lobster may help to study the ocean floor one day. What would your robotic aquatic animal help us do?

Class Discussion

Prompt your students with questions such as, "What would a tail or fin on your technology help your robot do?" (a specially shaped tail might help a submarine move through the water more efficiently). "What are we already doing underwater with technology?" (scuba diving, traveling, dolphin-safe fishing). "What aquatic animal could help us learn to do these tasks better?"

Student Activity Sheet for STREAMLINES Exhibit

TRY THIS!

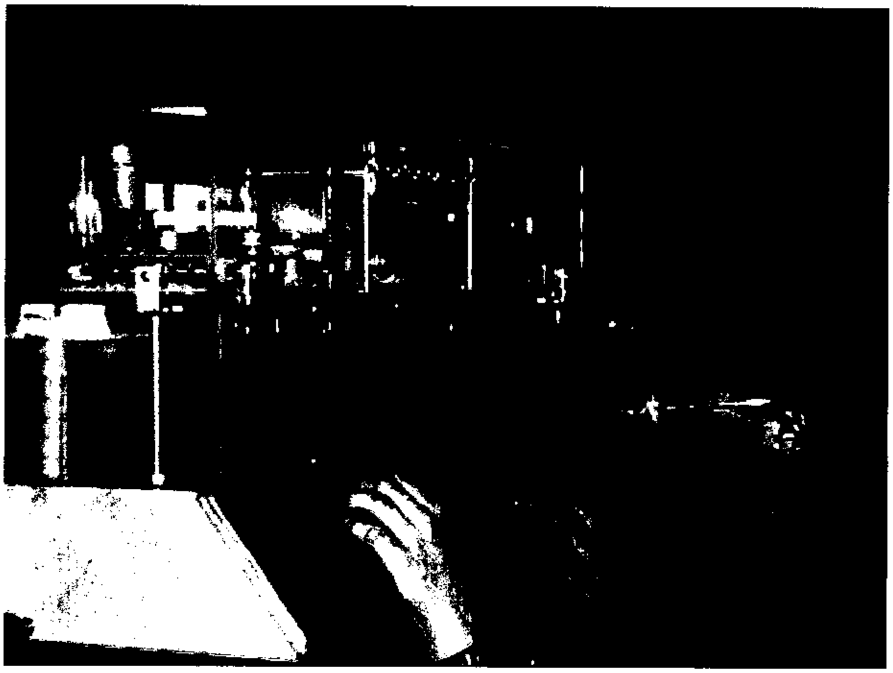
1. Look for the lines of mist in the experiment test area. (Hint: Leave the door open to see better. Look all the way left.)

2. Try the different shapes inside the exhibit <u>one at a time</u>. They will stick to the back wall. Stick them all the way to the left of the experiment test area. Draw how the air flow looks for each piece:

3. Draw the shape of the piece that has the smoothest flow. This piece is the most streamlined!

4. Adjust the speed of the air flow with the black knob to the right of the exhibit. What happens if you increase the speed of the air flow?

Student Activity Sheet for RIVER OLYMPIANS Exhibit



TRY THIS!

1. Watch the water in the top tube. Notice the white flow lines.

1. Use the lever to put one fish into the water. Draw the fish. Show where the white lines get mixed up:

2. Use the lever to take the first fish out of the water. Put the second fish in the water. Draw this fish. Show where the white lines get mixed up:

3. Use the lever to put the clear cylinder (all the way to the left of the tank) in the tank. Draw what happens to the white lines behind the cylinder:

Chapter IV: Sound

Background

Aside from light, sound is the major source of information available to animals about the location and nature of objects in their environment. The speed of sound in water is much higher in water than in air. At 20°C, sound travels at about 1521 meters/second in seawater, 4.3 times as fast as in dry air at the same temperature.

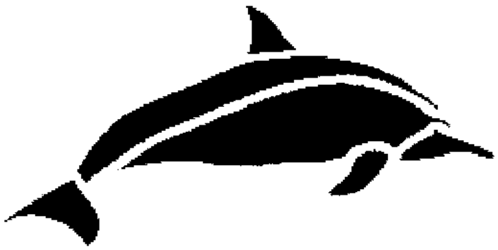
Water also transmits sound much more effectively than does air. For instance, at 20 Hz (Hertz or cycles/second), sound is attenuated nearly 6 million times faster in dry air than in fresh water. Seawater attenuates sound much more rapidly. As sound moves through a fluid, some acoustic energy is lost to viscous processes and eventually dissipated as heat. It is important to realize, however, that despite this attenuation, aquatic animals can communicate over long distances using sound. For example, whales and dolphins are thought to be able to communicate over hundreds of kilometers using sound. The U.S. Navy uses hydrophones to track distant surface ships and submarines.

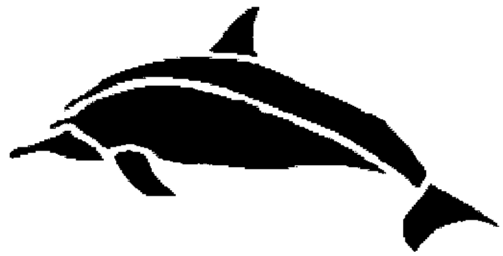
Echoes. When an acoustic wave bounces off an object and returns to its source, that is known as an echo. Echoes enable animals to sense and translate information on their surroundings. The bat emits short, high frequency "chirps" and listens for the echo. A similar process is used by some cave-dwelling birds to navigate in the dark, and by dolphins, porpoises, and whales to locate objects under water. People use sonic echoes through special equipment to find and track gamefish and submarines, and to map the ocean floor.

Animals

We have chosen one of our favorite animals, the Bottlenose Dolphin (*Tursiops truncatus)*, for our sound exhibit. Known for their inshore habits, playfulness around vessels and star performances at oceanariums, bottlenose dolphins, are probably the most popular of all cetacean species.

All dolphins are toothed whales belonging to the sub-order odontocetes, of the order cetacea. As a group, dolphins are often referred to as "small" cetaceans, even though some of them are quite large, attaining lengths of over 20 feet. In addition, although the terms dolphins and porpoises are often used interchangeably, they really refer to two different types

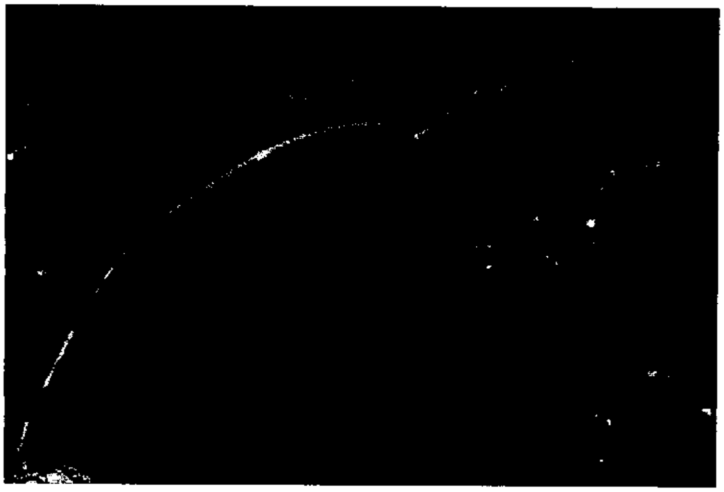




of animals. Dolphins possess a distinct beak. Their teeth are conical in shape. Most species of dolphins are larger than porpoises, with the males usually being larger than the females.

Dolphins of some kind occupy virtually all oceans and major seas as well as some large river systems. Their distribution, however, is not random. Each species has become specialized to fit into a particular niche. A niche relates to all aspects of a species' way of life, including not only its physical home but also its food, behavior, predators and physical environmental factors necessary for its survival. In short, the niche defines a species' role within an ecosystem. For each dolphin species this role is unique.

All dolphins are carnivores. Some feed exclusively on either fish or cephalopods (the class of marine invertebrates including squid, octopus and cuttlefish), while others have a more varied diet including fish, squid, crabs, shrimps and lobsters.

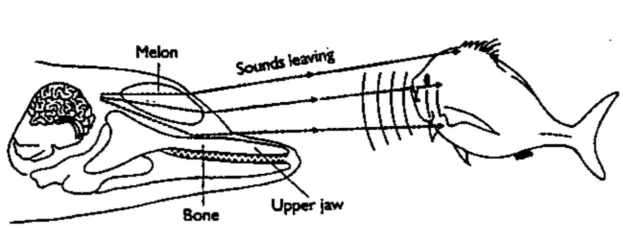


Dolphins have become marvelously adapted to life in the sea. Anatomically, their bodies have become streamlined to move effectively in their aquatic environment. Their hind limbs have disappeared, their front limbs have developed into flippers, and their powerful tail provides their chief means of propulsion.

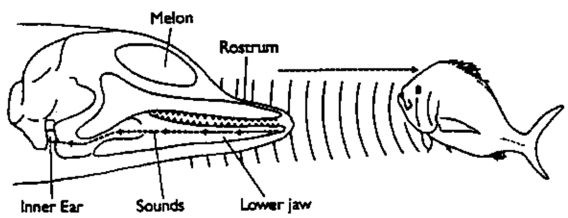
Another factor that increases dolphins' swimming speed by reducing their drag in the water is the smooth skin they possess. Unlike most mammals, a dolphin's skin is hairless, thick and lacks glands. It is also kept smooth by constantly being sloughed off and replaced. A bottlenose dolphin, replaces its outermost layer of skin every two hours. This is nine times the rate of human skin renewal. A drawback of their smoothness, however, is that their skin is easily scarred. Virtually all adult dolphins have an array of scars, notches and nicks that they acquired through interactions with companions, enemies or the environment. Scars on dolphins are so prevalent in fact that researchers often rely on them as a means of identifying individual animals. Like all other marine mammals, below the skin, dolphins have developed a thick layer of blubber to insulate them from heat loss.

Although dolphins are believed to have fairly good eyesight, their dark and murky environment often limits their visibility. Dolphins and whales have come up with an efficient way to combat this problem. They tend to rely chiefly on their sense of hearing to understand the world around them, much as humans rely on a combination of sight, sound and smell.

Dolphins and many species of toothed whales use their sense of hearing in a very sophisticated behavior known as echolocation. Echolocation is a process where a dolphin emits a steady series of split-second "clicks" through its blowhole. The "clicks" are pulses of ultrasonic sound (sounds repeated as rapidly as 800 times/second) produced in a dolphin's nasal passages and focused in a large, lens-shaped organ in the forehead known as the **melon**. The melon concentrates the sound pulses into a directional beam. When the outgoing sound waves or "clicks" bounce off objects in their path, a portion of the signal is reflected back to the dolphin. The bony lower jaw of the dolphin receives the incoming sound waves and transmits them to the inner ear where they are converted into nerve impulses and then transmitted to the brain.



Sound Production



Sound Reception

Through echolocation, a dolphin is able to determine the distance of a target on a continuing basis by measuring the time between emitting the clicks and their return. Dolphins regulate their rate of click production to allow the returning "echo" to be heard between outgoing clicks. Using this amazing skill, a dolphin can create an acoustic picture of its surroundings and can determine the size, shape, and direction of movement and distance of objects in the water. This permits dolphins to hunt prey over a greater range than the limits of visibility allow.

Exhibit

This exhibit deals with how sound travels in water compared to how sound travels in air. Through *Dolphin Sonar*, students explore the science behind the cetaceans' remarkable ability: echolocation. Dolphins use their ears to see. Dolphins send out sounds and listen for the echoes that come back from objects in the water. A dolphin can tell a great deal about an object by the echo it makes—that's like seeing with your ears.

Concept: Echolocation

Objective: Students will gain an appreciation of the dolphin's ability to echolocate. Students will make the connection that aquatic animals rely on senses other than sight to help them know their environment.

How to use: Aim the dolphin at each visible object in the tank while holding down the button. Listen carefully to the echo each object makes. Identify the hidden objects in the tank. Place object markers in the tank map to help remember what and where the hidden objects are. Then look at the tank from the side to see the hidden objects and check against the markers.

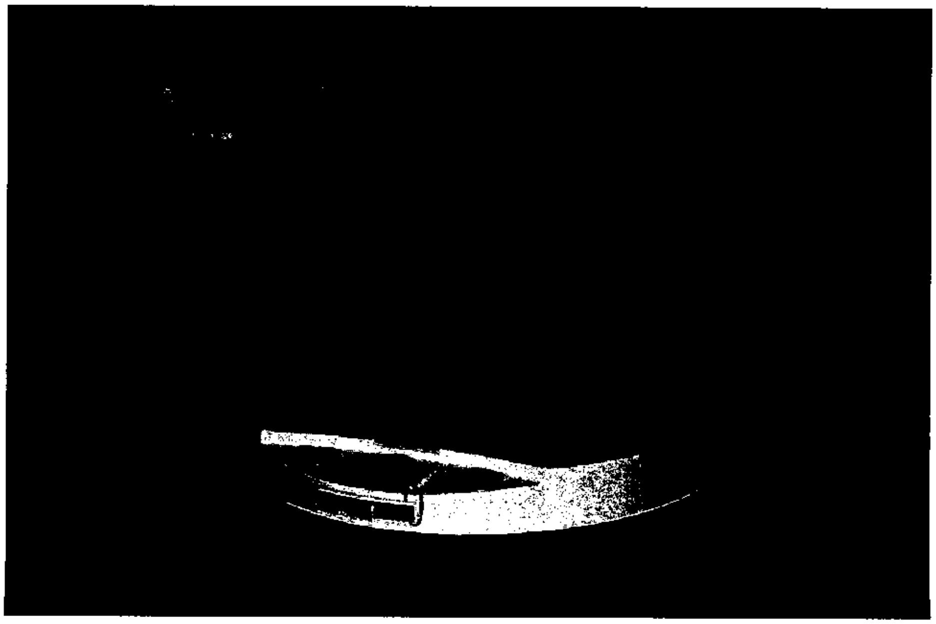
Explanation: You are hearing a slowed down version of a dolphin's sonar "clicks". Dolphins send out sonar clicks 250 times faster than these. On top of that, sound travels faster and farther in water than in air

Dolphins can hear much higher pitched (higher frequency) sounds than humans can. Dolphins can hear sounds up to 150 kHz (thousands of Hertz or thousands of cycles/sec). Humans hear sounds up to 20 kHz. In this exhibit we have changed the pitch so your ears can hear the sounds and their echoes.

The first short "thump" you hear is the sound being sent into the water from a transducer (sonar device). The transducer is under the dolphin shape at the front of the tank. The secondary sounds you hear are echoes bouncing back from different objects in the tank. The objects in our tank might be hollow or solid, metal or plastic, round or flat. Depending on what material you point the dolphin toward, and how far away that object is, the echoes you hear will sound different.

Dolphins use their sonar to help them find or avoid obstacles in dark or cloudy waters. This is called **echolocation.**

Physics-Biology Connection: Dolphins echolocate to help them know their surroundings. Dolphins send out sonar clicks and listen for the echoes that come back from objects in the water. This helps them detect things like obstacles, dangers to avoid, or a tasty meal! By listening to the echoes, a dolphin can tell the distance to an object, how fast the object is moving, its direction, and even what it is made of and its shape.



Activities and Exercises

SEEING SOUND

Materials: Balloon, Scissors, Can with both ends removed, Rubber bands, Tape, Glue, Mirror ~ 0.5 cm (1/2 in.) square

Procedure
1. Cut the neck off the balloon and stretch the remaining part tightly over one end of the can. Hold the balloon in place with rubber bands and tape the edge of the balloon to the can to keep it from slipping.
2. Glue the piece of mirror (face out) to the stretched balloon, about a third of the way in from the edge of the can.
3. Shine the flashlight onto the mirror at an angle, so that you can see a bright spot from the mirror reflected on the wall. If you don't have a plain wall to aim the spot at, use a piece of white cardboard as a screen.
4. Hold the can very still (or set it on a table, braced so it won't roll) and sing or shout into the open end of the tin. Watch the spot of light on the wall. Why does it vibrate quickly back and forth?

How does it work?
Sound is made by vibrations. When you sing or shout, the air rushing from your lungs passes through your vocal cords and makes them vibrate, producing pressure waves that travel through the air, like ripples in water. When these waves hit the stretched balloon, they make it vibrate. This, in turn, starts both the mirror and the light reflecting from it vibrating. Your eardrum is a stretched membrane something like the balloon. When pressure waves strike the eardrum, it vibrates and your brain interprets those vibrations as sounds.

HEAR THROUGH YOUR JAW!

A dolphin "hears" through its jaw; that is, sound travels along a dolphin's jaw to the inner ear. This activity allows your students to experience what it's like to hear through their jaws first-hand.

Material: A slinky

Procedure
1. Divide your students into partners. Have one student in the pair plug her ears with her fingers and lean forward slightly so her chin juts out. The second partner holds a slinky up to their partner's chin.

2. The partner holding the slinky to the other's jaw should hold the slinky so that the top part is kept in place on the partner's jaw, while the bottom is released and allowed to hit the ground.

3. Have the partners switch so each student experiences what it is like to hear through your jaw!

The sound produced from the slinky hitting the ground is "heard" by the first partner through the jaw bone. This activity can also be done by striking a tuning fork gently and placing it against the jaw.

SOUND WAVES IN THE WATER

Materials: Pan, Water, and Tuning fork

Procedure
1. Fill the pan with water and let it sit until the water is completely still.
2. Strike a tuning fork at the tip and touch the water with the base of the tuning fork.

How does it work?
The sound of the tuning fork can be seen in the water as waves—sound traveling through the water. Also notice that the waves bounce back off of the sides of the container, like an echo.

Adaptations
Objects can be placed in the water to observe the effect on the wave pattern. This illustrates the different echoes returning to a dolphin or whale, indicating the shape of an object.

DOLPHIN MARCO POLO

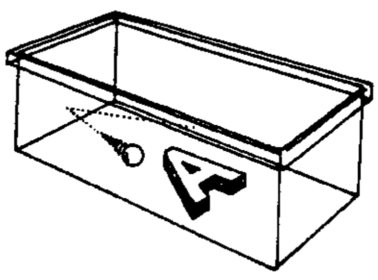
This activity allows your students to explore the implications of echolocation to a dolphin.

Procedure
Choose one student to be the dolphin, the rest are fish. Place a blindfold on the student dolphin. The dolphin says "CLICK", and the fish respond by saying "FISH". This is repeated as the dolphin tries to catch the fish for lunch. By listening to the fish, the dolphin should be able to move toward the "FISH" calls. Continue until the dolphin has caught enough fish for lunch. You can enhance the activity by having the students have a longer time elapse between "CLICK" and "FISH."

Explanation
Even though a dolphin might be swimming in murky water, it is able to find food by producing sound. The "CLICK" is the echolocation. "FISH" is the echo that the dolphin hears, letting the dolphin know that food is near. The echo tells the dolphin where a fish is, so the dolphin can move in that direction.

EXPLORING WITH SOUND ACTIVITY. This and the following activity are from the National Science Teachers Association (NSTA) "Jason" Curriculum. "Jason" is a submarine using Sonar to explore its environment.

Rationale: Sonars mounted on JASON provide most of the expedition's underwater measurements and images. This activity illustrates the basic principle of sonar, the use of sound energy to obtain information.



Objectives (Students will)
- Use sound to infer the shape of an object.
- Observe how different materials affect the properties of sound

Materials: Shoe box with cover, Tape, Marble, Large plastic or wooden three-dimensional toy alphabet letters or simple shapes made of various materials.

A. Introduction
Explain that the water is often too **turbid** (cloudy) or too dark to permit direct visual observations. In order to "see" an object underwater, instruments must depend upon energy other than reflected light. The crew will rely on sound energy to provide information about JASON's distance from the bottom and

from underwater objects. A skilled sonar operator can use the data sonar provides to infer other information, such as the shape of an object.

B. Lesson Development

1. Divide the class into teams of two. Assign each group member a role. Student A will construct the "black box." Student B will probe its contents.
2. Distribute materials. Student A will need tape, a marble, a letter or simple shape (to be concealed from student B), and a shoe box. Direct Student A to tape the letter to the inside bottom of the shoe box, place a marble inside the box, and tape the lid to the box before giving the box to Student B.
3. Challenge Student B to determine the identity of the letter or shape by listening to the marble as it rolls inside the box.

C. Conclusion

Help the students draw conclusions about "seeing" without using their eyes. Ask the following questions:

-- What form of energy helped you discover the identity of the letter or shape in the box? (sound)
-- What caused the sounds that you were hearing? (collisions and movements of the marble)
-- How could you tell if your "target" letter or shape was straight or curved?
(by listening to the way the marble moved around it)
-- Can you think of any animals other than humans that use sound for determining shapes? (whales, porpoises, bats)

Help students relate the closed shoe box to the turbid environment in which JASON often operates. Explain that although scientists don't use marbles to identify the shapes of underwater objects, they do depend upon the collisions and reflections of sound waves when they use sonar.

Note: If students have not succeeded in identifying the letter after considerable time and effort, ask them to state the information they do have; for example, the letter has two straight lines; it is curved; it has three points. Then ask them to draw what they think it might be. Putting the letter in a smaller box will also reduce frustration.

Adaptations

For younger students--Simple geometric shapes such as circles, squares, and triangles can be substituted for letters.

For older students--Let the students design their own mystery objects for the shoe box, using a variety of materials, wood, plastic, foam, and other materials of varying hardness. Students will discover that the shapes of hard objects are often easier to discern that the shapes of softer objects. In the same way, a skilled sonar operator can identify the shape of a cannon more easily than that of a piece of wood.

MEASURING WATER DEPTH ACTIVITY

Objectives (Students will)

- Describe sonar and how depths are calculated from a position on top of the water.
- Calculate depths from the data provided.

A. Introduction

Ask students how we can find the depth of a lake or other body of water when we cannot see the bottom. Some students may suggest weighted lines lowered over the side of a ship. Explain that sailors used such lines when entering a harbor or other shallow water area. However, a rope long enough to reach the deep ocean floor would be too large to carry on board ship and would take to long to use. Ask students what other problems there would be in using a rope. (They might mention the weight of the rope, the time lost in stopping to take a sounding, and the fact that no matter how much rope they took it might not be enough.)

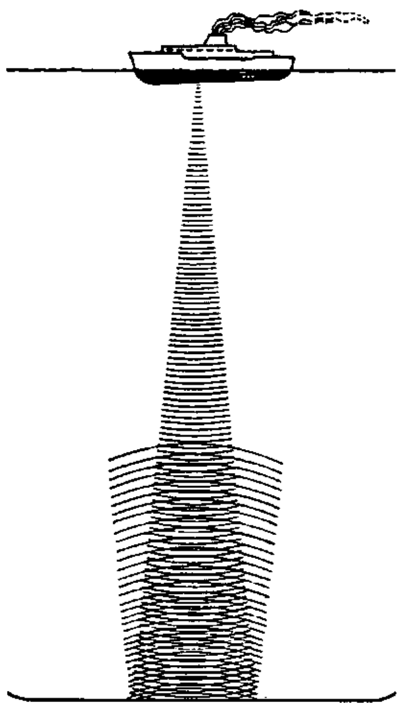
Tell students that today's oceanographers use sonar instruments to generate a sound signal that is bounced or "echoed" off the sea floor and then recorded on board the ship. By carefully measuring the round-trip time of the sound waves and taking into account the variables of temperature and salinity, the depth of the water and the distance to another object con be measured accurately.

B. Lesson Development

1. Explain to your students that the speed of sound in water is 1,500 meters per second, four times faster than the speed of sound in air. This speed can vary slightly depending on factors such as temperature and salinity.

Time X (seconds)	Speed (m/sec.)	÷	Equals Depth (meters)
0.20 sec.	1,500 m/s	2	m
0.15 sec.	1,500 m/s	2	m
0.25 sec.	1,500 m/s	2	m
0.30 sec.	1,500 m/s	2	m
0.43 sec.	1,500 m/s	2	m

2. Do this example on the board so that students can then calculate the depth at a sounding site.



Example: Round trip time = 0.35 seconds
0.35 x 1,500 =525
525 ÷ 2 = 262.5 meters

3. Have students work the problems from the sonar table you wrote on the board. To find the depth, multiply the time by 1,500, then divide the answer by two.

4. Sonar Activity. Give your students time to do it, then review their answers.

SONAR ACTIVITY DATA

You are the sonar operator for an oceanographic research ship. Your ship is searching for shipwrecks that have been reported in 1000 to 1200 meters of water. The captain asks you to give three locations to look for ships. This is the map that your sonar has generated. Use the formula (T)1500/2=D to calculate the depth of each location and write it in. Tell the captain which three grids to search.

	1	2	3	4
A	T=0.9 D=	T=1.0 D=	T=1.1 D=	T=1.2 D=
B	T=1.0 D=	T=1.1 D=	T=1.2 D=	T=1.2 D=
C	T=1.2 D=	T=1.3 D=	T=1.4 D=	T=1.5 D=
D	T=1.2 D=	T=1.3 D=	T=1.6 D=	T=1.7 D=

Use this space for your work.

Search Locations
1.
2.
3.

C. Conclusion

Ask: How has modern technology helped sonar operators? (Computers can do many calculations rapidly and store vast amounts of data.) What experience have students had with sonar? (Maps are produced using sonar, and motion pictures sometimes depict it in use.) Why are accurate maps of the sea floor or lake bottom needed? (Safe navigation, location of lost ships, and economic resources are a few answers to expect.)

ECHOLOCATION: "SEEING" WITH SOUND ACTIVITY

Introduction

An animal adaptation that was kept in mind in designing the Shedd Aquarium's Oceanarium was the unique sensory capabilities of the whales and dolphins. Odontocetes, or "toothed" whales use echolocation to navigate and find prey. They produce extremely high frequency sounds that bounce off the landscape and other animals. The whale or dolphin is able to analyze the returning echoes and determine the sizes or shapes of objects or animals and their distances, even in very deep, dark, or murky waters. Some researchers even believe the animals can stun prey by concentrating and "shooting" sound. Toothed and baleen whales also produce sounds thought to be used in communication.

What design features does the Oceanarium have? The pumps and filters in the Oceanarium were cushioned with rubber and insulated to minimize noise being transmitted into the pools. The side walls of the pools were constructed as sweeping curves rather than as a regular oval. Even the bottom was irregularly contoured to provide a varied surface.

As humans, we live in a rich visual environment. It takes effort to imagine the correspondingly rich auditory environment inhabited by marine mammals. This activity reminds students of some of the characteristics of light waves and asks them to apply the concepts to sound waves.

Materials: Juice or other cylindrical container with both ends removed, Balloon or thin rubber sheeting (a heavy-duty weather balloon from scientific supply house works well), Scissors, glue, Small mirrored surface (mylar sheet works well)

Procedure

1. Cut a circle of thin rubber sheeting larger than the end of a can, or cut a round balloon in half through its widest point and discard the half with the opening. Stretch sheeting over one end of the can, and secure it with glue or rubber bands. Glue a small mirror or piece of mylar to the middle of the stretched balloon. Allow it to dry.

2. Have one student shine a light onto the mirrored surface and focus the reflection on a white card. Have another talk into the open end of the can.

Class Discussion

-- What happens when a person speaks into the open end of the can?
(The energy of the sound waves moves the air particles, which stretches the balloon, causing the light spot to jiggle.)

-- Are the particles that transfer whale sounds the same as those that transmit human sounds? Explain.
(They are not the same. Human sounds are transmitted slower through low density air. Whale sounds are transmitted faster through higher density water.)

— Why is there no sound in the vacuum of space?
(There are no molecules to transfer the energy of sound.)

INTERPRETING SOUND ECHOES ACTIVITY

In humans, underwater sound reaches the auditory nerve by traveling by bone conduction through the skull. This diffuses the sound so it is difficult to determine in what direction the sound originated. In cetaceans (whales, dolphins, and

porpoises), the problem of bone conduction does not occur. Sound is received through the hollow, oil filled lower jaw. The oil vibrates and directs the vibrations to the inner ear.
Material: • Tuning fork

Procedure: Demonstrate bone conduction by placing a struck tuning fork on a student's cheekbone

Explanation
How does sound help the dolphins and whales distinguish materials? Sound is reflected differently by materials of different densities. Show students the ultrasound picture, and point out the light and dark areas. The lightest areas are the densest parts of the baby's body. The dark areas are less dense. By varying the frequency of the sounds used in ultrasound readings, such density differences can be made even more distinct. Dolphins and whales "fine-tune" the sounds they produce when scanning objects and in research studies can even distinguish between copper and steel objects.

Although our sense of hearing is far less sensitive than that of whales and dolphins, we can also hear sounds echoing off objects. In a very quiet room, have a blindfolded student tap the hard surface of the floor and try to get as close to a wall as possible without touching the wall. With a little practice, the student will learn to interpret the difference in echoes near a vertical wall or doorway.

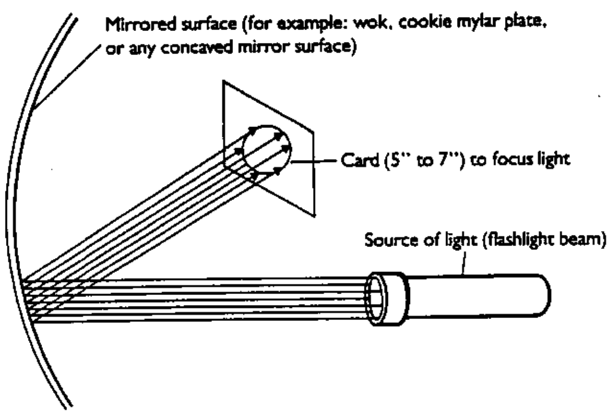
Classroom Discussion
-- Does this result suggest why the Shedd Aquarium was so careful to cushion and insulate the pumps and filters? (The animals are very sensitive to sound and use it to navigate. The insulation reduced the noise transmitted from the machinery to the water.)

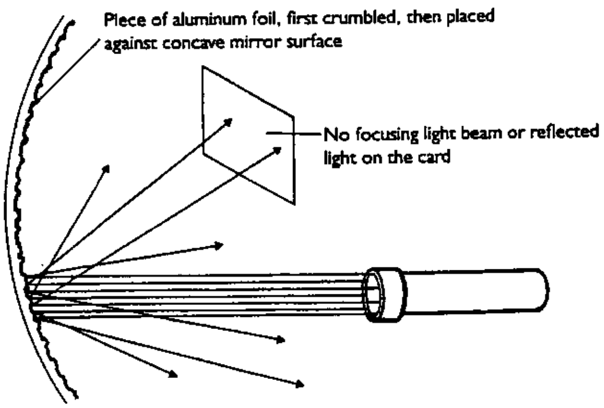
-- How might human activities affect whales and dolphins in the wild? (We need to be careful of marine mammal habitats when developing shipping lanes and conducting underwater exploration so that our sounds do not interfere with the animals.)

Regular and Irregular Reflections Activity
Materials: Flash light covered by card with pinhole or laser pointer, Shiny, concave surface (metal bowl, wok, even a flexible cookie sheet), Aluminum foil, Blank 5" x 7" card, Meter stick

Procedure: Have one student hold up the metal bowl or wok while another student shines a light onto the curved surface. Focus the reflected light onto the card. Note the sharpness of the reflection. Then, take a sheet of aluminum foil, wrinkle it, and, without smoothing it out too much, place it onto the concave surface. Use the light source again.

1. What happened to the image? It is no longer sharp. Each facet of the aluminum reflects the light in a slightly different manner.
2. Does this suggest why the Shedd Aquarium made the pools irregular rather than an oval and made the bottom of the pools bumpy rather than smooth? An irregular surface offers more variety to the animals and may reduce background noise.





Chapter V: Electricity

Background

Water is more electrically conductive than air. Electrical resistivity is a property of a material and not of the specific dimensions of an object. It is measured in ohm-meters or Ωm. The ohm (Ω) is the unit of resistance named after Ohm.

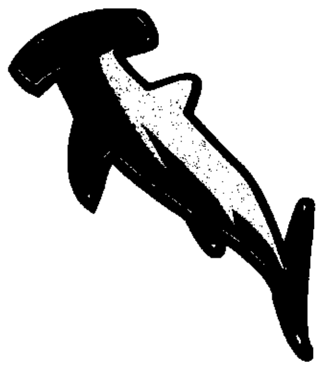
Georg Simon Ohm (1787 - 1854). Born in Erlangen, Germany, his later work as a physicist resulted in the 1827 discovery of the mathematical law of electric-current called "Ohm's Law."

The ohm, a unit of electrical resistance, is equal to that of a conductor in which a current of one ampere is produced by a potential of one volt across its terminals.. If you know the resistivity of a material, multiply by its length, and divide by its area, this will give you the resistance.

Air is 20 billion times more resistive than seawater. Also, the higher the temperature or salinity, the lower the resistivity. Because of this, the ability to detect electrical signals is fairly common among aquatic organisms. Most animals produce small amounts of electricity, for example, through small muscle contractions while breathing. Sharks and rays are able to detect this electrical activity, and use this ability to find their prey. Other fish use electric pulses to communicate. Especially in dark waters where the sense of sight may not be useful, these tiny electrical impulses may be the only clue that another animal is around. However, because the electrical field rapidly attenuates, an electric sixth sense can never replace vision or sound as a means for sensing the environment at greater distances.

Electricity and its behavior in water also present some aquatic animals with still other possibilities. The electric eel uses a strong pulse of electricity to stun or even kill its prey or to warn away an intruder. The shark detects the electrical field created when seawater (a conductor) flows in the earth's magnetic field. This ability allows the shark to orient and navigate in the absence of visual cues.

Animals



We have chosen **sharks** and **electric eels** for the exhibits on electricity.

Sharks have fascinated scientists for years. The shark has changed little in more than 300 million years in the earth's oceans, and they possess finely-tuned, sharp senses and unique sense organs like the **ampullae of Lorenzini**. Although they are considered to possess a low level of intelligence by many experts, they are legendary hunters of the seas.

Classified as fish, sharks are among the oldest creatures on our planet. Sharks differ from most fish because their skeletons consist of soft, flexible cartilage instead of bones. While the cartilage enhances a shark's swimming ability, it offers little support for the shark's internal organs out of water. Just a few minutes out of water will give a shark a fatal injury.

Sharks must also swim continuously to stay afloat because they don't have the air-filled swim bladder found in other types of fish. Most top-swimming sharks must also continue moving to obtain the oxygen necessary to stay alive.

As many as 62 species of shark roam the eastern waters of North America. Some stay in the high seas, far from shore, while others live close to the bottom, but many inhabit shallow waters in estuaries and close to shore.

Electric Eel is found in the Amazon Basin, in marshy areas or stagnant arms of rivers, areas where other fishes find it difficult to live because of the deficiency of dissolved oxygen.

The electric eel eats other fish, killing them with electric shocks of up to 600 volts. Electric eels can fatally electrocute a horse. Their vital organs are located immediately behind the head; the other 7/8 of its body is tail, containing the electrically generating organ. This organ is composed of 5000-6000 electrocytes, and is arranged like a dry battery. The head acts as the positive pole of the battery, the tail as the negative pole. When the eel is at rest there is no generation of electricity, but when it starts to move it emits electrical impulses at the rate of about 25/sec. During intense feeding discharges of up to 50/sec have been recorded.

These discharges aid in locating food and navigation, as well as the killing of prey. Small animals within range are killed outright, while large mammals may become dazed and drown. A human can withstand one discharge, but would not survive several.

As in other electric fish, low-amplitude electric discharges may function in communication, although this has not been well studied in this species. The species is not currently threatened or endangered, but may be in the future due to habitat destruction.

Exhibits

SciTech has three exhibits that explore how aquatic animals use electricity to survive and thrive in their environments: *Shark Navigation* and its companion exhibit, *Swinging Generator*, and *Electric Eel.*

Swinging Generator demonstrates the physics principle that moving magnets generate an electric current. This simple physics concept is of profound importance to the shark's ability to find its way in a dark and sometimes featureless ocean.

Concept: Faraday effect

Objective: Students will be introduced to the simple and important physics principle known as the Faraday effect. Students will later relate this principle to the shark's ability to navigate.

How to use: Swing the magnet past the coil. Watch the meter as the magnet swings. Notice that an electric current is being generated. Vary the parameters of the exhibit by:

- swinging the magnet slower,
- swinging the coil instead of the magnet, and
- altering the distance between the coil and magnet and
- then swinging the two past each other.

Explanation: Unseen lines of magnetic force spread outward from the magnet. Some of the lines of force go through the coil. Current is made in the coil as the number of lines going though it changes. The faster the number of lines changes, the more current is generated. This is known as the **Faraday effect**. Michael Faraday, English physicist 1791, 1867

Physics-Biology Connection: Sharks use this same physics principle to navigate in underwater darkness. Although sharks have excellent sight, they can't rely on sight in dark or murky waters. They need another, reliable way to find their way in the ocean. Their electric sense allows them to take readings like our meter, so they know what direction they are swimming.

SHARK NAVIGATION

Shark Navigation allows students to manipulate a model shark across a magnetic field (representing the Earth's magnetic field) to show the Faraday effect in action.

Concepts: Faraday effect, ampullae of Lorenzini

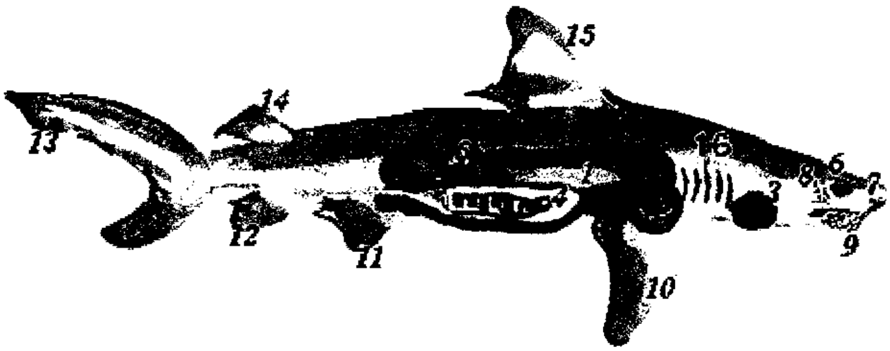
Objective: Students will make the connection between shark navigation and the Faraday effect.

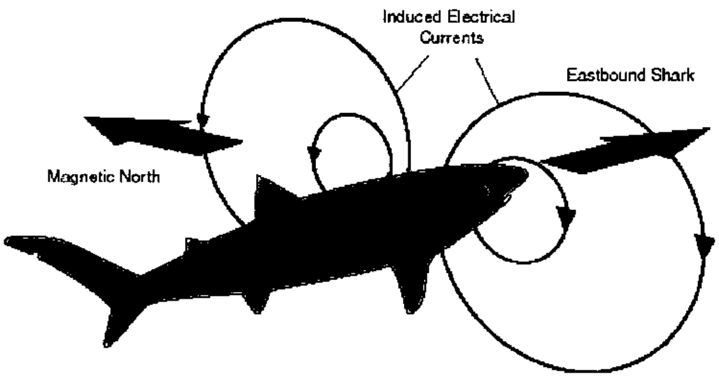
How to use: Move the model shark at the end of the white pole in different directions. Watch the colored lights on the oval picture of the shark at the top of the pole. Notice that the lights flash when the shark moves across the magnetic field, but not when it moves in the same direction as the magnetic field.

Explanation: There are magnets in this exhibit representing the earth's magnetic field. An electrical field is created when the shark moves across the earth's magnetic field. In the exhibit, the lights flash when electricity is generated. This is known as the **Faraday effect**.

Sharks sense these weak electrical fields through passages in their skin called **ampullae of Lorenzini**. The cells in their ampullae are so sensitive they can detect electric fields as small as 0.01 microvolts per centimeter! The colored lights on the oval shark picture are a visual way to see this electric sense. The fact that water is a good conductor of electricity makes it possible for sharks to possess this sixth electrical sense.

1.Liver
2.Spiral valve
3.Heart
4.Pancreas
5.Stomach
6.Eye
7.Nostril
8.Ampullae of Lorenzini
9.Teeth
10.Pectoral Fin
11.Pelvic Fin
12.Anal Fin
13.Caudal or Tail Fin
14.Second Dorsal Fin
15.First Dorsal Fin
16.Gills





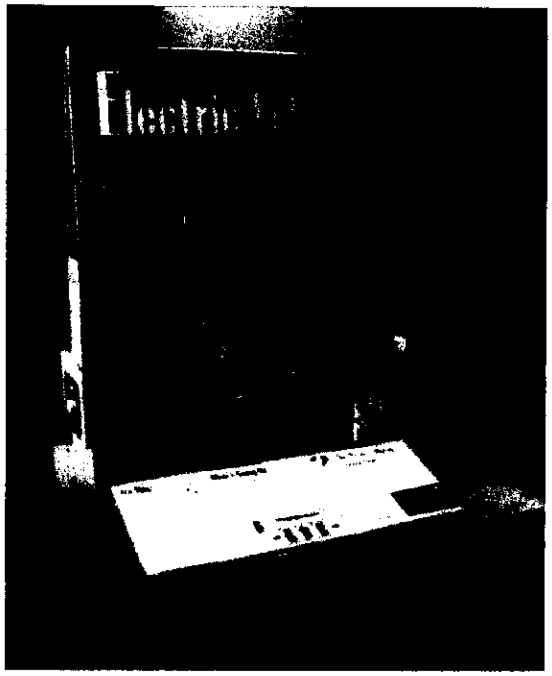
Physics-Biology Connection: A shark uses this ability like a compass to orient and navigate in the absence of visual cues. Besides navigation, sharks use their amazing electric sense to find prey, or food. Most animals conduct small amounts of electricity when they use their muscles, for example, as they breathe. Sharks sense these tiny currents and know exactly where their prey is.

ELECTRIC EEL
presents students with an opportunity to compare the electrical resistivity of air and water.

Concepts: Electrocytes, Electrical resistivity

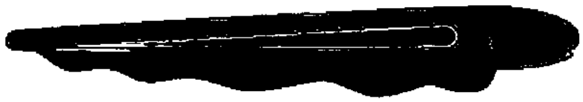
Objective: Students will learn that water conducts electricity much better than air.

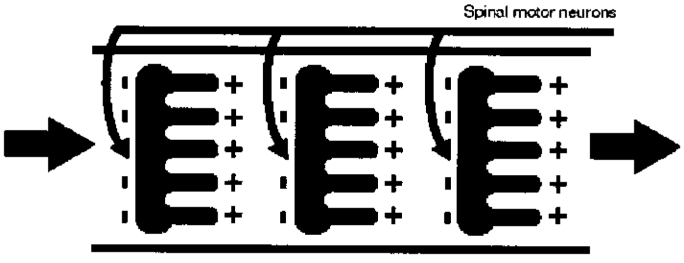
How to use: Use the probes to touch the body of the model electric eel in the upper tank (air). Notice the reading on the meter. Use the probes to touch the plates in the lower tank (water). Notice the reading on the meter. Students can vary the distance at which the probes touch the electric eel (air) and the plates (water).

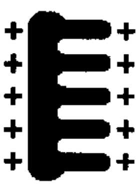


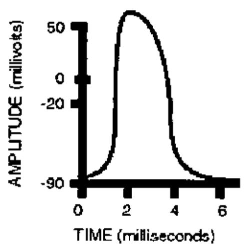
Explanation: An electric eel's body has thousands of tiny battery-like cells called **electrocytes**, which produce electric current. The electrocytes are arranged end to end like the batteries in a flashlight. In the upper tank of air, the probes must touch the eel itself to take a reading. In the lower tank of water, the probes only need to touch the copper plates leading to the water to take a reading. This is due to water's low **resistivity** to electricity. The eel emits a pulse of electricity. The graph shows how long the pulse lasts.

Physics-Biology Connection: Electric eels use their environment to help them survive. Taking advantage of water's excellent conductive properties, the electric eel sends out a pulse of electricity to stun an enemy, or to kill its prey. An older, longer eel (with more electrocytes) can generate a much stronger electric pulse than can a younger, shorter eel.









Electric eels can fatally electrocute a horse. The vital organs are located immediately behind the head - the other 7/8 of its body is tail, containing the electrically generating organ. This organ is composed of 5000-6000 elements, arranged like a dry battery. The head acts as the positive pole of the battery, the tail as the negative pole. When the eel is at rest there is no generation of electricity, but when it starts to move it emits electrical impulses at the rate of about 25/sec. During intense feeding discharges of up to 50/sec have been recorded.

These discharges aid in locating food and navigation, as well as the killing of prey. Small animals within range are killed outright, while large mammals may become dazed and drown. A human can withstand one discharge, but would not survive several.

Activities and Exercises

WATER CIRCUIT ACTIVITY

We know that electric current flows through metal, but will it flow through water? Your students can rig up a flashlight to answer that question.

Materials, Flashlight, Two 10" pieces of insulated wire (22-gauge), Clear glass bowl, Distilled water, Salt, Measuring spoon, Tape, Two copper plates

Procedure

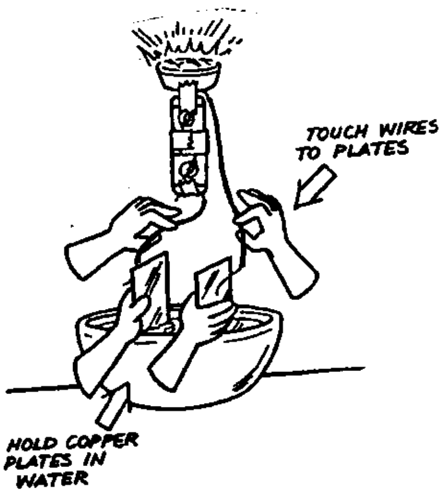
1. Unscrew and remove the flashlight lid and remove the contents. Tape the two batteries together (positive end to negative end).

2. Strip 1/2" of the insulation off both ends of both wires.

3. Tape one wire end to the negative end of your two batteries. Tape another wire end (from the second piece of wire) to the circle of metal (usually copper) in the light bulb piece.

4. With a long piece of tape, attach the flashlight bulb to the battery end as shown. Test that your flashlight works by touching the two free wire ends together. (It's okay to touch these exposed ends; not enough current is traveling through them to do any harm.)

5. Have a partner hold the copper plates in the bowl. Now touch the free wire ends to the plates. Does your flash light flash on?



6. Add salt slowly and watch what happens.

How it works

A material allows electric current to flow (or conduct) when there are charged particles (electrons) inside it that are free to move. In a normal light bulb, for example, the electrons in the bulbs tiny wire (called the filament) can flow easily. This flow heats the filament until it glows white hot and the bulb shines. However, when the electrons inside a material are held tightly in place no current can flow. This is what happens with distilled water, which is an insulator (it cannot conduct electrons). Adding salt stripped some electrons away from the water, allowing them to move around the copper plates, then through the wires to the filament to light the bulb.

Student Activity Sheet for ELECTRIC EEL Exhibit

TRY THIS!

1. Touch the buttons on the body of the eel in the upper tank with the two probes.
What does the meter say?_Does the meter react if you don't touch the eel?

2. Touch the buttons on the body of the same eel with the two probes at different distances from each other.
What does the meter say?

3. Touch the two probes into the water in the lower tank.
What does the meter say?_Does the meter react if you don't touch the water?

4. Touch the two probes into the water at different distances from each other.
What does the meter say?

Challenge: An electric eel has special cells in its body called electrocytes. The longer the eel, the more electricity it can discharge. Why?

Draw an electric eel here.

Student Activity Sheet for SWINGING GENERATOR Exhibit
Moving magnets make an electric current

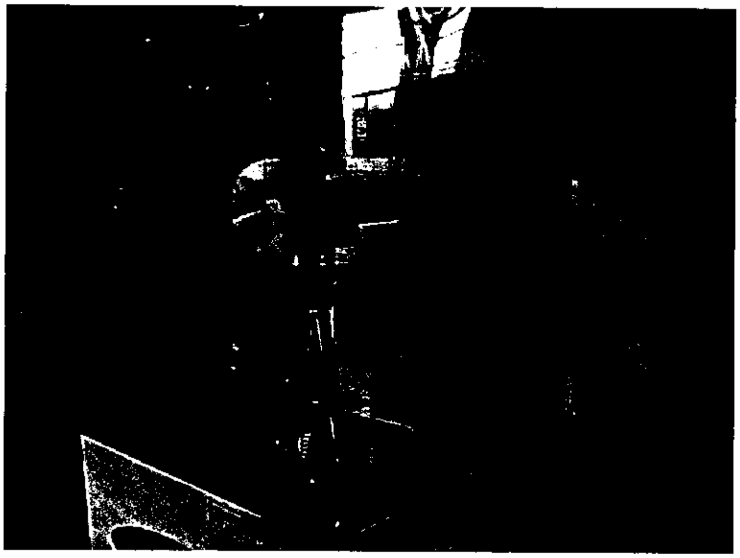
TRY THIS!
1. Swing the magnet past the coil. What does the meter do?

What happens if you swing the magnet more slowly?

What happens if you swing the coil instead of the magnet?

Draw the coil. Draw the magnet.
(Label the North and South poles)

Student Activity Sheet for SHARK NAVIGATION Exhibit
How do sharks find their way in the ocean?



TRY THIS!
Find the shark in this exhibit

Move the pole that holds the shark. Try moving the pole in different directions.

What happens to the colored lights on the picture of the shark?

Do the lights change when the shark swims in different directions?

Do the lights glow when the shark is not moving?

Can you tell which way the shark moves by looking only at the lights?

What are the ampullae of Lorenzini? (hint: read the signs)

Appendix A ASSESSMENT STRATEGIES

PROGRAM LEARNING GOALS

Through interaction with the exhibits and the activities in this manual, students will increase their knowledge of:

1. the basic principles that make living in water different than living in air;
2. relationships between principles of physics and the basic functions of an aquatic animal, such as movement and getting food;
3. basic concepts of aquatic biology;
4. applications of the principles of physics to technologies people design to function in aquatic environments;
5. the unique adaptations that aquatic animals have developed to survive in their environments.

Through interpretation of the exhibits and the activities in this manual, students will also increase the following skills:

1. observing phenomena
2. inferring cause-effect relationships
3. identifying patterns
4. recording data
5. making comparisons
6. making predictions

Each exhibit and activity lists both objectives your students will accomplish and the skills listed above that your students will use. The Alternative Assessment Strategies explores ways you can test your student's knowledge of the science and mastery of the skills.

Standard:
- Cognitive
- Affective

Alternative:
- Content
- Construct
- Creativity

Standard Assessment

1. *Cognitive*: Short-answer and multiple-choice pre-test and post-test will measure knowledge of concepts and information presented through the exhibits and ability to use skills developed through the exhibits.

2. *Affective*: Student surveys will assess students' attitude towards the content of the exhibits. These surveys will ask students to:

- Describe aquatic animals. Pre-survey and post-survey questions will determine differences in use of terminology.

- Recommend ways to learn science. Rank different ways to learn science.

- Explain how useful sciences are. Decide what is most useful of what they have learned.

By using an open-ended approach, determine whether the students know that they have learned science in an integrated way and what they value in this integrated approach.

Alternative Assessment

The following "alternative approaches" to assessment can be adapted for use as activities integrated into the learning experience as well as culminating activities that can reinforce what has been learned and also be assessed to determine the outcomes.

Three characteristics are recommended for assessing student achievement:

1. *Content*: Student uses words, describes concepts appropriate to these topics.
2. *Construct*: Student followed the instructions appropriately for the task.
3. *Creativity*: Student used varying levels, colors, methods, etc.

• <u>Design an aquatic animal</u>. Students make "blueprint" for animal, including a "key" identifying features and rationale for them.

• <u>Construct an aquatic animal</u>. Students make models of the animals they designed.

• <u>Make an exhibit to explain a Physics-Biology connection</u>. Students plan and present small-scale interactive exhibits that expand on the ideas they learned.

• <u>Write a "big book"</u>. Students write and illustrate display-like books for presentation of the exhibit content to younger students.

Appendix B. Language skills GLOSSARY

One of the challenges in teaching either science discipline, physics or biology, is the large number of new terms. Definitions of the terms used in this guide and in the exhibits are listed below.

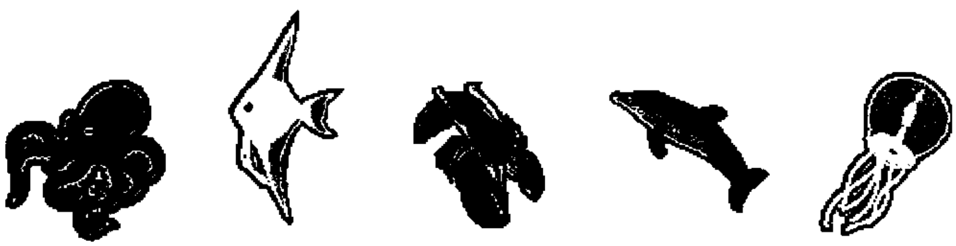
You can teach these words as vocabulary, or try a more active approach:

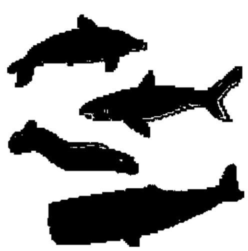
- Hold off on the vocabulary until after the students have used the exhibits and done some of the activities.
- Have students describe what they have observed, sharing the concept using their own word choices. For example, "Explain how a lens bends light." Discuss the new concept, then have your students find the word which best describes the concept they have just described.
- Generate a game similar to the television show "Jeopardy". The answer (the term) is given, and the contestants (the students), then phrase the question (the definition). Again, the students are given the opportunity to produce their own definitions.

absorption: interception of radiant energy or sound waves.
algae: any of a group of mainly aquatic plants such as seaweeds and pond scums.
ampullae of Lorenzini: passages in the Shark's skin. The cells in these passages are very sensitive to electric fields.
aquatic: growing or living in water.
Archimedes' principle: the buoyant force on an object is equal to the weight of the fluid displaced.

Artemia: another name for Brine Shrimp
attenuate: lessen the amount or magnitude. We apply it to radiant energy or sound waves.
ballast: a heavy substance used to control the stability and draft (how high it rides in the water) of a ship.
biomimesis: from "mime," to mimic; learning from nature to improve today's technology.
bladder: a sac in an animal that is a receptacle for a liquid or a gas.
buoyancy: the power of a fluid (gas or liquid) to exert an upward force on an object placed in it.
carnivore: flesh-eating animal.
cetacean: any of an order of aquatic (mainly marine) animals such as whales, dolphins and porpoises.
cilium (plural: **cilia**) a short, usually stiff, usually unicellular, marginal hair.
concave: hollow or rounded inward like the inside of a bowl.
conductor: a material that conducts electricity. One can also speak of heat conductors.
convex: curved or rounded like the outside of a ball.
crustacean: any of a large class of mostly aquatic animals including lobsters, shrimps, crabs, water fleas.
density: the mass of a substance per unit volume. Typical units: grams/cubic centimeter, pounds/cubic foot.
displacement: the volume or weight of fluid (as water) displaced by a floating body (as a ship).
dormant (or dormancy): biological activity suspended but being capable of being activated.
drag: something that retards motion or action, like air on an airplane.
echolocation: using sound waves to locate distant or invisible objects by the sound waves reflected back.
ecosystem: the complex of a community and its environment functioning as a unit in nature.
electromagnetic wave: simultaneous periodic variation of magnetic and electric fields, e.g radio waves, light waves.
electromagnetism: the branch of physics that deals with electricity and magnetism and the relationship between them.
embryo: an animal in the early stages of growth and differentiation.
energy: power expended over time: heat (calories), electrical (kilowatt-hours), mechanical, nuclear, and others.
environment: physical, chemical and biological factors that act on a living thing and determine its form and survival.
Faraday effect: electric current produced by the relative motion of a magnet and a conductor.
flagellum (plural **flagella**) tiny whiplike appendage, capable of movement.
fluid: a substance able to flow; a gas or a liquid.
focus (verb): bring the light rays together to a point
gas: a fluid (such as air) that has neither independent shape nor volume but tends to expand indefinitely.
gravity: having weight. The force that pulls masses together, e.g. a person and the earth.
habitat: the place or type of place where a plant or animal normally lives and grows.
herbivore: plant-eating animal.
Hz (Hertz or cycles/second): unit of frequency.
index of refraction (of a material): ratio of the speed of light in vacuum to the speed of light in the material
laminar flow: streamline flow in a fluid near a solid boundary; flow in "layers."
lens: a piece of transparent material with at least one curved side.
lift: the component of force acting on a submarine or airplane that pushes it up against the pull of gravity.
light: a form of radiant energy or electromagnetic energy.
liquid: flowing freely like water; neither solid nor gas. Atoms and molecules stay together but can move freely.
locomotion: the act or power of moving from place to place.
marine: of or relating to the sea or the ocean.
mass: a quantity of matter or material; the characteristic that relates the force on a body to the resulting acceleration.
melon: large, lens-shaped organ in the dolphin's forehead that concentrates and focuses sound pulses.
mirage: optical effect sometimes seen at sea or in the desert. Caused by refraction in heated air of varying density.
nanometer: measure of (small) lengths; one billionth of a meter.
Nauplii: baby Brine Shrimp.
photo-negative: swim away from light.
photo-positive: swim toward light.
predator: an animal that lives by killing and eating other animals.
pressure: force exerted on a surface divided by the area of the surface. Typical units: kilograms/sq. cm, psi.
protozoan (plural **protozoa**): any of a large number of one-celled animals.
radiant energy: light, radio waves, x-rays and other forms of electromagnetic energy.
ratio: division of one number by another. Density and Pressure are ratios.
reflection: when an electromagnetic ray (e.g. light) is bounced back by a shiny surface.

refraction: when an electromagnetic ray bends as it passes from one transparent material into another one.
resistance (electrical): the opposition offered by a body or substance to the passage through it of a steady electric current.
resistivity: given the "electrical resistivity" of a material, one can calculate the "resistance" if one knows its dimensions.
retina: the part of the eye where an image is formed.
salinity: how much salt is dissolved in the water.
solid: a state of matter where the atoms and molecules have a definite relationship to each other.
spectrum (electromagnetic): range of electromagnetic energies of different frequencies or wavelengths.
spectrum (sound): range of sound frequencies.
spermaceti organ: in the Sperm Whale's head, focuses and reflects sound and can adjust the whale's buoyancy.
streamlined: shaped to reduce resistance to motion through a fluid (air or water).
swim bladder: fish add/remove air from its swim bladder, to increase/decrease its volume and change its buoyancy.
teleost fish: any of a large number of fish with a bony skeleton. Note: sharks are not included.
thrust: force which propels and object forward.
transducer: a device, which converts a mechanical motion into electrical energy or vice-versa.
turbulent flow: fluid flow in which the velocity at a given point varies erratically.
vacuum: emptiness of space; absence of matter.
viscosity is the degree to which a fluid resists flow under an applied force.
vortex (plural **vortices**): a mass of fluid (usually liquid) with a whirling or circular motion.
wavelength: the distance between two peaks (or valleys) in a wave, like a sound wave or light wave.





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